Cane and Sugar Production

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Punjab Agricultural Research Board
Technologies for the Prosperity of Agricultural Stakeholders
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Chapter-1

Economic Importance

Introduction

Sugarcane is a world wide crop cultivated in 105 countries. From its very origin in earlier times to its present day production sugarcane has played its role in improving socio-economic conditions of human society. It is mainly used as a food crop for the production of raw and refined sugar, gur, shakkar and molasses. Improved cane varieties and production practices have been optimized for increase of cane yield per hectare in the fields and maximizing sugar recoveries in the sugar factories. Sugarcane has gained importance for its dietary value and its industrial utilization for a number of products. The crop is of immense economic importance for the prosperity of people. Its products and bi-products have revolutionized the native and international trade and the crop production trends have played dominant role in altering the economic and fiscal position of countries.

Dietary value

Sugar is used as sweetener in a number of kitchen dishes of varying tastes, beverages, and pharmaceutical products. Sugar is a cheap source of nourishment supplying its high energy content to the body in few moments. Sugar is an important constituent of human diet, has a pleasant taste and high calorific value of 387 per 100 gram (Anon, 1959). Sugar is also available in some fruits and vegetables (Table 1.01), but is not commonly derived as commercial products. Some form of sugar is manufactured from palm trees, sugar maple, sweet sorghum, maize, sugar beet and sugarcane (Table 1.02). Maize crop has gained international importance in the production of Glucose and has captured a large market, but the quantum of sugar per unit area that can be derived out of field crops is maximum in sugarcane.

Trend of using low caloric sweetener has now developed in some quarters. These sweeteners have found prominent place in beverages and food industry. Diabetic patients are mostly attracted to the use of sugar free sweeteners. Amongst the low energy sweeteners, saccharine is the oldest sweetener with sweetening value 300 times greater than usual sugar but leaves a bitter after taste. Some other brands of sugar free sweeteners include aspartame, hydrogenated glucose syrup, xylose sugar and sarbitol. The latest product sarbitol has sweetening quality 500 times greater than sugar and has no bitter taste. The use of energy-free sweetener is on increase day by day. Despite the increasing use of high fructose corn syrup (HFCS) and sugar free sweeteners, still sugar will remain the main sweetening agent and a part of human died for use in tea coffee, several kitchen dishes, deserts, ice cream, syrup, beverages and medicines.

Per capita consumption of sugar in continents of South America, Central America, Oceania, North America, Europe, Asia and Africa is reported to be 48.6, 45.7, 42.9, 39.2, 32.2, 15.8 and 15.6 kg respectively, during 2006, (Table-1.03). The data indicate that the developed
Table-1.01. Sugar contents in some fruits and vegetables

<table>
<thead>
<tr>
<th>Fruit/ vegetable</th>
<th>Sugar % by weight</th>
<th>Fruit/ vegetable</th>
<th>Sugar % by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>9.2</td>
<td>Peaches (fresh without stone)</td>
<td>9.1</td>
</tr>
<tr>
<td>Apricot (without stone)</td>
<td>6.7</td>
<td>Peaches (dried)</td>
<td>53.0</td>
</tr>
<tr>
<td>Apricot (dried)</td>
<td>43.4</td>
<td>Pears (fresh)</td>
<td>7.5</td>
</tr>
<tr>
<td>Banana (without stone)</td>
<td>9.6</td>
<td>Pineapple (fresh)</td>
<td>11.6</td>
</tr>
<tr>
<td>Dates (without stone)</td>
<td>63.9</td>
<td>Pomegranate juice</td>
<td>11.6</td>
</tr>
<tr>
<td>Figs (dried)</td>
<td>52.9</td>
<td>Raisins (dried-without stone)</td>
<td>64.4</td>
</tr>
<tr>
<td>Grapes (fresh)</td>
<td>15.7</td>
<td>Carrots</td>
<td>5.4</td>
</tr>
<tr>
<td>Melons</td>
<td>5.0</td>
<td>Sweet Potato</td>
<td>9.1</td>
</tr>
<tr>
<td>Mulberries</td>
<td>8.1</td>
<td>Citrus</td>
<td>&gt;</td>
</tr>
<tr>
<td>Mango</td>
<td>-</td>
<td>Grape fruit</td>
<td>&gt;</td>
</tr>
</tbody>
</table>


Table-1.02. Plants utilized for commercial sugar production

<table>
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<th>Plant</th>
<th>Sugar Content</th>
</tr>
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<tr>
<td>Palm trees</td>
<td>9 % sucrose on weight of palm juice</td>
</tr>
<tr>
<td>Sugar maple</td>
<td>2 % sugar maple sap</td>
</tr>
<tr>
<td>Sweet sorghum</td>
<td>9 % sucrose (Brix 19 %, Pol 15 %, Purity 79 %)</td>
</tr>
<tr>
<td>Maize</td>
<td>HFCS and Glucose obtained from hydrolysis of pulp developed from maize grains</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>13 – 15 % sucrose</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>10 – 13 % sucrose</td>
</tr>
</tbody>
</table>

Generally, Developed countries have larger consumption than developing and undeveloped countries. The countries having poor economy show quite low rate of consumption. Data in Table-1.03 show a number of countries in Africa and Asia with sugar consumption rates of less than 10. However, China and Japan are exception where low rate of sugar use could be due to their cultural heritage. The sugar use data shown in Table 1.03 seem to be an indicator of living standard of a nation. Within a certain limit, it is stated that sugar consumption increases in proportion to the rise in the living standard. For this reason immense potential has developed for marketing of world sugar.
Table-1.03 Per capital consumption of sugar in selected countries of various continents, during 2006.

<table>
<thead>
<tr>
<th>Continent</th>
<th>Country</th>
<th>Consumption kg capita&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Continent</th>
<th>Country</th>
<th>Consumption kg capita&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Continent</th>
<th>Country</th>
<th>Consumption kg capita&lt;sup&gt;1&lt;/sup&gt;</th>
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<tr>
<td>Europe</td>
<td>Austria</td>
<td>45.6</td>
<td>Africa</td>
<td>Algeria</td>
<td>35.7</td>
<td>Asia</td>
<td>Bangladesh</td>
<td>5.8</td>
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<tr>
<td></td>
<td>France</td>
<td>37.9</td>
<td></td>
<td></td>
<td></td>
<td>U.K</td>
<td>Mauritius</td>
<td>44.7</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>36.9</td>
<td></td>
<td>Ethiopia</td>
<td>4.6</td>
<td>Taiwan</td>
<td>27.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>U.K</td>
<td>40.9</td>
<td>North America</td>
<td>Niger</td>
<td>5.3</td>
<td>Iran</td>
<td>18.1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Canada</td>
<td>44.3</td>
<td></td>
<td>Nigeria</td>
<td>8.4</td>
<td>Japan</td>
<td>17.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>USA</td>
<td>30.9</td>
<td>Oceania</td>
<td>South Africa</td>
<td>33.4</td>
<td>Korea-REP</td>
<td>23.9</td>
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<td></td>
<td>Australia</td>
<td>49.8</td>
<td>South America</td>
<td>Sudan</td>
<td>26.4</td>
<td>Pakistan</td>
<td>25.2</td>
<td></td>
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<td></td>
<td>Argentina</td>
<td>46.8</td>
<td>Central America</td>
<td>Uganda</td>
<td>9.5</td>
<td>Philippines</td>
<td>23.2</td>
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<td></td>
<td>Brazil</td>
<td>59.7</td>
<td></td>
<td>Cuba</td>
<td>62.7</td>
<td>--</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Columbia</td>
<td>34.2</td>
<td></td>
<td>Mexico</td>
<td>47.3</td>
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**Grower’s prosperity**

Sugarcane is an important cash crop and where commercialized for sugar industry, has brought prosperity to grower’s community. In areas of cane concentration, healthy socio-economic change is witnessed, which has improved the living standard of growers. Installation of sugar industry has helped increase the communication net work in villages that has narrowed the links between cities and far-flung areas of the country.

**Manpower use**

Sugarcane is a source of employment for millions of people both at the farm sector and sugar industry. For example in Pakistan, all most 15,000 to 25,000 families are involved in sugarcane zone of one factory. Innumerable manpower is employed in cane harvesting, transport, loading and un-loading of cane. Six hundred to 1000 personals, both skilled and un-skilled, are employed in one sugar factory. Hundreds and thousands of manpower is engaged in sugar transport and marketing network. Huge involvement of manpower in farm machinery with transport system of tractors, trolleys, and trucks can very well be visualized to depict the quantum of business in various sectors. This all is besides the business of sugar and sugar industry.

**Source of food fodder and fertilizer**

Sugarcane is a multiple source of food and fodder. Besides its use for production of sugar
and chewing taste, during harvesting season, tops and trash are additional source of feed to live stock. During years of fodder scarcity cane crop, as such, is fed to live stock. Trash when used as mulch conserves moisture in soil and later, on incorporation in soil, is the source of organic fertilizer. The press mud and fly ash products of sugar industry are high valued organic fertilizers.

**Government revenues**

Sugarcane is a main source of revenue to the Government. In Pakistan, the revenue is derived in the shape of GST (general sale tax) on the sale of sugar which in 15% of sugar price. A substantial amount is recovered as sugarcane Cess Fund @ Rupee. 1.00 per maund of sugarcane delivered to sugar mills and Land revenue and water rates (more or less rupees 300 per acre of cane) amount to billions of Rupee. per annum and are the direct source of income to the government. The excise duty on molasses and alcohol is also a big source of revenue to the government.

**Foreign exchange earner**

Sugar has a great importance in the national and international market. Sugarcane is valued as a foreign exchange earning crop through the export of sugar and its products. Still several countries produce cane to attain self-sufficiency in sugar production and to save foreign exchange by meeting their own sugar requirements. During 2000, sugar imports and exports in the world total a quantum of 35.2 and 39.0 million tonnes which amount to 9.41 and 9.56 billion dollars, respectively (Annon, 2000). It shows that the sugar is one of the major agricultural commodities of the international trade. Thus the sugar plays important role in national and international economy. The volume of export/import of molasses and alcohol is also of great economic significance in international trade.

**Source of energy/power**

Molasses the main byproduct of sugar industry is utilized for production of alcohol, rum feed for live stock. Ethanol has now gained high importance as an energy product. There is competition for sugarcane to use as sugar crop or as feed stock for ethanol production utilized as bio-fuel in vehicles. Price mechanism in oil and sugar is going to be deciding factor to switch the industry to the production of sugar or bio-fuel.

Use of high pressure steam boilers and efficient use of energy in the sugar factories has given new vistas of co-generation from bagasse and trash to export surplus electric power to national grid system. Work on technologies is under way to develop high biomass cane with increased primary energy efficiency and to improve energy efficiency in the process. Production of bio-gas from vinase fermentation is another source of cheaper energy in distilleries.

**Industrial utilization**

Sugarcane occupies a prominent place for high bio-mass fibre production and molasses. Every part of cane plant from tops to bottom is utilized in one form or the other, directly by man kind or in the industry. As a raw material, sugarcane has attained worldwide importance for dozens of industrial derivatives. Main byproducts of cane is known to be the molasses used for alcohol, bagasse utilized for energy production, co-generation,
manufacture of particle board and filter press cake used as organic fertilizer. With respect to bagasse use in co-generation and use of alcohol with gasoline to run the vehicles, it is now called the bio-fuel and its extensive use in manufacture of industrial products and by-products, sugarcane plant is now considered as a bio-factory. The compounds derived from molasses, filter press cake and bagasse make over 50 derivatives in industrial process. These organic chemicals, being highly value added, have surpassed the sugar in market economy. In the present day market economy the profits derived from the manufacture of sugar have markedly been minimized. More attention is now being paid to efficient utilization of by-products. Besides a large list of by-products, considerable quantity of bagasse is saved for energy production in the factory. In this context co-generation is now an important field for supply of surplus electricity to the national grid. Today the focus is to adopt sugar production technology to yield energy based co-products, ethanol and electricity.

Now sugarcane is not simply a cash or sugar crop, it has become a segment of a complex mechanism of agro-based industry. Some countries have to sustain cane crop to meet their local markets, others have global influence and have to grow cane under international sugar agreements, while some have to support the by-products industries affiliated with cane crop. A small rise or fall in cane production has global implication on market economy. Cane acreage fluctuates depending upon market forces, socio-economic conditions and crop competitions. With high population pressure and high market economy crises, Pakistan is trying to increase its production level.
Chapter-2

Regional Distribution

The sugar is produced form sugarcane in tropical and sub-tropical regions and sugar beet in temperate regions of the world. Sugarcane is grown in countries within latitudes 37º N and 32º S of equator. The sugar beet on the other hand is mostly grown beyond the limits of 35º latitudes to about 60º latitudes. Of the world present sugar output, about 76 % is produced from sugarcane and about 24 % from sugar beet. Share of cane sugar has shown an increasing trend during the last 50 years, while beet sugar production has shown a gradual decline from a cane: beet ratio of 59.4: 40.6 during 1959-60 to 76.0: 24.0 during 2004 (Table 2.01).

Table-2.01 Contribution of cane and beet for sugar production in the world, 1959-60 through 2003-04

<table>
<thead>
<tr>
<th>Crop year</th>
<th>World sugar production</th>
<th>Cane sugar</th>
<th>Beet sugar</th>
<th>Cane %</th>
<th>Beet %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1959-60</td>
<td>50,084</td>
<td>29,772</td>
<td>20,312</td>
<td>59.44</td>
<td>40.56</td>
</tr>
<tr>
<td>1969-70</td>
<td>72,992</td>
<td>43,265</td>
<td>29,727</td>
<td>59.27</td>
<td>40.73</td>
</tr>
<tr>
<td>1979-80</td>
<td>84,321</td>
<td>50,526</td>
<td>33,795</td>
<td>59.92</td>
<td>40.08</td>
</tr>
<tr>
<td>1989-90</td>
<td>108,861</td>
<td>60,914</td>
<td>38,947</td>
<td>64.22</td>
<td>35.78</td>
</tr>
<tr>
<td>1999-2000</td>
<td>136,025</td>
<td>98,527</td>
<td>37,498</td>
<td>72.43</td>
<td>27.57</td>
</tr>
<tr>
<td>2003-04</td>
<td>143,971</td>
<td>109,389</td>
<td>34,582</td>
<td>75.98</td>
<td>24.02</td>
</tr>
</tbody>
</table>


Cane area and yield trends

The data in Table 2.02 indicate that Asia grows 44.42% area of the world cane followed by South America (31.20%), N.C.America (14.49%), Africa (7.19%) and Oceania (2.68%). The maximum area (35.45%) falls in countries situated in latitude ranges of 20º - 25º N or S. The countries in latitude ranges of 10º - 20º grow cane on 31.41 % of total world cane area, followed by 24.16 % grown in 25º - 35º latitude. The equatorial belt of 0 -10º grow a little area around 9%. Africa and Asia have relatively higher proportion of cane grown in 25º - 35º latitudes, while cane area in America and Oceania mostly fall in latitude ranges of 20º - 25º. Europe has negligible area under cane, confined in Spain.

On global level sugarcane is grown in 105 countries located in equatorial, tropical and sub-tropical regions. Cane area, production and yields of principal cane growing countries are shown in Table-2.03. During 2002, sugarcane in the world was grown on an area of 20.18 million hectares with cane production of 1338.17 million tons. With respect to area, Brazil occupy leading position by growing cane on an area of 25.10 million hectares followed by India, China, Cuba and Pakistan with 4.41, 1.42, 1.04 and 1.08 million hectares, respectively.
Table-2.02 Cane area of various continents located in different latitude ranges, during 2000.

<table>
<thead>
<tr>
<th>Continent</th>
<th>Latitude ranges – (percent area distribution)</th>
<th>% share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-10</td>
<td>10-20</td>
</tr>
<tr>
<td>Africa</td>
<td>472</td>
<td>279</td>
</tr>
<tr>
<td></td>
<td>(34.23)</td>
<td>(20.23)</td>
</tr>
<tr>
<td>N.C. America</td>
<td>107</td>
<td>590</td>
</tr>
<tr>
<td></td>
<td>(3.85)</td>
<td>(21.22)</td>
</tr>
<tr>
<td>S. America</td>
<td>725</td>
<td>2030</td>
</tr>
<tr>
<td></td>
<td>(12.110)</td>
<td>(33.91)</td>
</tr>
<tr>
<td>Asia</td>
<td>408</td>
<td>3048</td>
</tr>
<tr>
<td></td>
<td>(4.79)</td>
<td>(35.76)</td>
</tr>
<tr>
<td>Europe</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oceania</td>
<td>7</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>(1.36)</td>
<td>(15.53)</td>
</tr>
<tr>
<td>Total</td>
<td>1719</td>
<td>6027</td>
</tr>
</tbody>
</table>

During midst of 20th century world average yield was around 42.5 tons cane per hectare (Table 2.03). From amongst the principal cane growing countries, Brazil, India, China, Thailand, Philippines and Guatemala, had the cane yields 38.7, 32.1, 35.2, 17.5, 18.5 and 37.6 t ha\(^{-1}\) respectively, much below the world average. The past five decades have experienced new advances in cane production technology. Scientific research has touched new horizons in cane variety improvement through conventional breeding and genetic engineering, mechanization in cane culture and harvesting and plant protection measures. The concentrated efforts have brought vast improvements in cane yields. During 2002, Brazil, India, China, Thailand, Philippines and Guatemala did many efforts to improve their yields to 71.0, 67.4, 64.8, 93.6, 70.6 and 94 t ha\(^{-1}\), respectively, thus raising their yields over the world average of 66.1 t ha\(^{-1}\). However, individual countries in continents show much variation in yield increase, due mostly to uneven adoption of technology and uneven supply of resources in developed and developing countries (Table 2.03). Pakistan holds an important position in cane area and production in the world but ranks much behind the principal cane growing countries in average yield (48.1 t ha\(^{-1}\)). Indonesia show wide fluctuation in yield due to climatic features. Thailand has made a great head way both in cane area and yield per hectare.

In Pakistan, during 2007-08, sugarcane was grown on 1.24 million hectares, of which the Punjab province shares 67% area, while Sindh and NWFP share 25% and 8% area. Out of a total cane production of 63.9 million tonnes cane, Punjab, Sindh and NWFP contribute 63%, 29% and 7% share, respectively. The average yield of the country is around 51.5 tonnes cane per hectare. The Sindh province produce higher yields of cane (60.9 t ha\(^{-1}\)), compared to Punjab (48.72 t ha\(^{-1}\)) and NWFP (45.72 t ha\(^{-1}\)). The cane
### Table-2.03. Cane area and yield trends in principal cane growing countries of the world during the period 1950 – 2002.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>Area</td>
<td>848</td>
<td>42.5</td>
<td>6459</td>
<td>11343</td>
<td>13249</td>
<td>16878</td>
<td>19186</td>
<td>20180</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>47.2</td>
<td>51.2</td>
<td>54.3</td>
<td>61.3</td>
<td>65.0</td>
<td>66.3</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>Area</td>
<td>1672</td>
<td>38.7</td>
<td>1367</td>
<td>45.0</td>
<td>56.1</td>
<td>61.7</td>
<td>67.6</td>
<td>71.3</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>1367</td>
<td>38.7</td>
<td>45.0</td>
<td>56.1</td>
<td>61.7</td>
<td>67.6</td>
<td>71.3</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>Area</td>
<td>1204</td>
<td>32.1</td>
<td>2455</td>
<td>48.3</td>
<td>2610</td>
<td>3430</td>
<td>4200</td>
<td>412</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>1132</td>
<td>32.1</td>
<td>48.3</td>
<td>2610</td>
<td>3430</td>
<td>4200</td>
<td>412</td>
<td></td>
</tr>
<tr>
<td>Cuba</td>
<td>Area</td>
<td>304</td>
<td>41.9</td>
<td>1132</td>
<td>36.7</td>
<td>1361</td>
<td>1350</td>
<td>1041</td>
<td>1041</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>41.9</td>
<td>36.7</td>
<td>1361</td>
<td>1350</td>
<td>1041</td>
<td>1041</td>
<td></td>
</tr>
<tr>
<td>Pakistan</td>
<td>Area</td>
<td>161</td>
<td>33.2</td>
<td>562</td>
<td>44.4</td>
<td>719</td>
<td>854</td>
<td>1010</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>33.2</td>
<td>44.4</td>
<td>719</td>
<td>854</td>
<td>1010</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>Area</td>
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<td>35.2</td>
<td>300</td>
<td>46.7</td>
<td>652</td>
<td>1068</td>
<td>950</td>
<td>1422</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>35.2</td>
<td>46.7</td>
<td>652</td>
<td>1068</td>
<td>950</td>
<td>1422</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>Area</td>
<td>203</td>
<td>17.5</td>
<td>123</td>
<td>33.5</td>
<td>416</td>
<td>686</td>
<td>922</td>
<td>793</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>17.5</td>
<td>33.5</td>
<td>416</td>
<td>686</td>
<td>922</td>
<td>793</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>Area</td>
<td>112</td>
<td>59.8</td>
<td>410</td>
<td>62.5</td>
<td>546</td>
<td>350</td>
<td>618</td>
<td>632</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>59.8</td>
<td>62.5</td>
<td>546</td>
<td>350</td>
<td>618</td>
<td>632</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>Area</td>
<td>126</td>
<td>45.9</td>
<td>157</td>
<td>74.2</td>
<td>288</td>
<td>340</td>
<td>428</td>
<td>417</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>45.9</td>
<td>74.2</td>
<td>288</td>
<td>340</td>
<td>428</td>
<td>417</td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td>Area</td>
<td>152</td>
<td>55.2</td>
<td>135</td>
<td>96.8</td>
<td>297</td>
<td>320</td>
<td>418</td>
<td>414</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>55.2</td>
<td>96.8</td>
<td>297</td>
<td>320</td>
<td>418</td>
<td>414</td>
<td></td>
</tr>
<tr>
<td>Columbia</td>
<td>Area</td>
<td>45</td>
<td>98.6</td>
<td>260</td>
<td>45.9</td>
<td>170</td>
<td>304</td>
<td>397</td>
<td>430</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>98.6</td>
<td>45.9</td>
<td>170</td>
<td>304</td>
<td>397</td>
<td>430</td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>Area</td>
<td>80</td>
<td>59.7</td>
<td>95</td>
<td>81.3</td>
<td>215</td>
<td>369</td>
<td>366</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>59.7</td>
<td>81.3</td>
<td>215</td>
<td>369</td>
<td>366</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>S. Africa</td>
<td>Area</td>
<td>160</td>
<td>42.9</td>
<td>96</td>
<td>75.8</td>
<td>425</td>
<td>272</td>
<td>322</td>
<td>325</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>42.9</td>
<td>75.8</td>
<td>425</td>
<td>272</td>
<td>322</td>
<td>325</td>
<td></td>
</tr>
<tr>
<td>Philippines</td>
<td>Area</td>
<td>22</td>
<td>18.2</td>
<td>235</td>
<td>50.5</td>
<td>320</td>
<td>300</td>
<td>315</td>
<td>305</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>18.2</td>
<td>50.5</td>
<td>320</td>
<td>300</td>
<td>315</td>
<td>305</td>
<td></td>
</tr>
<tr>
<td>Vietnam</td>
<td>Area</td>
<td>16</td>
<td>37.6</td>
<td>41</td>
<td>30.0</td>
<td>79</td>
<td>135</td>
<td>302</td>
<td>320</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>37.6</td>
<td>30.0</td>
<td>79</td>
<td>135</td>
<td>302</td>
<td>320</td>
<td></td>
</tr>
<tr>
<td>Guatemala</td>
<td>Area</td>
<td>229</td>
<td>33.9</td>
<td>223</td>
<td>51.0</td>
<td>45</td>
<td>314</td>
<td>109</td>
<td>182</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>33.9</td>
<td>51.0</td>
<td>45</td>
<td>314</td>
<td>109</td>
<td>182</td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td>Area</td>
<td>-</td>
<td>43.3</td>
<td>195</td>
<td>54.7</td>
<td>105</td>
<td>330</td>
<td>270</td>
<td>295</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>43.3</td>
<td>54.7</td>
<td>105</td>
<td>330</td>
<td>270</td>
<td>295</td>
<td></td>
</tr>
<tr>
<td>Egypt</td>
<td>Area</td>
<td>-</td>
<td>78</td>
<td>88.9</td>
<td>48.0</td>
<td>118</td>
<td>116.6</td>
<td>113.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td></td>
<td>78</td>
<td>88.9</td>
<td>48.0</td>
<td>118</td>
<td>116.6</td>
<td>113.6</td>
<td></td>
</tr>
</tbody>
</table>

Area in “000” ha: Yield in tons per hectare
Source: F A O Production Year Books, Rome, Italy.
Cane and Sugar Production

cultivation in Baluchistan province accounts for a negligible production of only 40,900 tones from 800 hectares. Sindh province has the climatic condition relatively more favorable for cane production than the conditions observed in other cane growing regions. Low average yields are due mainly to irrigation constrains, low input resources and conventional methods of cane cultivation. Though of course, cane yields as high as 100 – 150 t ha\(^{-1}\) in Sindh and 80 – 120 t ha\(^{-1}\) in Punjab and NWFP are obtained with individual growers under good crop, irrigation and land management practices. Thus there is wide gap between potential yield and average yield of cane.

Table 2.04 Development in area and yields of cane in Pakistan during fifty eight years 1950-2008

<table>
<thead>
<tr>
<th>Province</th>
<th>Cane area(000ha)</th>
<th>% increase</th>
<th>cane yield (t ha(^{-1}))</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pakistan</td>
<td>219.3</td>
<td>1241.3</td>
<td>466.0</td>
<td>51.49</td>
</tr>
<tr>
<td>Punjab</td>
<td>170.0</td>
<td>827.2</td>
<td>386.5</td>
<td>48.72</td>
</tr>
<tr>
<td>Sindh</td>
<td>8.1</td>
<td>308.8</td>
<td>3712.3</td>
<td>60.86</td>
</tr>
<tr>
<td>NWFP</td>
<td>41.3</td>
<td>104.8</td>
<td>153.75</td>
<td>45.72</td>
</tr>
</tbody>
</table>
Climate and Weather Effect

The ideal climate for sugarcane is spelled as long warm growing season with adequate rainfall, fairly dry and cool but frost free ripening and harvesting season and freedom from tropical storms (Mangelsdorf, 1950). Ideal habitat of sugarcane may be defined as a tropical wet-dry climate with adequate rainfall to restore soil water surplus to save the crop even in possible dry season (Blume, 1986). The climatic parameters including day length, temperatures and humidity have direct effect on cane growth and its maturity, and these in turn are influenced by sun light, latitude ranges, elevation and precipitation. In different climatic regions growing period of cane crop varies between 8 and 30 months, and the weather changes play significant role in plant growth and development and yearly fluctuations in yield and quality of cane. More than half the variation in annual yields is due to weather changes and the rest to other agronomic factors (Biswass, 1988).

Relationship of latitude with Yield and Quality

Cane yield

The importance of latitude lies in providing day length more or less conducive to cane growth and maturity. Lower latitudes provide longer days for growth period of cane. Therefore, the yields are generally higher on latitude below 20°, while yields fluctuations are quite large at higher latitudes (Srinivasan and Benergee, 1957). As such cane yields in South India (8°-20°) are much higher than in North India (25°-32° N). The analysis of yield data in different states indicate that advance in cane growing from latitude ranges of 8° to 32° brought a step wise drop in cane yields. The average yields were noticed to be 104.21, 87.27, 59.09 and 57.12 t ch⁻¹ in latitude ranges of 10°-15°, 15°-20°, 20°-25° and 25°-32°, respectively (Table 3.01).

Similarly average yields of Pakistan are higher in lower Sindh (24.5-27°) that avail of longer days and relatively more favorable temperature and humidity. On the other hand cane yields of the regions located in higher latitudes of Punjab and NWFP (27°-34° N) are considerably low due to extreme temperatures and low humidity. Nevertheless, this principle may not hold good in various countries falling in different latitude ranges. The survey of global area indicates some very interesting climatic features of countries lying in favorable climatic zones but having very low yields. On the other hand a number of countries can be quoted which produce very high cane yields besides their location in subtropics or temperate zones. Climatic hazards like cyclones and drought and lack of technical know how and conventional planting techniques may nullify the effect of favorable latitude ranges. This fact can well be illustrated from the yield data given in Table 3.02

Sugarcane has been considered a tropical plant due to the climate favorable for cane growth in tropical regions. But in present day agriculture, the world favorable climate has been substituted by favorable environment. As the profitable commercial crops are being
obtained through modern agriculture techniques and cane varieties adopted to cope with the constraints of local environments even in subtropical regions that do not have the ideal habitat of cane production. High yields of cane and sugar are obtained under such dry environments where satisfactory soil water balance can be achieved by irrigation water under optimum soil and crop management practices. The cane varieties have been developed which owing to their great adaptability can be cultivated under a variety of climate and soil conditions. The cultivation of sugarcane is therefore spread in tropical, sub-tropical and temperate regions between latitude ranges of 32° S and 37° N (World map-page 15).

Table-3.01. Cane yield trends observed in sugarcane growing states¹ / provinces² of India / Pakistan * located in different latitudes, during 2005-06

<table>
<thead>
<tr>
<th>Country- Latitude range°</th>
<th>State</th>
<th>Cane yield tha¹</th>
<th>Regional average tha¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>India-8° – 15°</td>
<td>Kerala</td>
<td>99.8</td>
<td>104.21</td>
</tr>
<tr>
<td></td>
<td>Tamil Nadu</td>
<td>108.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Karnataka</td>
<td>100.7</td>
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¹ Cooperative Sugar, October-2002

In tropical tracts sugarcane gives better yields in equitable temperature over summer and winter seasons, and evenly distributed rainfall throughout the year. However cyclones and droughts adversely affect cane crop in some regions. Beyond the tropical belts, sugarcane is cultivated in subtropical regions of South America, USA, Mexico, Central and South Africa, Australia, India, China and some sub-tropical islands, where temperatures are favorable for growth and adequate precipitation and soil moisture is available to meet the water demand of the crop. Sugarcane is also cultivated successfully in some regions of said continents where climatic factors are not very conducive; temperature during summer may exceed 45°C and cane is subject to severe frost during
## Table-3.02 Cane area and yield of various countries falling in different latitudes, during 2000

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Cane area: ‘000’ hectare; Cane yield: ‘000’ tons
### Cane and Sugar Production

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winter. Successful cane cultivation in Nile valley of Egypt, Haptapah regions of Iran, and continental areas of Punjab (Pakistan and India) can be quoted for instance. Though the sugarcane has shown wide adaptability in diversified climate, yet facts remain that yields largely vary according to regionally different environmental conditions. Under optimum inputs yields in climatically favorable environments are the highest. It is generally observed that cane cultivation in regions of suitable latitude ranges has by far great economic edge on subtropics or temperate climate. As the crop produced under subtropical conditions require more investment in soil, water and crop management practices, to achieve higher sugar yields for harvesting profitable return.

**Cane quality**

Sucrose contents of cane are reported to be influenced by solar radiation, duration of sunshine, precipitation, atmospheric humidity and temperature (Biswas, 1988), and these factors are largely influenced by latitude. Lower latitudes assure longer days with increased sunshine duration during growth phases of plant. As such high sucrose contents in cane are noted at around 18° S and 18° N (Shaw, 1953). Sugar contents drop rapidly from these latitudes towards the sub-tropics and less rapidly to wards the equator.

High sugar recoveries demand relative temperature disparity (RTD) value around 14°-16°C, low daily mean temperature 22°-26°C and low relative humidity (<50 %), during ripening. Wider range between a day (maximum) and night (minimum) temperature during ripening results in higher sucrose contents (Das, 1941). From the analysis of climatic data, it is concluded that countries or regions having low temperature (21°-24°C) and low precipitation (500-1000 mm) produce better quality cane. High altitudes of 1000 mm or more within equatorial climate and low altitude of subtropics also produce good quality cane (Blume, 1986). On the other hand tropical countries or regions with high average temperature (25°-27°C) and high precipitation of more than 1500-mm produce more bio-mass of cane but of low sugar contents. Lower sucrose contents in equatorial tropics, than much drier environments of sub-tropics, is due to higher temperature, more cloudiness and precipitation and consequently less insulation (Blume, 1986).

The favorable effect of altitude on quality is due to low temperature. In the tropical areas where the weathers are distinctly wet and dry, moisture status inside the cane is a dominating factor in the synthesis and translocation of sugars. Under such conditions control on irrigation and fertilizer is exercised to hasten or delay the maturity (Humbert, 1968). In modern agriculture, high sucrose contest are achieved irrespective of latitude, in regions of low precipitation of both tropics and sub-tropics, if optimum soil water balance has been achieved by human control.

In the light of foregoing discussions climatic features have distinct behavior on plant growth and maturity phases

- High yield of cane per hectare is the result of a large biomass production which is caused by high temperature, high precipitation and longer growth season. These, however, do not favor high sucrose recovery in cane.
- High sucrose contents in cane are a function of relatively low temperature and...
low precipitation during maturity phase, which otherwise depress growth.

The climatic behavior of countries differs widely. The sugar production strategy of each country is entirely different. Under conditions like Hawaii, long crop duration with moderate temperature favors luxuriant growth and heavy yields during harvest season of 24-28 months, but maturity has to be induced through leaf sheaths moisture control. On the other hand countries with distinct climate of moderately hot summer and cool winters have the environment quite suitable both for growth and maturity phases. Long summer months with good moisture supplies assure luxuriant growth while winter is most suitable for high sugar synthesis and storage during short maturity season. The most feasible situation is to compromise on sugar yield per hectare per year or per month of crop harvested.

**Effect of Different Climatic Factors**

Sugarcane is grown all the year round and is exposed to all the seasonal variation of weather. The variation in weather parameters like sunlight, temperature, rainfall, humidity and solar radiation affect the different phases of growth like germination, tillering, cane formation and cane stalk elongation, as well as the maturity and ripening phases of plant.

**Sunlight**

Sunlight absorbed by leaves is directly used in the process of photosynthesis to produce plant biomass by assimilating CO₂ from atmosphere. The photosynthetic capability of sugarcane is especially high because it uses a specialized C₄ biochemical pathway to trap CO₂. The C₄ pathway allows sugarcane to assimilate more of CO₂ at higher rates than other plants with C₃ pathway. Thus sugarcane plant is the most efficient user of solar energy to synthesize carbohydrates. Sugarcane is thus considered to be one of the most productive plants in terms of biomass production per unit of light intercepted.

Sunlight plays vital role as intensity and as photo period to control and activate various growth processes in its vegetative phase and in flowering. The sugarcane yield is governed by:

(a) The amount of sun light exposure to the crop over its life time,

(b) Ability to intercept and use the light energy to produce carbohydrates.

Light intensity is associated with growth regulating substances and their movement for various bio-chemical functions in plant. The amount of sunlight available to plant depends on climatic conditions and latitude of the crop site. The desirable locations with respect to light availability are within 30°N or 6°S, and more so on tropical latitude ranges.

In comparing sugarcane yields among crop growth periods, the most important one is the length of the time that the crop is grown. Crops grown over a longer time span will be exposed to greater cumulative light and have the potential to produce greater yield. Thus a crop grown over a 18 months period has a potential to produce more than the crop grown for 12 months.

Sun light interception by leaves is an important variable limiting sugarcane yields. Leaf
surface determines the amount of sunlight that the crop can receive. In larger leaf surface area greater amount of light energy is available for photosynthesis and yield. For this reason early and rapid growth of crop is essential to gain the large surface area of leaf for light interception.

In full sunlight plants produce more dry matter, are healthier, stalks are thicker but shorter and leaves are broader and green. Light is perhaps the most important factor for promoting tillering in cane. In cloudy regions as well as in shade tillering is considerably less. Abundant light in initial phase of growth promotes tillering and as the plant grows to close in, light is curtailed that cause tiller mortality.

**Temperature**

Temperature is one of the most important factors affecting different plant development phases. Countries in sub tropics experience violent fluctuations in temperature during various growth spans of plant. The crop might be exposed to scorching heat with maximum mean temperature of $40^\circ$-$42^\circ$C reaching to highest maximum of $48^\circ$-$50^\circ$C in some countries in summer, and temperature around freezing in winter. The effect is severe in continental type of climate, while ocean winds in coastal belt have great influence to moderate the temperature effect. On the other hand the countries in tropical and equatorial climate experience a little variation in maximum and minimum temperature during summer and winter months, except on mountain heights or regions under the influence of cold or hot sea currents.

**Germination:** A good stand of cane crop is primarily established by good germination, which is mainly affected by temperature of the environments. Germination is reported to be optimum between temperature range of $28^\circ$-$33^\circ$C (Biswas, 1988). Germination is accelerated in the temperature range of $26^\circ$ to $33^\circ$C, is sensitive at $22^\circ$C and is decreased at $18^\circ$C and below (Yang and Chen, 1984). The $32^\circ$C-$38^\circ$C is reported to be the optimum temperature for germination and that the germination is reduced at $21^\circ$C and is completely suppressed below $10^\circ$C (Humbert, 1968).

In Pakistan climatic condition, the ideal temperature for good germination is available in September before winter and in March after winter months. During September, almost 75 percent germination is obtained within a 20-25 days of cane planting, when the temperature is well above $25^\circ$C. Germination is gradually reduced thereafter and is completely checked in December- January. Since temperature during February- March is some what lower it takes four or five weeks to complete germination. The germination period may be prolonged if cool weather persists due to rains.

**Tillering:** Tillering in cane is noticeably correlated with temperature. Tillering gradually increases with increasing temperature until maximum is reached some where around $30^\circ$ C (Dillevign, 1952). Tillering is reported to be greater at daily mean temperature of $26^\circ$C (Singh and Singh 1966).

**Growth:** Growth is characterized by increased stalk length and girth of cane and development of leaves and roots. Growth process in cane plant takes place through photosynthetic activities in leaves, uptake of nutrients and moisture through roots. Temperature is the chief growth controlling factor. The $26-27^\circ$C is the ideal temperature for optimum growth; growth is checked at $10^\circ$C and $27^\circ$C is optimum for both growth
and nutrient absorption (Humbert, 1968). The critical temperature for cane growth is 8-20°C (Biswa, 1988) and Bacchi et al, 1977), and that the growth ceases as the temperature falls below 12°C and if it is less than 5°C the leaves become pink.(Biswa, 1986; Parthasarathy, 1972).

Photosynthesis in cane is generally reduced as the ambient temperature is decreased from 23.1 to 13.6°C (Burr et al, 1957). Canopy development is a vital out come of growth; however, rate of development is governed by prevalence of moderate temperature between 21°C and 38°C with relative humidity of 50% (Kakade, 1985). At a temperature of 35°C the decrease in growth rate is due to increase in photorespiration (Chu and Kong, 1971). Cane is found to thrive at temperature as high as 45°C in Pakistan.

Studies have revealed that low soil temperature influence N, K contents and chlorophyll in the leaves so strongly that even in the presence of adequate nutrients, the level of these elements in the leaves is drastically reduced (Kanwar and Singh, 1979). The lower leaves die and uppers show yellow- green appearance. The 27°C is the optimum temperature for growth and nutrient absorption (Burr, 1948). Seven folds decrease in P uptake was noticed as the temperature decreased from 22.1°C to 16.7°C (Burr et al, 1957). A drop in root temperature from 23°C to 19°C cuts P in intake to one third and reduces N intake to about one half.

Maturity and Ripening: By termination of growth low temperature and less humidity favors the crop for ripening. A gradual reduction of these factors during four to six weeks before harvest tends the crop towards ripening (Kakade, 1985). Large differences between day and night temperatures favor the process. A 10°C to 12°C is considered the minimum temperature for ripening (Parthasarathy, 1972). However, the ripening process is accelerated with drop in humidity in the environment and leaf moisture in the plant. To hasten ripening process mild drought conditions may be created by withholding irrigation.

Humidity

A high degree of atmospheric humidity and proper soil moisture is essential for proper growth of cane crop. However, high humidity that persists for long periods may inhibit evapo-transpiration and thereby affect growth. High humidity may also invite infection of some viral and fungal diseases. On the other hand low humidity with high temperature increase the evapo-transpiration to off set the water balance in plant thus to hamper growth.

Atmospheric humidity is associated with coastal environments as well as with rainfall pattern of the area. A positive correlation has been found between rate of cane elongation and rainfall (Sun and chow, 608). Cane yields are often high in regions where crop water requirements are met through rains (Humbert, 1968). For a good crop growth uniform distribution of rainfall is more important than total rainfall, and light showers are more beneficial than heavy rains. Besides meeting the water needs of plants shower influence cane growth through moisture absorption by leaves, raising atmospheric humidity and keeping the leaves surfaces clean for optimum transpiration and respiration. On the other hand heavy rain may impede the drainage of cane fields and cause severs lodging if associated with strong winds. Nevertheless moderate rainfall of 750-1000 mm
supplemented by sufficient and timely irrigation is considered best for healthy crop growth.

Dew

Dew deposits on leaf surfaces help in foliar absorption of moisture. It also delays the rise in leaf temperature and thus reduces the rate of evapo-transpiration. Dew is of paramount importance for cane growth in semi-arid regions to promote growth of cane to some degree. The amount of dew deposit is estimated to be 0.25 to 0.40 mm per night with a total of 25 to 30 mm per annum (Biswass, 1988). Thus dew deposits help to mitigate the severity of water stress to certain degree in moisture stress areas.

Climatic Hazards

Some climatic hazards like frost, hailstorm, wind storm; drought and cyclones have drastic effect on growth and yield of cane and the effect varies with intensity and frequency of each of these calamities.

Frost

Frost is the most damaging thermal factor that causes foliar damage, bud mortality and juice quality deterioration in cane crop. During winter, as the air temperature falls to 0°C and even low, the cell sap freezes and injures the whole tissue in affected plant parts. The top portion of leaves is worst affected. The tissue injury is noticed in the apical bud of the central whorl of immature leaves, where tissues assume water soaked appearance of up to one inch. After a few days of the frost occurrence the injured portion turns brown and decays. The spindle can be pulled out with ease.

In mild frost new heart-leaves may be reproduced when plant revives its growth. In sever frost all leaves of top portion of cane stalks and buds are damaged. Each successive frost damages the still lower buds, and whole of cane foliage may get dry if frost persists for longer duration. The buds on the cane stalk look soft and brown or black inside.

In frost incidence actual minimum temperature recorded during frosty nights is not as important as the length of time the crop is exposed to frost. Several hours’ exposure to a temperature of -1°C is far more injurious than 5 minutes at -4°C (Martin et al, 1965). The crop dries out causing considerable loss in cane weight and severe reduction in sugar mills recovery. However, if cool dry conditions prevail, the sugar deterioration is not that rapid. The rate of deterioration is accelerated with rise in temperature due to the fungal and microbial activities in injured tissues. Besides the frost effect on juice quality, seed crop is also damaged due to decay of buds in severe frost years. Frost has also lethal effect on initial growth of pre-winter sown crop. All the foliage may get dried in winter; however, the underground stubbles would re-sprout with the on set of spring season. Sprouting depend on the intensity of frost damage.

After the winter is over and plants revive growth; a sudden fall in temperature below 5°C cause chilling injury to newly developed leaves. The dew-moisture in the whorl get chilly and the intact tissues of the young growing leaves get damaged. As the leaves grow the expanded leaves show the damaged section as band, called “banded chlorosis”.
Frost occurrence is a usual phenomenon in northern regions of Pakistan and intensity varies with years. Mild frosts are common in Punjab province and upper Sindh, however severe frosts are also experienced in some years. Cane crop suffers more in dry sandy areas. Winters are mild in lower Sindh however; Siberian wind from Russia may make the weather chilly after a cycle of several years.

**Hail storm**

The hailstorms damage the standing cane crop by causing mechanical injury to plants. The cane leaves are torn to shreds and most tops are stripped of tops and trash. The extent of damage depends on the intensity and velocity of the storm. The hailstorms in Pakistan are not very frequent and are experienced in localized pockets. Nevertheless sugarcane is the hardy crop and can recover after fall of hails.

**Wind storm**

Winds play a significant seasonal role on the global scale, as it is associated with the movement of clouds and rains. Winds affect the growth of crop by their effect on microclimate. Dry winds reduce atmospheric humidity and increase evapo-transpiration rate thus subject the plants to moisture stress. In drier regions of sub-tropics they are of great economic importance while considering the value of irrigation. High windstorms on the other hand cause considerable damage to a full-grown crop. The crop lodges badly and may also be up rooted. The nature of damage depends on the velocity and the pattern of windstorm. The wind blowing in one uniform direction may not be as damaging as the storm in variable direction. In Pakistan, windstorm of velocity of 60-120 Km/ hour may occur once or twice a year. Still more violent storms have also been experienced after several years cycle. Windstorms cause severe damage to cane crop in the form of cane yield losses and significant reduction in sugar recovery. Great problems are faced in harvesting, loading and disposal of lodged crop.

**Sun burn**

Sun burn is characterized by whitish patches and dead areas in the top leaves of young cane. Half or two third length of blades first shows dull grayish green patches, which gradually dry to trash. It happens in hot dry weather, when due to high temperature, low humidity and drying winds; transpiration of moisture from leaf surfaces is at much higher rate than the moisture up take through roots. This imbalance in transpiration desiccates the leaf tissue to dead streaks, white blotches or partial or complete dead areas on leaf blade. This violent action of dry weather does not appear on leaf sheath and lower surface of mid rib. Sun burn symptoms start appearing from unfurled leaves leading down to fourth or fifth leaves. Old leaves are not affected. The sunburn is not concerned with the moisture status of soil. The sunburn symptoms may appear even when the cane field is at field capacity or is saturated with water. It is just the physiological imbalance in moisture loss from leaf surface and moisture uptake by roots. As such the phenomenon is also
called the physiological drought. The effect is not lasting and the plants recover as the weather get mild.

Sunburn is a usual phenomenon noticed in almost all the cane growing regions of Pakistan during May- July months. Cane varieties, however have different threshold temperature to tolerate sunburn in different soil types.

**Drought**

It is the severe shortage of water to restrict the growth of plant. It could be meteorological drought, agricultural drought or both. Meteorological drought occurs when the rainfall for the period /season is less than 75% of the normal rainfall and the crop is devoid of any kind of irrigation. It is of great concern to cane crop prior to and during active stage of cane growth. The cane growth is severely affected and even the irrigation fails to mitigate the ill effect of drought.

Agricultural drought occurs when the available soil moisture during active growth stage is inadequate for healthy crop growth.

In case of physiological drought, water is available in soil but plant is not in a position to take up moisture from soil. In saline soils, water moves away from roots due to plasmolysis, causing wilting in plants. Under waterlogged conditions as well uptake of moisture by plants is considerably reduced.

Under drought conditions water uptake by plant is restricted; plants loose vitality and vigor and plant growth is severely checked reducing the size of leaves, cane girth and length of internodes. Severe drought increase fiber contents of cane stalks, tissues of cortex section are squeezed making it hollow in some varieties.

**Sugarcane Agro-Climatic Zones of Pakistan**

Climate and soils are the main factors determining the efficiency in cane production. Nature has bestowed Pakistan a wide range of soil type and climate. Pakistan is located between latitude range of 24.5° to 36° N and avails of coastal, sub-tropics, and semi-temperate climates in plains, plates and mountain heights. However, sugarcane cultivation is confined in part of coastal area and plains, and plains of river Indus and adjoining rivers in Sindh, Punjab and NWFP. Climate is mostly semi-arid and temperature conditions vary widely in topography, but are generally continental in type. Due to wide meteorological difference a number of climatic regions can be earmarked for cane growing.

**Sindh**

The Sindh province has two typical cane production zones, the lower Sindh and the upper Sindh. The lower Sindh constitute Hyderabad and Mirpur Khas division, which are bordered by Arabian Sea coast. This zone, on the southwestern periphery is partly in the range of coastal winds. In this region summer is not that scorching, is mild and frosts are rare. Compared with other regions, daily mean temperatures are relatively higher in winter and lower in summer and monthly mean show lesser variability in maximum and minimum. During May and June months, mean maximum is higher (40°-42°C) but mean minimum (26°-28°C) is favorable for growth and maturity phases. Temperature range is
relatively milder in Badin and also towards Thatta district. Badin area also remains cloudy more often during May-July months.

Annual rainfall is very low in Hyderabad (178 mm) and Badin (222 mm) districts; however, humidity level is relatively high due to constant flow of coastal winds. At around noon time temperature during summer is increased but on the whole humidity level is favorable for crop growth. Due to higher humidity, evapo-transpiration is considerably lower than other regions. These meteorological levels, on the whole account for favorable condition for growth and yield of cane. Low relative humidity (46-66%) and mild mean minimum temperatures (8°-16°C) free from frost during ripening are favorable for good sugar recoveries. The upper Sindh that include Sukkur and Larkana divisions, is much away from the influence of coastal climate. The summer and winter months experience extreme weather. Rainfall is extremely low (88.2 mm). During summer relative temperature is higher, compared to lower Sindh, as such climate is not much favourable for cane plant. Yield of Sukkur division is relatively better while yield of Larkana is extremely lowest in the country.

Punjab

The climate of Punjab province is characterized by very hot summer and very cold winter. Hot weather commences by the month of April and hot spell quenches with the first shower of monsoon some times during June. The temperature may go as high as 48°-50°C in extreme periods of May to July, with mean maximum range of 37-42°C and mean minimum range of 28-23°C for the corresponding period. During winter mean minimum range of 4°-6°C is observed associated with occasional mild frost. Severe frost may occur after 3-5 years cycle. Climate is more extreme towards southwest regions in Multan and Khanpur zones. Precipitation influences severity of weather. More or less two third of total rainfall is received during monsoon beginning in mid or late June. Rainfall pattern of upper Punjab is higher and declines gradually towards central and southern Punjab. As such Lahore receives annual precipitation of 629 mm, followed by 435 mm in Sargodha, 367 mm in Faisalabad, 187 mm in Multan and only 97 mm in Khanpur. The northwest zone, D. G. Khan is also situated in dry region. Due to low precipitation atmospheric humidity is very low around 33-40 percent during summer and 55-65 percent during winter. High temperature and low relative humidity increases the rate of evapo-transpiration during summer. As such low humidity and high aridity increase the crop demand for irrigation water to cope up with atmospheric moisture stress. Sandy loam soils in that area show severe response to extreme temperatures with sunburn symptoms in summer and frosts in winter. Full-grown crop may also be subject to windstorm of 6-120 Km velocity, once or twice a season.

Cane yields of Punjab are generally low, with average yields 48 tones per hectare. However, within province average yield of 60 tons is obtained in tracts of abundant ground water. Effect of dry climate is mitigated through soil and irrigation management for better irrigation water use efficiency. Mean minimum temperature during ripening is low (4°-8°C), hence average recovery is markedly low (8.25%). Severe frosts in some years have detrimental effect on sugar production.
NWFP

The province faces extreme climate during summer and winter months with mean maximum and minimum temperature ranges of 36°-41°C and 4°-5°C respectively. Summer is more severe in D. I. Khan, and winter is more severe in Peshawar division. This difference is due to variation in rainfall pattern of both the zones, as Peshawar receives annual precipitation of 404 mm compared with 271 mm in D. I. Khan. In this region, RTD factor is higher and humidity is very low and these meteorological factors have not much favourable effect on growth and yield of cane. Mean minimum temperature is very low 4°-5°C and frosts are of common occurrence in the area. The cane yield of the province is around 45 t ha⁻¹.
Chapter-4

Cane Breeding

Origin and Botanical Classification

Sugarcane, though a tropical plant, is cultivated in both the tropical and sub-tropical regions. Sugarcane is also being grown in extreme climate and in areas most unlikely for its production. This wide spread cultivation is due to the morphological and genetic changes in cane that occurred because of inter-breeding among various species. Cane varieties have been developed that are resistant to a wide diversity of growing conditions. Knowledge on the origin and botanical classification of cane is important for utilizing the specific genome for improvement of characters.

Sugarcane is a perennial grass and the present day cultivated varieties of sugarcane are the hybrids of different species of the genus *Saccharum*. The genus *Saccharum* has its origin from the following family ancestors:

*Family*: Poaceae (Gramineae)
*Sub-family*: Panicoideae
*Tribe*: Andropogoneae
*Sub-tribe*: Saccharineae
*Group*: Saccharastrae
*Genus*: Saccharum

Taxonomists and cytogenticists have given a number of hypotheses on the origin of *Saccharum*. Besides the genus *Saccharum*, which comes under the tribe *Andropogoneae*, have nine other genera, namely, Miscanthus, Erianthus, Narenga, Sclerostachya, Miscanthidium, Eccoiopus, Erichrysis and Imperata. Based on morphological similarities, crossability / breeding behaviour and evolutionary relationship, the genera *Saccharum, Erianthus, Narenga, Miscanthus and Sclerostachya* are of great concern to cane breeders. They are closely related inter breeding groups concerned in the origin of sugarcane. These have been grouped as *Saccharum complex* (Mukherjee, 1954). Later, another genus *Ripidium* was recognized as section of *Erianthus* (Grassl, 1971). As a result of evolutionary process during natural course of crosses amongst various genera of *Saccharum* different species were developed. Generally six species have been recognized which include: *S. officinarum*, *S. spontaneum*, *S. sinense*, *S. barberi*, *S. robustum* and *S. edule*. Of these, *S. officinarum*, *S. sinense*, and *S. barberi*, are cultivated, while others are wild forms. The classification by Grassl (1974-1977) recognizes only four species i.e *S. officinarum*, *S. spontaneum*, *S. robustum* and *S. sanguineum* Grassl, while *S. sinense*, *S. barberi* and *S. edule* are considered to be generic hybrids.

The species *S. officinarum, S. barberi* and *S. sinense* are the sweet forms of introgression among the *Saccharum complex* (Daniel’s, et al, 1975). According to Daniel’s et al, (1975), the indo-Burma China region, *S. spontaneum, Erianthus sect*, *Ripidium* and *Sclerostachya* are found as the center of *Saccharum complex*. Naidu and Srenivasan (1987) were of the view that there are two major centers of diversity for sugarcane, New
Guinea and adjoining islands and chain of Indonesia for *S. officinarum* and *S. robustum* and northern India and the region bordering China and Burma form the center for *S. spontaneum* and other related grasses like *Erianthus, Schlerostachya, Narenga* etc.

The economic importance and origin of different species of the genus *Saccharum* is described as under.

1. **Saccharum officinarum L (2n = 80)**

   The species is used primarily for sugar production and is often known as the noble cane. The species in general has thick soft, juicy stem with low fiber having high sucrose contents. They have poor tillering and shallow root system, broad leaves with self-trashing habit. It lacks resistance and hardiness. Have high individual stalk weight and produce good yield of cane and sugar under optimum conditions, therefore are good for milling purposes in sugar industry. Being soft and sweet, some varieties are very much relished as chewing cane.

   As a group they are susceptible to many of the serious cane diseases. However, some strains show resistance to smut, fiji and downy mildew. Being donor of sucrose genes has been extensively used as best breeding stock. Selfing show in-breeding depression, however, considerable improvement has been brought about by inter-variety crosses. The species generally transmits ‘2n’ gametes in inter specific crosses with *S. spontaneum and S. barberi*, but normal ‘n’ gametes in inter specific crosses. The species in general is considered to have 2n = 80 chromosomes (Vijaylakshmi, 1967). Many workers have accepted 10 the basic chromosome number of this species and described it as an octoploid or of higher ploidy (Roche and Daniels, 1987). However, Jagathesan and Ratnambale (1967) indicated that this is not a simple ployploid, some varieties have shown variable number of 68 to 99.

   The species is of tropical origin; however there has been controversy on the place of its origin. Babu (1990) reviewed and postulated that the specie was originally present in west Bengal region of India. From the views of different workers two opinions could be developed: (a) that it originated from *S. robustum* by long continued natural selection by natives, in New Guinea (Grassl, 1974, 1977) and (b) that it evolved from *S. spontaneum, Miscanthus, Erianthus, Erundinaceus* through introgression, and later it was migrated to the region of diversity where it was adapted (Rocke and Daniels, 1987).

2. **Saccharum spontaneum L (2n = 40- 128)**

   The species is highly adaptable, resistant to diseases, cold, drought and other difficult growing condition. For this reason this species is widely used to interbreed with *S. officinarum* to develop adaptable and vigorous germ plasm for diverse conditions.

   The specie forms a complex group of wild canes and has a wide indigenous range from dwarf bushy types with narrow leaves and thin stalks to erect broad leaved and thick tall stem. Stalks are hard pithy or often hollow in center. Has profussed tillering and vigorous root system. Have very low sugar and little juice quality, however superior juice quality has been recorded in some species (Vijayalakshami, 1967). Clones are immune to sereh and mosaic and resistant to red rot. It withstands drought, cold and salinity. The species has contributed vigor, hardiness, tillering and resistance to environmental stress and
diseases and pest tolerance to commercial varieties (Naidu and Sreenevasan, 1979). The species is widely distributed over a large geographical area in a latitude range of 8° S to 40° N (Mukerjee, 1950). It extends from Japan and Indonesia / New Guinea through Indo-Pakistan sub-continent to the Mediterranean and Africa (Panje and Babu, 1960). India is both the center of origin and center of diversity of S. spontaneum (Babu, 1979). It is generally accepted that this species originated in northern India and that it is a product of introgression among members of saccharum complex (Daniel’s et al 1975).

It is rich in genetic variability with reference to morphological adaptation and taxonomic differences in different habitats of riverbeds, sea coasts and forests. In its wild form tall and thick types have been used as shelter, wind break and fencing material of gardens (Mukerjee, 1957). Varieties with thin stalks and vigorous tillering are used as fodder for animals in famine days.

The species has been extensively used in nobalization in S. officinarum and S. robustum. In India the first product of nobalization was Co 205 (Vellai x S. spontaneum). Some try-specific crosses among (S. officinarum x S. barberi) x S. spontaneum have been made to develop useful commercial canes in India (Rocke and Daniel’s, 1987).

3. Saccharum barberi Jesw (2n = 111-120)

The specie has its origin in north India and is commonly knows as Indian canes. They are named after the name of well-known breeder C. A. Barber. Barber considered the species has arisen from S. spontaneum through mutation and selection. Parthasarathi (1946) was of the opinion that it has originated through natural hybridization between S. officinarum and S. spontaneum in the regions of Bengal, Bihar and Orissa. Barber (1915, 1916, 1917, and 1922) made extensive studies of the species and recognized five groups. The groups reviewed by Babu, (1990) are, S. barberi, Mungo, Narenga, Saretha, Katha, Sunnabile and Dhaulu.

In general, canes are small barreled, hard with high fiber and have vigorous root system. They are not commercially good for sugar industry; however comprise a variety of forms, which were grown for ‘gur’ manufacture in earlier times. Juice of ‘Katha’ form was relished as beverage. They are tolerant to extreme temperature, drought and water logging. They are immune to sereh disease. Some varieties are resistant to mosaic but as a group lack resistance.

Flowering in these species is generally sparse and late. Clones have to be identified for flowering. Flowers show wide diversity in fertility ranging from normal seed setting in Katha to complete sterility in Mungo group (Ehirajan, 1981). Male fertile varieties have been earmarked and are used for inter specific hybrids. The variety Co 213 is the result of cross between Black cheribon (S. officinarum) x chunnee (S. barberi).

4. Saccharum sinense (2n = 116-118)

The species include Chinese and Japanese canes. The canes are hard, thin and fibrous, tall with relatively broader leaves and used for fodder. Stalk is small barreled, however, Uba, variety is thick, soft and sweet and is cultivated in China from pre-historic times. It has satisfactory sucrose contents but is low yielding. In China, it is mainly used for chewing and for production of crude sugar to small extent.
In view of Parthasarathy (1946), the species was originated as natural hybrid between indigenous forms of *S. spontaneum* and *S. officinarum*. According to Grassl (1964) the species was developed in China-Japan area by introgression between *S. officinarum* and *tetraploid Miscanthus*. Heinz (1987) postulated that various members of *saccharum complex* including *Erienthus*, *Miscanthus*, *Sclerostachya* and *S. officinarum* are involved during introgression at various levels of ploidy of these species.

Both the species *S. barberi* and *S. sinese* have great value in cane breeding work, as they possess desirable traits like heavy deep root system and tolerance to drought. Commercial varieties PoJ 213, PoJ 234, H32-1063 and Co 213 are outcome of their crosses. Their use in breeding is limited due to poor flowering and low fertility, which may be related to aneuploidy and higher irregular meiosis resulting from hybrid origin.

5. **Saccharum robustum** Brandes & Jesw. ex Grassl : (2n = 60, 80)

Stalk is thick, tall and erect. Some clones are known to be as tall as 10 m. Stalk thicker near nodes with swollen growth rings. Stalks are hard and tough with high fiber, pithy in the center with little juice and sugar. Some varieties are known to have high Brix.

The species occurs in wild, but is confined to New Guinea, Indonesia and somewhat extended to part of Philippines. In geographical distribution it is the closest wild relative of *S. officinarum*. Daniel’s and Roach (1987) concluded that the species has very diverse population of plants derived from introgression of *S. spontaneum* with other genera (*Eriathus, Arrundinaceum* and *Miscanthus*) in New Guinea.

The species generally flowers freely in all of their established locations. The forms of *S. robustum* are known to have been in use of in breeding work with varying success in Barbandos, Queensland, Florida and Hawaii (Babu, 1990). The varieties CP 50-28, CP 55-30 and CP 70-1527 are descendents from *robutum* hybrids.

6. **Saccharum edule** Hassk (2n = 60 – 80)

It is a traditional Melanesian vegetable cultivated for edible inflorescence in villages of New Guinea and Fiji (Daniel's, 1967). It has pubescent leaves, swollen and aborted inflorescence and is sterile. It is of little importance for breeding work.

Brandes (1939) suggested that it is a mutant form of *S.robustum*, while Grassl (1967) was of the view that *S.edule* originated from introgression of *S. robustum*. At present the species is regarded as product of introgression of *S. officinarum* or *S. robustum* with other genera (Roche and Daniel's, 1987).

From the matter already discussed it could be concluded that the six species of sugarcane and the related genera comprising of *S. erianthus, S. miscanthus, S. narenga* and *S. sclerostachya* form the basic genetic resources of sugarcane. They form a closely related interbreeding group involved in the evolution of the cultivated sugarcane referred to *Saccharum Complex* (Mukerjee, 1957 and Daniels, 1975). The present day cane varieties under cultivation are complex hybrids and have totally replaced the pure species from the cane fields. However, the basic sources of the Saccharum species with its related genera and some historical and commercial hybrids have been preserved in the gene pool. This germplasm has been conserved in the two world collections in USA, at Subtropical Horticulture Research Station, Miami, Florida, and in India, at Sugarcane Breeding
Institute, Coimbatore and Sugarcane Breeding Research Centre, Kannur. At Kannur (India), method has also been standardized for the in vitro storage of sugarcane germplasm at 10°C in liquid medium containing minimum nutrients (Sreenivasan and Jalaji, 1985). Following change of media, only once a year, plant can be stored for a period of 3 years, without any detectable cyto-morphological changes.

In cane breeding, wild species of *Saccharum* and allied genera have played great role for sugarcane improvement. The wild germplasm available have been characterized for transmission of specific characters with respect to biomass improvement and tolerance to drought, water logging, lodging, diseases and pests. In cane hybridization programme, the use of specific species and genera has helped develop a number of commercial varieties. The agronomic and quality potential and tolerance to various diseases, pests, drought, frost, water logging is due to the merit of the original species-parents used in hybridization. Attempts have been made to improve sugarcane varieties by developing broad based parental lines using various species and making their crosses and back crosses with *S.officinarum* in nobalization processes. The species and genera known for transmission of specific characters to complex hybrids reviewed by Nair (2005) are reproduced as under.

### Saccharum species and the related genera utilized for transfer of species characters

<table>
<thead>
<tr>
<th>Species /Genera</th>
<th>Characters</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>S. officinarum</em></td>
<td>Sucrose, stalk weight</td>
</tr>
<tr>
<td><em>S. bareri</em></td>
<td>Sucrose, resistance to drought, cold, salinity, red rot</td>
</tr>
<tr>
<td><em>S. sinense</em></td>
<td>Sucrose, resistance to drought, cold, salinity, red rot</td>
</tr>
<tr>
<td><em>S. robustum</em></td>
<td>Yield, fibre, water logging resistance</td>
</tr>
<tr>
<td><em>S. spontaneum</em></td>
<td>Tillering, vigor, yield, resistance to red rot, smut, rust, pests, drought, water logging.</td>
</tr>
<tr>
<td><em>Erianthus Spp</em></td>
<td>High biomass production, fibre, pest resistance, drought, water logging, salinity.</td>
</tr>
<tr>
<td><em>Miscanthus</em></td>
<td>Cold tolerance, diseases resistance</td>
</tr>
<tr>
<td><em>Neranga</em></td>
<td>High tillering, earliness, water logging resistance</td>
</tr>
<tr>
<td><em>Sclerostachya</em></td>
<td>High tillering, earliness, water logging resistance</td>
</tr>
</tbody>
</table>

The present day breeding philosophy is to broaden the genetic base by crossing and back crossing the existing hybrid with wild relatives (Legendre, 1989). Apart from the use of *S.spontaneum* and *S.robstum*, introgression of *Erianthus* species is also considered important in improving high productivity and adaptability (Hogarth et al, 1997). The other approaches being persuaded include inter specific improvement of the individual Saccharum species, prior to inter specific hybridization (Nair et al, 1998) and the cytoplasmic diversification of the new hybrids by using *S.barberi, S.robstum* and *Erianthus* as female parents. The effort is to develop new varieties that are complex hybrids of inter specific and inter generic origin. The *Schlerostachya* has also been used to develop hybrids.

In hybridization programme, the use of *Erianthus* has proved useful in production of
varieties with high biomass production and tolerance to pests and diseases (Nair, 2005). The high polyploidy nature of *Saccharum* species makes it difficult to have precise analysis of their relationship using nuclear markers. The genomic in situ hybridization (GISH) studies have shown that *S. barberi* and *S. sinense* were derived from inter specific crosses between *S. officinarum* and *S. spontaneum* (D. Hont et al, 2002).

The chloroplast polymorphism studies have also shown close relationship of chloroplast genomes of Saccharum species (Takashi et al, 2005). It was found that all Saccharum species except *S.s spontanum* share *S. officinarum*, *S. robustum* type cytoplasm. Parents of *S.s sinense* and *S. barberi* are genetically closely related to *S. officinarum* and *S. robustum*. The study also supported the view that *S. spontanum* is the ancestral species in Saccharum.

**Flowering and Seed Production**

**Sugarcane arrow**

Group of flowers in sugarcane is termed as inflorescence, which consist of a large, open plume like panicle commonly called the arrow or tassel. The sugarcane arrow normally takes about 75 – 85 days to emerge from the time of floral initiation (Moore, 1974; Marcoll, 1977). First symptom of panicle is the appearance of the terminal shoot in the form of a long cone with shorter leaf blade. The blade, until the time the panicle prolongs to gradually emerge the arrow/tassel. Ramification is high at bottom of the panicle and decrease gradually in apical direction. The panicle is developed from the terminal growing point of the cane stalk. Before emergence, it is enclosed tightly by the leaf sheath. Size of the panicle varies with climate and variety and has a length of 20 to 50 inches. Whorls of long silky callus hairs cover the spikelet. Silky hairs help dispersal of seed by wind to long distances. Flowers are produced in spikelets held on short branch called rachis. Spikelets are in pair of which lower one is sessile and the upper is pedicillate. Cane flower is complete; contain a pistil and three feathery stamens. The flower is enclosed tightly by glumes. The two outer glumes are hard and keeled and the two inner ones called lemma and palia are soft and papery. Pistil has two wedges shaped lodicules, which in humid atmosphere bulge and helps to thrust apart the glumes to open the flowers for emergence of stamens. The stamens are versatile and each has peduncle and anthers on the tip. The ovary is uni-locular containing single ovule and the pistil has two purple stigmas at the apex.

Spikelets on the top of the tassel bloom first and opening of flowers continue inward and downward until the flowering is completed. On an average, it takes about two weeks to complete flowering in a tassel. Temperature plays major role in blooming of flowers. On completion of flowering, the ripening process and seed maturity is completed in about 15-20 days. On maturity seed disperse by wind, quite easily, due to silky hairs. At very low temperature, blooming is delayed and at high temperature arrow emergence is checked, it may dry, partially opened and pre-mature without pollination and seed setting.
Anthesis and pollination

Flowers usually open around sunrise, but anther dehiscence does not occur for some time, often a few hours, when certain amount of drying has taken place (Stevenson, 1965). Anther dehiscence varies from variety to variety, being little, vigorous and intermediate; some varieties show little dehiscence with anthers containing little or no pollen while other show vigor that anthers split from top to bottom.

Pollen viability

Cane varieties show great variation in respect of viability of pollen. Some varieties are self-sterile and others self-fertile. The degree of fertility varies considerably with varieties. In some cases pollen is viable but may not be healthy enough to extend its pollen tube to the female gamete. Panicle development and male fertility takes place at 21°C (Berding, 1981; Brett and Harding, 1974). Heinz and Tew (1987) reported decline in pollen production in male fertile clones where night temperature remain between 14.5
and 16.0°C for a period of 5 – 10 days. A temperature of 22°C and R. humidity of 96% is considered optimum for pollen germination. (Artswager, 1957). Yousuf and Malukra (1964) have observed 26°C to be the optimum temperature for pollen germination. Further, the reddish brown anthers possess sound pollen compared to yellow colored, shriveled and papery anthers. Yellow unopened lobes contain little pollen and are invariably sterile.

Sugarcane pollen is short lived and normally loose viability in 20-30 minutes; moist air may prolong viability for three hours (Moore and Nuss, 1987). It has further been reported that life of pollen can be prolonged to about 10 days when stored at 4°C under 90-100% R. H. A number of instances have been quoted for freeze (-10°C) drying the pollen and storing for nine months, but data is not conclusive.

Pollen fertility

To assure crossing, pollen grains must be normal, fertile and functional to germinate and pollinate female gamete. For rapid testing the fertility, simple staining tests are employed.

Staining tests

The most common method to check the pollen viability is to stain the pollen grain with Potassium Iodide solution or Aceto-carmine drops applied on pollen grains placed on a glass slide and observed under the microscope. Healthy fertile pollen gives dark blue color with the former stain while the later stain give orange red color, to the pollen grains. Weak, abortive and infertile pollens are shrieveled and are without stain. Through these tests, the percent non-aborted pollen observed under microscope field calculated as an index of pollen fertility.

Pollen germination

The best test for pollen fertility is by checking the germination of pollen grain. Germination of pollen checked on filter paper and cellophane sheet soaked in 26% sugar solution. After 2 hours of pollen dusting, fertile pollen show healthy development of pollen tube (Narasimhan, 1963). Yousuf and Malukra (1964) successfully used hanging drop method with 26% sucrose solution and 0.7% boric acid in Agar media. Fasihi (1979) reported hanging drop testing used for pollen germination in a media containing calcium nitrate (300 ppm), magnesium sulphate (200 ppm), potassium nitrate (100 ppm), boric acid (100 ppm) and sucrose 25%. Spikelets ready to dehisce collected from the arrow, wrapped in a paper. Next morning pollen is collected and kept in humid chamber, where it can be kept alive for almost 8 hours. Pollen test performed either through hang drop method or through germination of pollen.

Seed setting and maturity

The pollen is shed on stigma and germinates. The pollen tube extends through stigma to the embryo sack of the ovary, for fusion of male and female nuclei. In favourable environment, it takes almost 15 minutes for germination of pollen tube and fertilization of ovule for seed setting. The cane seed is quite small having a size of about 1.0 x 0.5 mm. A total of 1000 seeds would weigh 0.5 to 2.5 grams (Rajendra Prasad and Tripathi, 1999). Seed viability depends on the conditions conducive for flowering, health of the plant and cane varieties. As many as 2013 florets per gram with seed set of 3.1 to 22.7%
has been recorded (Rao, 1980). The germination varies with the environment and varieties, showing a range of 0 to 700 seedlings per gram of fuzz (Breux and Miller, 1987).

Fuzz is usually collected from 3 to 8 weeks after setting of crosses. Depending on climatic conditions, ripening period varies from 25 to 45 days from the time of setting a cross (Ramdoyal et al, 1999). Low temperature prolongs ripening period. At Mauritius Sugar Industry Research Institute, trial has shown that fuzz could be harvested almost fourth week after setting the crosses and that the seed viability would not increase beyond six weeks after cross initiation (Ramdoyal et al, 2000)

Seed collection

To collect seed the arrow is wrapped with craft paper bag from the very start of the flower opening. Bagged seed is liable to damage if proper ventilation not provided against build up of moisture and temperature that encourage fungal growth (Breux and Miller, 1987). Mature arrow cut and brought to the seed collection room. The arrows kept upright by wall side or tied and hung on a rack for drying purpose.

Seed drying

Cane fuzz (seed) is very delicate and after harvest looses its viability when stored at room temperature. Mature fuzz has moisture contents of 12-13 % at the time of harvesting. The fuzz at this moisture left at room temperature looses 90 % of its viability in 70 days (Rao, 1980). Therefore time lapse between mature seed, harvesting, drying and storage should be the minimum. Delay in seed handling before proper drying and storage will certainly have adverse effect on viability.

Drying of seed to reduce moisture content is important to improve germination and storability. Harvested panicles are placed in cloth or craft paper bags and being in specially constrained sheds or in glass house.
Fuzz is dried naturally or mostly by hot air to facilitate drying. Forced hot air circulation may be provided through electric blowers for about 48-60 hours. During drying temperature of the room/chamber should be kept at 35°C -38°C at about 30-35% R.H to reduce its moisture to 10% or less (Berding, 1978). Forced air dried seed gave 46% better germination than drying under green house conditions at ambient temperature (Berding, 1976). Sun-drying is not a desired practice and may hamper germination. Dried seed manually cleaned of the rachis branches of the penicle, labeled where necessary and bagged. Before, bagging seed may be treated with fungicide. Seed bagged in craft paper bags; fine tin foils may also be used for the purpose. Silica gel moisture absorbent keep the seed dry in seed pouch.

De-fuzzing

De-fuzzing is the removal of pubescence hair from sugarcane spikelets. The technique has several advantages like control of fungi and bacteria. Seed treatment and storage is easier and efficient due to reduction in volume and weight, easier handling of seed for testing and storage.

A number of methods have been tried. The fuzz is placed on a rug, covered by nylon/plastic sheet and rubbed with hands in circular movement, until the hair is removed. It may then be sieved. The fuzz may be treated with 50% sulphuric acid to remove the hair (Sudawa Singh, 1987). Scarifying machine has been developed that works with ½ HP motor at 1740 RPM and removes the hair (Breux, 1981). Defuzzing is also done by rubbing fuzz on wire mesh sieve (Balasundaram, 1990).

Seed storage

Most of the breeding stations maintain seed bank for which proper storage conditions are essential to keep up seed viability for a longer time. Longevity is increased at low humidity and low storage temperature. The storage temperature varies from 10 to - 20º C (Ramdoyal et al, 2003). Rao, (1980), has made comprehensive studies on storage condition. Seed dried to 10.4% moisture in warm air and sealed in plastic bag with silica gel did not show drop in germination at room temperature (28ºC); Fuzz stored without silica gel showed steady drop in germination. Fuzz germination was not affected when stored in refrigerator at -10º C, without silica gel. Plastic packed seed with silica gel was successfully stored in a freezer (-10º C), over a two years period without much drop in viability. However, silica gel is to be replaced at 6 months interval. For a short-term storage, seed is stored in Kraft paper bags with silica gel at room temperature or in refrigeration at above freezing temperature. For longer period of storage, either, Kraft paper bag, plastic bag or Aluminum polyethylene laminated moisture proof bags used to contain seed in deep freeze storage. Silica gel is a preferred desiccant. Anhydrous Ca Cl is used at Bureau of Sugar Experiment Station (BSES) (Breux and Miller,1987).

In some countries like Australia, Barbaudos, South Africa seed storage is reported for 10 – 25 years. In such cases the fuzz is dried to 5-6 % moisture contents and stored with silica gel in high density polythelene bags at -10º C or even low temperature (Ramdoyal et al, 2003; Rao, 1980). Defuzzed sugarcane seed dried to 7 % moisture content, packed in polythene laminated aluminium foil pouches and stored at -20ºC in a deep freezer, could maintain its initial germination viability for five years (Prasade et al., 1998).
In Australia, panicles bearing seed are dried in open-weave terylene bags using dehumidified conditions in an insulated chamber at 11 - 13º C and 15 – 25 % RH (Hogarth and Allsopp, 2000). This dries the seed to 4.5 % moisture in about four days, ideal for long term storage. Seed is then stored in sealable aluminium foil bags and stored in deep freeze conditions (- 20º C), until required for germination.

**Germination test**

Seed viability should better be tested before the seed is stored. For the purpose, half gram seed is taken and planted in small trays/ metal flats with sterilized soil media. The seedbed is kept moist at favourable temperature (25ºC) and germination is completed within 5 days of planting. It helps to assess seed viability as seedlings per gram of seed. The precise test is to place about 0.1 to 0.2 de-fuzzed seed in Petri dishes with moist cotton wool and keep inside seed germinator at 30ºC and 90% RH (Rajendra Prasad and Tripathi, 1999).

**Factors Affecting Flowering in Sugarcane**

The critical factors controlling the mechanism of flowering in sugarcane are; photoperiod, temperature, maturity and moisture (Coleman, 1968). Each of these factors has separate effect on individual process in the production of flowering stimulus, and for flowering to occur; these factors must coincide simultaneously within the specific limits. For this purpose cane plant must have reached the ripeness-to-flower stage at the time it is exposed to the inductive photoperiod. The night temperature for the inductive photoperiod must be within certain limits and the plant must be metabolically active. The metabolic activities of plant are affected by a whole range of environments where the plant is grown, that include rainfall, temperature, radiation, vegetative growth and nutritional status of plant, type of soil, soil moisture, growth stage and pests and diseases. If any of these factors are not optimally provided at the same time, the process of flowering will not occur.

Cane species and varieties have different timings of flowering. As for example S. spontaneum flower early in the season while S. officinarum flower much latter. Similarly cane varieties within this species have different flowering time, as well as low temperature ranges influence the fertility. Thus it affects the synchronization in crossing program. Therefore, the knowledge of factors affecting flowering time, intensity and fertility is important for a successful cane-breeding program.

**Latitude**

Sugarcane is a tropical plant and the time and consistency of flowering depends on the distance from the equator. On the equator and between latitudes 5º N and S of the equator; it flowers all the year round. As the distance from the equator increases, flowering becomes seasonal following the changes in day length (Paliatseas, 1962). Data available show that most of the varieties flower profusely within tropical limits of 5º - 15º N or S, while in sub tropics flowering is spars and defective (Ethirajan, 1987). At the extreme northern / southern limits of induction, only free bloomers or those requiring least number of daily stimulus will bloom. Therefore, cane-breeding stations in Indonesia (6º S), Coimbatore (11º N), Barbados (13º N), Puerto Rico (18º N), Queensland (19º S) and Taiwan (23º N) observe high flowering intensity in most of the varieties. As such
these stations have developed their breeding programme based on natural flowering. However, artificial induction houses have been devised for initiating flowering in a few non-flowering clones/species or for synchronization of flowering time. On the other hand countries, like South Africa (29°S), Louisiana (30°N) and Egypt (31°N), situated much away from the equator face great problems in cane breeding. Most of the varieties growing at this latitude do not flower under natural conditions and the varieties are forced to flower under induced stimulus of light and temperature (Paliatseas, 1962; Barnes, 1964; Chilton et al, 1965; Nuss, 1977).

In Pakistan, “Murree” situated at 33°N, and being quite away from the equator does not provide natural home for cane crop to flower freely. Only very free blooming varieties flower under these conditions. Almost the same flowering pattern observed at Malakand in N.W.F.P. However, in coastal area of Sindh (24.4°N), which is lying near to tropical limits, a large number of cane varieties have been reported to flower profusely (Fasihi et al. 1988, 1993; Fasihi and Malik; 1981; Malik et al, 1986).

Flowering time is greatly influenced by latitude. Sugarcane flowers all the years round at 0 - 5° latitude, North or South. As the cane proceeds away from the Equator, the flowering time confined to certain photo period ranges (Moore, and Nuss, 1987). In Northern Hemisphere cane flowering at 10°N is observed in October, and the flowering time is delayed with the increase in latitude. At around 20°N flowering would commence by November and at 30°N in December (Mangelsdorf, 1956). Almost similar pattern is observed in Southern Hemisphere where flowering takes place from March through June. According to Brett (1951) flowering time is delayed by approximately 2 days for each one-degree displaced from the equator to the tropics and temperate zones. Flowering period observed at cane breeding stations located in various latitude are given in Table-4.01.

Table-4.01 Time of flowering initiation at different locations

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Location</th>
<th>Time for commencement of flowering</th>
</tr>
</thead>
<tbody>
<tr>
<td>11°N</td>
<td>Coimbatore, India</td>
<td>October</td>
</tr>
<tr>
<td>13°N</td>
<td>Barbados</td>
<td>October</td>
</tr>
<tr>
<td>20°N</td>
<td>Hawaii</td>
<td>November</td>
</tr>
<tr>
<td>23°N</td>
<td>Taiwan</td>
<td>October</td>
</tr>
<tr>
<td>26°N</td>
<td>Southern Florida</td>
<td>December</td>
</tr>
<tr>
<td>8°S</td>
<td>Pasoeroean, Java</td>
<td>April</td>
</tr>
<tr>
<td>17°S</td>
<td>North Queensland</td>
<td>May</td>
</tr>
<tr>
<td>20°S</td>
<td>Mauritius</td>
<td>May</td>
</tr>
<tr>
<td>29°S</td>
<td>Mount Edgecombe – Natal</td>
<td>May</td>
</tr>
</tbody>
</table>

Source: Moore and Nuss, 1987

The data reviewed indicates that latitude has very specific influence on cane flowering. The importance of the latitude is its function to change day length, which may be responsive or inhibitive to flower induction.
Photo-period

This is a principal decisive factor controlling flowering in sugarcane. It pertains to the minimum critical day length required to induce flowering. Flower initiation in cane takes place in shortening days of the year; hence it is considered a short day plant (Burr et al, 1957; George and Laleuatte 1963). Nevertheless, photo-periodic requirements of the various floral stages are best met by intermediate day length, followed by gradual shortening days (Moore, 1987). So on the basis of initial induction sugarcane could be classified as IDP, while recognizing the development of panicles and flowers, as a qualitative short day response. However, for flower induction, dark period has a great importance. As light interruption of dark period inhibit flowering, while dark interruption of light period has no effect.

Day length required for induction

Day length pertains to the stimulus that the plant receives from a specific photoperiod in inducing physio-chemical changes in plant, for converting it from vegetative to flowering stage. The optimum photoperiod for induction process is 12 hours and 35 minutes, and cane fails to flower when photo period differs from this day length by + - 15 minutes (Coleman, 1959, 1962). For flower induction, cane plants are exposed to these day lengths at various dates depending upon their Latitude. Decreasing the photoperiod by about one minute per day, for 100 days beginning with 12.5 hrs in mid July, was considered best for easily inducted clones; hard to flower clones required some more than 100 days (James and Miller, 1971). In glass house studies in Louisiana, a minimum of 45-55 days were required for initiation of easy flowering varieties and 60-70 days for reluctant flowering varieties (Paliatseas, 1971).

It has been concluded that flowering stimulus develops at night from the metabolites synthesized during photosynthetic process in the day. A night period of 11 hours 32 minutes is very conducive to flowering (Clements and Awada, 1964; Coleman, 1959). The cane plant is so photosensitive that an 11-hours night has been completely without effect and a 12.00 hours night not as favorable as 11.50 hours night. Just deviations of 15 minutes inhibit flower initiation (Coleman, 1959). However, the matter of concern is that the day length/nycte-period required for floral induction is not the same at all the Latitudes. More number of required inductive nights is available near to the equator than the distance away from it. This difference can well be observed from Fig.on page 38, which gives the period of optimally required night lengths for various Latitudes (Clements and Awada, 1964).

The information available in the figure indicate that at 0° Latitude, 11:52 hrs nights are observed consistently through out the year, but this is not as favorable as decreasing photo-period of 12:00 to 11:50 hrs, as such cane varieties do not flower more abundantly. At 10° away from the equator the 11:50 – 12:00-hrs nycte-period is available for 49 days when cane exposed to proper period of flowering, hence flowering is profused. At 30° Latitude, a period of only 24 days is available, thus varieties are reluctant to flower. General assumption could be derived from the table that 11: 30 hrs darkness is ideal for flowering and that 12 hrs is passing away from the ideal (Clements and Awada, 1964). It indicates that the sugarcane varieties when exposed to 11: 50 - 12: 00 hrs nycte-period for a large number of days would flower readily and profusely.
In Louisiana, both decreasing and fixed day lengths used, not only to produce out of season flowers, but also to synchronize the flowering of varieties that normally flower at widely different times. A decreasing day length of one minute per day starting at 12 hours 32 minutes and finishing at 11 hours 42 minutes has been very effective in getting most of the breeding stocks to flower (Dunckelman and Legendre, 1982). A fixed day length of 12 hours 25 minutes for 60 days or more has also been used with good results for various breeding canes. The S. officinarum may require 80-100 recurring cycles photoperiod to produce tassels. According to Miller and Li (1995), a longer exposure to a constant day length (12: 25) combined with a slower decline in day length gave better emergence. An effective photo-period treatment for Florida, Louisiana and Texas varieties had 30-45 days of constant day length followed by day length decline rates of 30-60 seconds per day. For foreign commercial cultivars and hybrids an effective treatment was 45 days of constant day length followed by declining day length at a rate of 45 seconds per day. For clones of S. officinarum, S. robustum, S. sinense and S. barberi, at least 60 days of constant day length were required, followed by declining day length at 30-45 seconds per day. The period of decline continued until a day length of 11: 30 hrs was reached. After this, the day length kept constant until the experiment terminated. At South African Sugar Association experiment station, flower initiation occurs at critical day length of 12 hr 30 mins, on around 8 March. In photoperiod house a day length decline of 30 sec/day is used after floral initiation (Redshaw, 1998).

In sugarcane, flowering is induced by a slow decrease in day length from 12 h 30 min. Flowering is best in areas where the day length declines at a rate of 30 to 60 seconds/day from about 12 h 45 min (Berding, 1995) and 12 h 30 min (Moore and Nuss, 1987). This occurs naturally in countries where flowering is profuse such as Barbados, Coimbatore (India) and Hawaii. In areas 5° N or S of the Equator, the long days are less than 12 h 45 min and change in short days is much less than the required 30 to 60 s/d, hence flowering
is not profuse. Similarly, in higher latitudes of 30º or more, the inductive period is too short for many clones to flower. Usually, photoperiod treatment commences after sunset (Bret and Harding, 1974) or before sunset (Berding, 1995).

Flowering is also initiated by exposing the cane to constant inductive day length for periods of 30 to 60 days and then reducing the day length by natural decline (LeBorde et al, 1997) or by decline of between 30 and 100 s/d (Miller and Li, 1995). Peaks in flowering are achieved in the former case by keeping the cane in the constant day lengths for different period and the date on which the treatments are discontinued (LeBorde, 1997).

Can-cultured stools of cane have also been used to modify flowering time (Dunckelman and Legendre (1982). If stools left outdoors during cool weather, after flowering has started, the elongation and eventual emergence of tassels from the boot may be greatly delayed or prevented altogether. On the other hand, if cans of the same clones are moved into a warm green house at intervals, flowering may be extended for several weeks. This technique used primarily in the management of flowering and pollen production in many of the early flowering clones or species.

Twilight acts as an extension of day lengths. MacColls (1977) observed that both morning and evening twilight are important and increase day length by about 15 minutes.

**Light intensity**

The day length of 12.5 hrs must be high intensity light. When part of the light period is low intensity light many more days (60-90) compared to normal 20 days, are required for induction (Clements and Awada, 1964). It appears that certain levels of photosynthetic products made available to produce maximum amount of flowering stimulus, at full light intensity.

In the photo induction process, dark period has the main importance in phytochrome conversion mechanism. Any interruption in dark period would check the process of induction. During this period, even a maximum of 50-ft candle minutes light can prevent flowering. Both indecent and fluorescent light affect the dark reaction (Burr, 1950). Coleman (1957) concluded that 15 inductive nights were essential for floral induction. The inductive nights are additive over non-inductive, and do not need to be continuous. It is important that inductive nights could be observed without light interruption. If sequence of non-induction night is long the stimulus may be dissipated or diluted (Carr, 1955), and to bring about flowering, additive inductive nights would be required. With less then 15 inductive nights the flower primordial is never developed or parly developed or reverted to a vegetative condition (Coleman 1963, 1965).

**Role of light**

Cane varieties and clones show great variation in sensitivity to light interruption. Burr (1950) observed that flowering was prevented when 50-ft candle of light was applied to H 37-1933, just for one minute during inductive night. In contrast to this 4000 ft ca-min at mid night was not inhibitory to a S. spontaneum. Var. Mandaloy (Julian, 1972). Similarly, some cane varieties show differences in the length over which the clones can be inducted to flower. Therefore, in a planned crossing programme photo period requirements of cane varieties have to be determined for inducing flowering.
Considering the role of light intensity, Coleman (1960) reported inhibition of flowering if plants were under a shade cloth to reduce sunlight ca 100,000 lux, 500 cal² /day, to 20% of normal. Maximum flowering occurs under very bright sunlight (Clement and Awada, 1964). Nevertheless, sugarcane grows well and flowers where sunlight is only 50% of normal, ca 50,000 lux 250 cal / cm² /day, but not in area where sunlight reduced by 80% (Coleman 1960). The light of main photoperiod must be between ca 100 to 250 cal/cm² / day, in a 12.5 hrs day to induce flowering in sugarcane (Coleman, 1960).

Temperature

It is the most important factor in controlling the flowering in sugarcane. Although photo period remains the same each year at a geographical location, but high and light flowering years often occur which is due to yearly fluctuations in temperature. The photo induction during dark period is temperature-sensitive and involves a thermo-chemical reaction (Lockhart, 1967). It suggests that cane flowering is primarily a photo-period response, but is conditioned by other factors, among which temperature and moisture are especially important. Temperature plays vital role in relation to specific phenomenon of (a) flower induction (b) bolting (c) emergence of inflorescence (d) development of pollen (e) flower opening and seed setting.

Flower induction is prevented when night temperature drops below 18°C (Coleman, 1963 b; Gosnell 1973). Temperature below 18°C is a temperature of non-inductive nights and four nights of this temperature will reduce induction and more than 10 such nights will prevent induction (Coleman, 1968; Paliatseas, 1962). The day time optimum temperature is around 28°C and in photo-period houses night temperature must be controlled between 21°C-27°C for successful induction of many clones (Coleman, 1968). Field studies show that night temperature of 18°C during induction can prevent flowering. The optimum temperature for flowering during night is about 23°C (Nuss, 1980).

Maximum temperatures, which generally occur during the light period, are not much critical so long as the vital functions of plant parts are not affected. The critical temperature during dark period was considered to be about 27°C (Moore, 1987, Clement and Awada, 1967). A daytime temperature of 28°C to be the optimum; sugarcane flowering is reduced when this temperature exceeds 31°C at induction. Temperature in excess of 32°C is detrimental to flowering (Berding, 1995). It has been concluded that night temperature of 21.5°C - 23.5°C with moderate day temperature of 26.5°C - 30.5°C provide proper conditions of tasseling (Clement and Awada, 1964).

Diurnal temperature variation

Diurnal variation in temperature is considered important for flower induction. Clement and Awada (1964) gave a number of illustrations to show that the narrow range (5°C-7°C) in day and night temperature was more favorable for flowering than were the actual temperature extremes within critical limits. The effect of the maximum, minimum and the diurnal temperature variation on flowering is clearly indicated in Table-4.02. Even in most favorable photo inductive regions for cane flowering, unfavorably low temperature as well as wider diurnal temperature variations have been reported to depress flowering in Hawaii and South Africa.
Panicle growth and seed setting

Under unfavorable temperature, panicle will not emerge and flowers would not bloom. Panicle emergence delayed at temperature below 21°C (Clement and Awada, 1964; Musset and Brett, 1977). Low temperatures also reduce rate of elongation and final growth of panicle (Awada and Paxtan, 1979). The temperature below 5°C would delay flowering and varieties would not emerge inflorescence at all (Barnes, 1964).

Floral parts are very sensitive to temperature extremes. A temperature of 25°C-26°C considered optimum for anther dehiscence and pollen viability (Yousaf and Malukra, 1964).

Table-4.02 Temperature ranges at various cane flowering sites in the world during induction period

<table>
<thead>
<tr>
<th>Site / Period</th>
<th>Max</th>
<th>Min</th>
<th>Rang</th>
<th>Flowering intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coimbatore 11°N (India)</td>
<td>Aug</td>
<td>32.2</td>
<td>22.2</td>
<td>9.3 Heavy</td>
</tr>
<tr>
<td></td>
<td>Sep</td>
<td>31.5</td>
<td>22.0</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td>Oct</td>
<td>30.9</td>
<td>21.7</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>Nov</td>
<td>29.8</td>
<td>19.8</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Dec</td>
<td>28.2</td>
<td>19.3</td>
<td>8.9</td>
</tr>
<tr>
<td>Queensland 17°S (Australia)</td>
<td>Jan</td>
<td>32.0</td>
<td>22.5</td>
<td>9.7 High</td>
</tr>
<tr>
<td></td>
<td>Feb</td>
<td>32.5</td>
<td>22.3</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>Mar</td>
<td>30.0</td>
<td>21.5</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>Apr</td>
<td>21.5</td>
<td>19.9</td>
<td>10.6</td>
</tr>
<tr>
<td>Kailua 21°N (Hawaii)</td>
<td>28.8</td>
<td>21.4</td>
<td>7.4</td>
<td>Heavy</td>
</tr>
<tr>
<td></td>
<td>27.7</td>
<td>21.0</td>
<td>6.4</td>
<td>Heavy</td>
</tr>
<tr>
<td></td>
<td>29.6</td>
<td>19.3</td>
<td>10.3</td>
<td>Medium/Light</td>
</tr>
<tr>
<td></td>
<td>32.8</td>
<td>18.4</td>
<td>14.4</td>
<td>None</td>
</tr>
<tr>
<td>Natal 29° S (S. Africa)</td>
<td>Cap. St. ucia</td>
<td>27.9</td>
<td>20.3</td>
<td>7.6 Heavy</td>
</tr>
<tr>
<td></td>
<td>&quot;</td>
<td>28.8</td>
<td>18.8</td>
<td>10.0 Light</td>
</tr>
</tbody>
</table>

Source: Clements and Awada (1964)

Low temperature during later stage of bolting and flower emergence is detrimental and pollen viability adversely affected by very cool night (Arceneux, 1965; Barnes, 1964; Bret, 1950; Fasihi and Ahmed, 1968). Ovule sterility is also a factor of low fertility in low temperature (Dunkelman, 1965).

High latitudes face problems of decrease in flowering and decrease in pollen viability. This decrease is due to low inductive day lengths and low temperature during flowering process. Due to low temperature panicle size is short (50-75 cm), in Muree hills, compared to well developed panicles (115-125 cm) in coastal areas of Sindh.

Moisture

Both moisture and temperature are related for regulating internal environment for effective biochemical reactions and translocation of metabolites. Adequate moisture is essential for different stages of flowering, including induction and development, timing of emergence, anthesis and seed setting (Moore, 1987).

Flowering in cane is greatly influenced by moisture (Clement & Awada, 1964, Pereira et al, 1983) and is also very sensitive to drought conditions (Gosnell, 1973). It is why flowering in commercial cultivation is reduced by restricting water prior to and during
induction phase (Smith, 1973). In general, sugarcane flowers better and has better pollen fertility in wet tropics (Hogarth et al, 1997).

In areas where temperatures are seldom inhibitory to flowering, the variation in flowering between years is primarily the result of annual differences in moisture (Moore, 1987). There is experimental evidence to show the positive relationship in increasing flowering with increasing water, showing the need of frequent irrigation for breeding plots (Moore, 1987). Therefore, cloudy and rainy weather considered favorable for flowering, (Burr et al, 1957; Gosnell 1973). In arid environment spray mists has been reported to increase flowering (Amin, et al 1972).

At Los Mechis, Mexico, tassels were controlled by withholding irrigation from August 10 to September 20 (Humbert et al, 1969). It was further observed that irrigation interval of 14 days during August-September increased the percentage of tassels, whereas it decreased when interval increased by more than 20 days. There is another experimental evidence to show that irrigation interval of 7 and 14 days gave 50 and 41.5% flowering respectively, while preventing irrigation gave no flowering at all (Wong, 1980). To have abundant flowering, it has to be ensured that no water stress occurs. Therefore, in glass house conditions flowering pots are watered daily (Nuss and Berding, 1999).

Flower and anthers opening are affected by relative humidity. Flower opening and anther extrusion usually occurs some hours before sunrise. Where relative humidity is high plant is hydrated and floral parts are quite turgid, anthesis occurs as humidity drops near sunrise. The pollen after shedding rapidly desiccates and remains viable for 20-30 minutes only (Moore, 1987). Low humidity at anthesis leads to poor seed set (Nuss, 1971).

In Muree Hills, flowers show normal growth if frequent rains are received, but during scanty rains and shortage of water in streams the plants and flowers get desiccated associated with high temperature (38-40°C). Under moisture stress condition flowers do not bloom, arrows emergence is checked, anthers get dry, and ratio of cone formation and arrow emergence get much widened. Seed viability is zero to extremely low.

Cane varieties

Cane varieties considerably differ in their requirements of effective day length which is reflected in their time of flower initiation and duration of arrowing (Mangelsdorf, 1953). Cane varieties show different response to flowering at different Latitudes and different temperature and moisture conditions. The varieties flowering at 25° N may not flower at 13° N (MacColl, 1977). In-fact varieties respond differently to various photo stimuli (Ellis et al, 1965). In a cross breeding programme, flowering time in case of natural flowering and photoperiod requirements for controlled flowering have to be ascertained for synchronization. Similarly, some clones have different critical temperature response to flowering or flower inhibition.

Cane varieties are classified as non-flowering, shy flowering, moderate flowering and profuse flowering under given favorable conditions. At the equator, sugarcane flowers all the year round when day length is almost constant at 12 hours and 7 minutes. Floral primordial initiated when the day length has 12:5 hours duration. However, this floral initiation has no bearing on the appearance of flowers. Early flowering and late flowering
varieties may have floral initiation at the same time, but the rate floral stalk elongation may be different and cause differences in the time of flowering (Babu, 1990)

Flowering time has a great influence on flowering intensities in varieties. Heavy flowering is observed in early flowering varieties (70-80 %), while less than 33 % flowering is common in late flowering varieties (Moore, 1987). Similar behavior is observed, in early flowering varieties L 116, CP 43-33 and HS 2 and late flowering variety BL 4, in lower Sindh.

Cross breeding among varieties of different genotypes is done to widen the genetic base and to induce variation in the progeny clones. Therefore, in a breeding programme consistency in flowering, flowering intensity and seed viability in a given variety is earnestly required. A simple approach to arrowing without considering the breeding behavior of varieties and transmission of desired character to the progeny is always a futile effort. Therefor, breeding programme in hill stations of Pakistan carry no significance. However, Pakistan has potential of cane breeding work in its coastal areas.

**Age of plant**

As the stage of active growth (the juvenile phase) is over, the plant comes into ripeness to flower condition. At this stage, plants should have attained an age of 6 months and formed 5 – 6 inter nodes above ground, with physiologically active leaves, to receive sufficient flowering stimulus for floral induction (Redshaw, 1998). The age of cane when initiation starts is to be 100 days for tropical areas and 150 – 200 days for sub-tropical areas (Nuss and Berding, 1999). The juvenile phase can be extended by very high application of nitrogen fertilizer, but experimental shortening of this phase has not been reported (Gosnell, 1973). Heavy soil and late application of fertilizer, 6-8 weeks prior to inductive phase, may prevent or reduce flowering, because plants remain in vegetative stage and do not come to ripeness-to-flower condition (Coleman, 1968).

**Leaves**

Leaves play primary role in flower induction. Cane leaves play part in photosynthesis, dark conversion and timing process of photo induction. For this, young leaves are active in production of flowering stimulus. Lang (1965) and Salisbury (1961) experimentally proved that perception of the photoperiod and production of the flowering stimulus generally occurs in the most rapidly expanding youngest leaves.

When young blades excised once or twice during induction, flowering decreased or delayed and results were opposite when older leaves were excised. The results indicate the production of trans-located stimulus from the younger blades – top visible dewlap (TVD) and flowering inhibitory from the lower blades (Julian, 1969; Chu and Serapion, 1972, 1974). This physiological effect offers an opportunity to delay flowering by trimming young leaves (Chu and Serapion, 1980; Skinner, 1961) and to enhance flowering by trimming old leaves (Brett and Harding, 1974), during induction phase. Removal of leaves or damage of leaves by hail storm/wind storm May off set floral induction.

This physiological role of leaves is being utilized in commercial cultivation to curtail flowering. Defoliation and removal of spindle or spray of parquet in first fortnight of
August is quite effective for complete inhibition of flowering (Moore, 1987). Similar results reported by spray of Ethepon to suppress flowering. This practice also reduces pithiness and improves juice clarification (Silva et al, 1989).

**Nutrition**

For maximum flowering, cane plants must show vigorous growth. However, this growth could be controlled by balanced nutrition. Excess nitrogen, especially at the time of induction inhibits flowering (Allam et al 1978; Clement and Awada, 1967; Gosnell, 1973; Nuss 1977; Stevenson, 1965). Heavy nitrogen application in August alters the C:N ratio to suppress flowering (Humbert, 1968). Application of ammonium sulphate @ 0, 90, 150 and 200 kgs/acre gave 5, 18, 10 and 0 percent flowering respectively (Wang, 1980). Correlation exists with the supply of irrigation water, as N inhibition was noticed with adequate supply of water (Allam et al, 1978). However, clones differ in their inhibitory response to excessive nitrogen (Gosnell, 1973). The management of ‘N’ has to be precise; too much ‘N’ reduces or delay flowering and too little may affect the amount of flowering, the size of panicle and seed set. The extent of inhibition is affected by the age of cane and the availability of water (Nuss and Berding, 1999).

**Cane Flowering Control**

The flower induction, initiation and development as well as anthesis are affected by day length, temperature, humidity and nutrition status of soil and plant. A change in either of these factors affects the flowering in cane. This philosophy is used to regulate flowering time for synchronization in flowering of different varieties and species. Control on cane flowering with respect to advance or delay flowering time is now the main tool in hybridization. For an effective crossing program, cane flowering time of early and late flowering varieties must synchronize. Knowledge of the exact time of floral initiation and flower intensity is necessary and the facilities to advance or delay flowering should be available.

**To advance flowering**

**Photo-period control:** Late flowering varieties can be induced to flower relatively earlier by special photoperiod treatments. At equatorial latitude (0-5°), where natural day length does not reach 12.5 hrs, flower initiation may be induced earlier by a few weeks by illuminating plants 20 minutes before sun rise and there after gradually reducing the time between artificial and natural dawn (Moore and Nuss, 1987). Earlier flowering was also obtained by moving plants in to a dark room 15 minutes before sun set (MacColl, 1977).

The date of flowering can be advanced by starting the initiation process earlier or by increasing the rate of decline from 30 to 60 s/d. However, the faster decline reduces pollen fertility and pollen shed (Moore and Nuss, 1987).

A continuous decline in day length of 30 seconds per day is a normal treatment for flowering in artificial conditions (Brett and Harding, 1974). Flowering hastened by 19 days when the rate of decline was changed from 30 seconds to 60 seconds per day (Nuss and Brett, 1977).

**Temperature control:** Under sub-tropical conditions, low temperature during winter month delays flowering. If flowering plants kept in optimum temperature in crossing
chamber, flowering is hastened by 20-40 days (Brett et al, 1975)

**Delay flowering**

Cane flowering can be delayed by delaying induction or by retarding the rate of panicle development (Moore and Nuss, 1987).

*Photo period control:* Photoperiod houses are used for delaying the onset of flowering of early flowering varieties, and for advancing flowering time of late flowering varieties (Brett and Harding, 1974). Delayed flowering of early flowering clones, particularly by interrupting light with light breaks, up to or beyond inductive dates, can also be achieved (Moore and Nuss, 1987). Time of flowering can also be delayed by up to six weeks by placing plants in constant day length of 12.5 hours; however, subsequent development is recorded (Moore and Nuss, 1987).

Flowering can be delayed by artificially increasing day length through supplemental lamps over the natural inductive day lengths (Brett and Harding, 1974).

The flowering can also be delayed by delaying the start of the whole inductive process such as described by Berding and Moore (1996). Another way is to begin with a constant day length and only start with declining day lengths later, or start with declining day length and during this period halt the process by implementing constant day length (Nuss, 1980). The delay is proportional to the number of days exposed to constant day lengths.

In sub-tropical areas, flowering is delayed by exposing the canes to cooler ambient temperature (Brett et al, 1975).

Delay in flowering is also achieved by additional 'N', applied either before initiation commences or 20 days after the initiation process has begun. Flower initiation occurs, but panicle emergence is delayed by up to 20 days (Nuss and Berding, 1999).

*Light interruption:* Two hours light breaks at midnight up to the time to allow natural induction to occur, delay flowering (Midmore, 1980). Flowering may be delayed up to six weeks by placing plants in constant day length of 12.5 hrs (Brett et al, 1975; Nuss, 1978; Paliatseas, 1974).

**Delay in Panicle Development**

After completion of flower induction, flower development can be delayed up to 30 days by constant day lengths, by light breaks and by long days (Moore and Nuss, 1987).

*Temperature control:* Low temperature in the environment delays flowering development. However with the use of methods to advance or delay flowering time, pollen viability is also affected (Moore and Nuss, 1987). The temperature below 18°C and above 32°C at the time of initiation is critical to inhibit flowering. Seed set is also reduced by temperature; where this falls below 18°C or rises above 27°C; pollen fertility is also reduced.

**Prospects of Seed Production in Pakistan**

Generally, sugarcane does not flower in main land of Punjab and NWFP provinces.
However, some varieties are reported to flower in isolated pockets situated at higher altitudes. In Punjab, studies on flowering have been carried out in Murree Hills, at an altitude 2400-3500. In NWFP, cane flowering has been reported in Malakand area. Cane flowering in Sindh is confined in coastal belt.

**Latitude available for flowering**

Murree Hills (33°N) and Malakand (34°N) are situated in extreme limits of Northern Hemisphere in Pakistan, while coastal belt of Sindh (24.5°N) is somewhat nearer to tropical region. The data on photo inductive days developed from sunrise and sunset hours in Murree and Thatta are reproduced in Table-4.03. In the coastal belt, almost 22 photo inductive days are available for exposure of cane varieties to the required nycti-period (11.50 – 12.00 hrs) from 7 to 28 September. At this site, the decline in day length is at the rate of 1:30 minutes per day. A good number of varieties avail of the flowering opportunity in favorable temperature conditions. In Murree Hills, sugarcane is exposed to required nycti-period for only 15 days (20 September to 5 October). The day length declines at the rapid rate of 2 minutes per day. Since day length is not appropriate to flowering stimulus, the chance of photo induction for flowering in Murree Hills is limited to only a few free flowering varieties.

**Salient features of cane flowering sites “Pail & Chharapani-Murree”**

01. The site is situated at 33°N and hardly avails of chance of flower induction in 15 inductive days. It does not provide required photo-inductive days for flowering in most of the varieties.

02. Diurnal variations in temperature are much wide. The maximum temperature during September and October being 29.7 and 28.2°C, while the minimum in these months is 20.5 and 16.1°C, respectively (Table-4.03). Low temperature is a little below the marginal range of required temperature (Fasihi and Malik, 1985).

03. Chilling winter with frosty nights and hailstorm follows photo-induction period, thus panicle emergence is delayed till the termination of spring season, while often occurrence of frost and hailstorms damage flower primordial. Arrow emergence takes place during April and the temperature as low as 10.2°C – 17.3°C, observed during March - April; hamper panicle emergence and anther dehiscence (Fasihi and Malik, 1988). The highest maximum temperature during, May – June, reaches at 38-40°C and is associated with low humidity. Due to hot dry weather the panicles get dry premature and flower emergence is abnormal (Fashihi and Malik, 1985).

04. Not all the varieties and species flower at this station, most of the varieties are non-flowering, while some others are infertile; thick commercial hybrids do not flower at all.

05. Varieties show very erratic behavior of flowering each year. The varieties flowering one year may not produce arrows the following season. Flowering intensity and pollen visibility show extreme variation in different seasons. Therefore, systematic hybridization programme is not possible in natural flowering conditions.

06. Seed viability is extremely low with a total of none to 10-20 seedling per gram of fuzz.
Salient features of cane flowering sites in coastal area of Sindh

01. Cane flowering site in coastal area is situated at Thatta located on 24.5° N, latitude which is close to tropical limits and avail of 22 photo-inductive days for flowering.

02. During flower-induction period the mean maximum and minimum temperatures at Thatta are 33° C and 25° C, respectively (Table-4.04). These temperatures are close to inductive ranges and diurnal variation in temperature is not much wide. However, abnormal weather changes associated with dry spell affect flowering intensity in some cane varieties in some years.

03. Flower induction period is followed by relatively low temperature in autumn/winter months. The factor limiting pollen viability is the mean minimum temperature (11-17° C), during November – February months. However, mean maximum is normal; humidity is somewhat low due to low precipitation and wind blowing. It also delays the panicle emergence in late flowering varieties. Pollen shedding and seed viability is affected due to low temperature.

04. A large number of varieties, including thick and medium thick commercial canes, flower in this area. Number of flowering varieties is high with profuse arrowing in cane fields near to the sea coast. The arrowing in different varieties ranges from 30 to 70 % in different years (Fashihi et al, 1993; Kerio, 2000). The arrowing intensity is gradually reduced with the distance away from the coast.

05. Arrowing intensity varies with the variation in season depending upon weather changes and irrigation facilities available. Arrowing commences during early mid November and continues till December. A few varieties flower late during December – January. In most cases November – December is usual period of flowering. Arrowing intensity is high in early flowering varieties.

06. Pollen viability is low due to low night temperature and low air humidity. Thus, seed viability is adversely affected. Different varieties show a germination rate of 20-100 seedlings per gram (Fashihi et al, 1993; Malik, 2001).

07. In view of more number of flowering varieties and high flowering intensity at Al-Asif Sugar Mills, Garho, a planned cross breeding programme can be successfully run. However, for a systematic crossing programme among desired parental lines photo thermal houses are needed for synchronization in flowering time and to assure pollen viability.

Malakand

Much detail is not available, but its Latitude range (34°N) and cool temperature (4°C) during winter confine its usefulness to a very limited flowering and seed production work.

Unless and otherwise the breeding station is completely photo-thermally controlled, sporadic, erratic and uncertain flowering in nature cannot be virtually utilized for crossing work. For a viable breeding work, cane breeders would always recommended a site with profuse natural flowering. In the case of Pakistan coastal area of Thatta (Sindh) has the climate very conducive for natural flowering in most of cane varieties. Hybrid seed production is possible under photo-thermal conditions as in South Africa, China, Australia and Egypt.
Table-4.03 Day Lengths* Observed at Thatta** and Murree**

<table>
<thead>
<tr>
<th>Date</th>
<th>Day length hrs/mts</th>
<th>Daily drop mts/sec.</th>
<th>Date</th>
<th>Day length hrs/mts</th>
<th>Daily drop mts/sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12:37</td>
<td>-</td>
<td>1</td>
<td>13:10</td>
<td>-</td>
</tr>
<tr>
<td>Sept. 5</td>
<td>12:32</td>
<td>1:00</td>
<td>5</td>
<td>13:00</td>
<td>2:00</td>
</tr>
<tr>
<td>7</td>
<td>12:30</td>
<td>1:00</td>
<td>7</td>
<td>12:57</td>
<td>1:40</td>
</tr>
<tr>
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<td>12:24</td>
<td>1:36</td>
<td>10</td>
<td>12:52</td>
<td>1:40</td>
</tr>
<tr>
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<td>12:18</td>
<td>1:12</td>
<td>15</td>
<td>12:40</td>
<td>1:36</td>
</tr>
<tr>
<td>20</td>
<td>12:12</td>
<td>1:12</td>
<td>20</td>
<td>12:30</td>
<td>2:00</td>
</tr>
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<td>12:04</td>
<td>1:36</td>
<td>25</td>
<td>12:21</td>
<td>1:48</td>
</tr>
<tr>
<td>28</td>
<td>12:00</td>
<td>1:20</td>
<td>28</td>
<td>12:15</td>
<td>2:00</td>
</tr>
<tr>
<td>30</td>
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<td>30</td>
<td>12:11</td>
<td>2:00</td>
</tr>
<tr>
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<td>1:36</td>
<td>5</td>
<td>11:59</td>
<td>2:24</td>
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<tr>
<td>10</td>
<td>11:42</td>
<td>1:24</td>
<td>10</td>
<td>11:48</td>
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</tr>
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<td>11:35</td>
<td>1:24</td>
<td>15</td>
<td>10:38</td>
<td>2:00</td>
</tr>
</tbody>
</table>

* Favorable photo inductive days: 12.30 hrs to 12.0 hrs.
** Meteorological Department Government of Pakistan.

Table-4.04 Temperature ranges and cane flowering at Pail (Murree) and Thatta

<table>
<thead>
<tr>
<th>Month</th>
<th>Pail (Murree)*</th>
<th>Thatta -1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Av. Max</td>
<td>Avg Min.</td>
</tr>
<tr>
<td>September</td>
<td>29.7</td>
<td>20.5</td>
</tr>
<tr>
<td>October</td>
<td>28.2</td>
<td>16.1</td>
</tr>
<tr>
<td>November</td>
<td>24.8</td>
<td>11.1</td>
</tr>
<tr>
<td>December</td>
<td>19.3</td>
<td>6.9</td>
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<tr>
<td>January</td>
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<td>4.8</td>
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<tr>
<td>February</td>
<td>17.8</td>
<td>6.1</td>
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<tr>
<td>March</td>
<td>22.4</td>
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<td>April</td>
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<td>June</td>
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<tr>
<td>July</td>
<td>33.7</td>
<td>26.3</td>
</tr>
<tr>
<td>August</td>
<td>31.3</td>
<td>22.5</td>
</tr>
</tbody>
</table>

1. The temperature data recorded at Thatta Sugar Mills Ltd. (Average for 1985 to 1989)
2. Temperature data for Pail recorded at Sugarcane Breeding Sub-station, Murree
Arrowing in cane fields has a detrimental effect on the yield and quality of cane crop. Growers always look for non-flowering varieties for economic yields. With the initiation of flowering, apical leaves get shorten and with the appearance of tassels pith develops in upper half portion of cane stalk. Fibre contents of cane increase with decrease in juice extraction. Since sugars and metabolites are drastically consumed for flowering and tassel development, cane stalk get slender and gradually loose weight. The yield losses vary with cane varieties and the time between flowering and harvesting, temperature and soil moisture. Excessive moisture promote flowering and yield losses, while drought condition during induction phase depress flowering. Losses during winter are less and are accelerated with the advance in temperature. So long as the cane tassel is unripe, flowers are yet opening; there is not much effect on yield. Stalk vigor is considerably reduced by the time flowers mature and shed from panicle. Early flowering varieties have high intensity than late flowering varieties thus would have more depressing effect.

Extensive work has been done on the quantitative losses in cane yield and juice quality. A yield loss of 25 % was recorded in a crop showing 75 % flowering intensity (Clements and Awada, 1964). A study in Barbados showed a linear relationship between flowering and cane yield indicating 0.47 % and 0.28 % loss of yield for each 1 % flowering of plant and ratoon crop (Rao, 1977). Cane varieties show varying effect on flowering. The varieties that produce side shoots after flowering showed lesser losses then the varieties flowering without side shoots (Julian, et al, 1980).

The flowering stalks initially show increased contents of sugar, nevertheless, sugar production is low as the sugar is later consumed for development of tassel. Further, the flowering stalks have higher fibre that has drastic effect on juice extraction. The juice extraction of flowered stalk was reported to be 17 % less than the un-flowered stalk (Lopez, 1965). As such sugar production is less due to very low juice extraction. The worst effect on juice extraction was noticed up to 7th top inter nodes. To reduce the ill effect of fibre, it is advisable to cut out most fibrous portion of top cane along with tassel. 

Effect of cane flowering on yields
while harvesting.

**Measures to avoid flowering in cane**

- Selection of non flowering varieties
- Selection of varieties, though flowering but showing lesser losses
- Depressing flowering by chemical spray
- Withholding irrigation just before and during floral initiation

**Soil Moisture Control:** Drought conditions during induction phase depress the process of flowering in cane. Thus withholding irrigation from August 10 to September 20 was found be an effective mean of tassel prevention (Humbert, 1969). For lower Sindh area of Pakistan irrigation control would be needed during the full month of September. In case soil, structure retain enough moisture for longer period, this practice may not be fully effective. Successful water management needs thorough knowledge of soil type, irrigation scheduling and the flowering time in a given variety.

**Defoliation:** It has already been established that flower stimulus is produced in spindle leaves (Coleman, 1967). In case the leaf function is ceased or reversed cane flowering would be checked. Based on this principle cane flowering has been controlled by reverting the activities of leaves through the use of chemicals or by complete defoliation of apical leaves. In India, spray of Diquat @ 0.25 liter in 15 liter of water during 15-24 September gave a satisfactory control of flowering (Humbert, 1969). Application time should carefully be assessed. The chemical has to be sprayed just before the stage of flower stimulus production for deriving good results. The other chemicals known to check cane flowerings are Maleic hydrazide, Gramoxone, Paraquat, CMU (Singh and Reddy, 1976; Yang, 1972). Chemicals affect flowering through defoliation, leaf burning, dehydration and metabolic inhibition. The Maleic hydrazide has growth suppressing activity than by leaf destruction action of most of other chemicals. The effect of these chemicals is temporary, and by the time the flower induction stage is over new flush of leaves appear and plants recover to regain normal growth. The crop, which has to be harvested early in the season need not to apply the treatment, it may have adverse effect. Only the crop meant for late harvesting should be treated.

Defoliation of spindle leaves has proved quite effective to check flowering. Time of defoliates is extremely important. Apical- spindle leaves have to be trimmed of just prior to the induction phase. In India (Lukknon), leaf trimming between September 14 and 26 gave total inhibition of flowering without any adverse effect on yield (Panje, 1969). Results have been verified in Mauritius (Julien, 1969).

**Cane Variety Development in Pakistan**

Pakistan has a good infrastructure of research work in three cane growing provinces. Since cross breeding facilities have not been developed, variety development program is mainly carried out through introduction of cane varieties and import of cane fuzz. The variety evolution programme at the provincial research stations is summarized in this section. Varieties released by various provincial research institutes are given in Table-4.05.
Punjab

The Sugarcane Research Institute, Faisalabad, is the main base of variety evolution that supported the sugar industry of both Punjab and Sindh provinces.

The imported fuzz and germplasm is the main source of variety selection in the province. Mass selection is made from seedling population available from the fuzz and the imported germplasm. Seedling clones and germplasm are evaluated in various selection stages for yield and quality characters and diseases tolerance. Out field trials are planted in various agro-climatic regions of the province to test varieties adoptability in different ecological condition.

Up to 1947, the period of independence, cane varieties and fuzz were received from Coimbatore, India. Main variety under cultivation was Co 312, with some area under CoL 5, CoL 9 and Co 313. During 1950-60 period cane varieties CoL 29, CoL 44 and CoL 54, raised from Coimbatore fuzz, were approved for commercial cultivation in Punjab. Later, different sources of fuzz supply were explored which helped in variety selection work at Sugarcane Research Station, Faisalabad (Layalpur).

A cane flower station was established at an altitude of 2500-3500 feet, in Murree Hills, during 1953-54. Some varieties give sporadic flowering, fuzz is not obtained in desired varieties and arrows developed are subject to extreme climatic vagaries. As such cane fuzz is not much viable. Only two varieties L-116 and L-118 could be developed from open pollinated fuzz. Therefore, main reliance has been on fuzz imported from cane breeding stations abroad.

The fuzz imported from Barbados during 1952-53 helped produce two commercial varieties BL 4 (1968) and BL 19 (1967). BL 4 became very popular due to high yield potential and high sugar contents under good input condition. This variety later became the most favorite variety of lower Sindh and shared 95 % area of total cane cultivation. The other lot of Barbados fuzz received during 1976-80 gave two commercial varieties BF 162 (1990) and BF 129. The former variety widely spread in Southern Punjab and considerably raised the sugar recovery level of sugar industry. The variety BF 129 was got approved in Sindh.

The fuzz import from Canal Point and Louisiana (USA) started during 1980. This is now the main source of cane variety selection program and has helped release varieties by the name CPF. Meanwhile some fuzz was also received from Brazil and the varieties developed have been named as SPF.

Cane varieties have been collected from different local and exotic sources. The varieties are evaluated for their adaptability while testing their performance in various selection stages at the research station and out field trials. Triton got popularity for some period in the province. Co 1148, though not approved due to low sugar contents, but it got popularity due to better ratooning and spread in vast area of the province. Cane varieties from Canal Point CP 43-33, CP 72-2086, CP 77-400 and CoJ 84 from India were got approved for commercial cultivation in some specific areas.

In Private sector, Shakarganj Sugar Research Institute, situated at Jhang, is very active in variety development program. The selection program is based on the fuzz imported
from Sao Paulo (Brazil), Canal Point (USA), Natal (S. Africa) and Brisbane (Australia). The variety SPSG 26 has been approved for commercial cultivation. Dozens of varieties have reached in advance stages of selection.

Table-4.05 Progressive Release of Cane Varieties in Cane Growing Provinces of Pakistan

<table>
<thead>
<tr>
<th>Period</th>
<th>PUNJAB</th>
<th>SINDH</th>
<th>NWFP</th>
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<tbody>
<tr>
<td></td>
<td>Fuzz</td>
<td>Exotic/local varieties</td>
<td>Fuzz</td>
</tr>
<tr>
<td>1950-55</td>
<td>CoL 29</td>
<td>-</td>
<td>Co 421</td>
</tr>
<tr>
<td>1955-60</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1960-65</td>
<td>CoL 54</td>
<td>-</td>
<td>Co 547, PR 1000</td>
</tr>
<tr>
<td>1965-70</td>
<td>BL 19</td>
<td>-</td>
<td>Co L 54, Co 622</td>
</tr>
<tr>
<td>1970-75</td>
<td>L 116</td>
<td>-</td>
<td>BL 4, NCo 310, Co 997</td>
</tr>
<tr>
<td>1975-80</td>
<td>L 118</td>
<td>Co 975</td>
<td>BL 19, Co 658, L 113, L 116</td>
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<td>1985-90</td>
<td>BF 162</td>
<td>-</td>
<td>-</td>
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<td>1990-95</td>
<td>-</td>
<td>-</td>
<td>CP 67-412</td>
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<td>SPSG 26, SPF 213, CPF 237</td>
<td>CP 43-33, CP 72-2086, CP 77-400, CoJ 84</td>
<td>NIA-98, Th 10, HS 2</td>
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Sindh

Variety development work in Sindh has been confined as introduction of local and exotic varieties. Sugarcane Research Station, Tandojam concentrated its work as introduction, acclimatization and release of varieties; varieties are however tested in different selection stages, for various economic characters. Some varieties evolved at Faisalabad and Mardan have been adapted for commercial cultivation in Sindh. In earlier
stages Co 421, Co 547 and Co 997 were widely grown. The variety PR 1000 imported from USA covered vast area of lower Sindh, and was later on swept by BL 4. The variety BL 4 has been the most favorite variety of sugar industry in lower Sindh. NCo 310 and Co 622 have also been growing in pockets. The upper Sindh region was covered by CoL 54 which was widely replaced by L 113/ L 116 and CP 67-412. The latest release of the research station is BF 129.

Quaid e Awam Agricultural Research Institute, Larkana, has initiated variety selection work from imported fuzz and cultivars and has selected two varieties.

Nuclear Institute of Agriculture (NIA), Tandojam, has also been active on evolution of varieties through tissue culture. Two varieties NIA 98 and Nia 2004 have been got approved for commercial cultivation.

Sugar Crops Research Institute, Thatta, has also been working on cane variety development programme since 1982, and has evolved one variety Th. 10. The variety has shown good adoptability in the province.

A number of promising lines have reached in selection stages.

In private sector Dewan Sugar Mills has established a Research Institute entitled "Dewan Farooque Sugarcane Research Institute" at Dewan City in Thatta District. The institute initiated variety development programme based on local open pollinated fuzz and the fuzz imported from Canal Point (USA). A number of promising lines have been screened and are being finely evaluated for commercial releases.

Variety Decline

It has long been observed that sugarcane varieties tend to show gradual loss of vigor and yield and run out after being grown for a few years in a particular area. Though some varieties like NCo 310, Co 312, CoL 54, Tritron and BL 4 have shown stable performance over several decades. From genetic standpoint variety decline should not occur, as in sugarcane the variety is clonally propagated and there is no genetic segregation or mixing, neither does somatic mutation appear frequently. The exact cause of variety deterioration and yield decline has not always been determined with certainty. However, a number of biotic and a biotic stresses are associated with variety decline.

a. An appearance of new disease or the evolution of new races of an old disease to which the variety is not resistant.

b. Multiplication of soil organisms, which attack roots of cane crop, undergoing progressive changes which enable them to attack variety previously resistant and productive.

c. Continuous degradation of soil fertility and land productivity. Poor physical condition of soil with lack of organic matter, depletion of trace elements, restricted root proliferation following soil compaction might be the cause of yield decline. For a variety that requires rich soil and ample irrigation, changing soil and environmental stresses would gradually depress yields.

However, with improvement of soil fertility the variety regain its position. With persistent pressure on soil, marginal areas are coming under cultivation and in
the absence of required inputs of fertilizer, irrigation and optimum cultural operations, prevalent varieties do not show good response.

There could be a number of factors of yield decline including pests, diseases, soil and nutritional problems and several cultural aspects of cane cultivation. The main cause of yield decline is unconsciously attributed to cane variety. The solution to the problem is to develop site specific varieties for each of the problems associated with soil, irrigation, cultural practices, plant protection and other abnormal environments. Good hygienic conditions in soil and seed may rejuvenate the variety, but ultimate solution to the problem is to evolve and release superior varieties to replace the run out varieties at frequent intervals.

**Cane Breeding**

**Breeding Objectives**

The main objective of cane breeding is to improve varieties, so as to produce more tons of sugar per hectare/month. During the past 7-8 decades significant achievements have been made in the development of cane varieties. Breeding efforts have brought about 25-50% improvement in sugar yields in different countries. Cane varieties are evolved to meet the demand of growers as well as sugar industry. Variety requirements for the farms vary with change in weather, soil conditions, cultural operations, diseases and pests epidemic. Mechanization in cane culture and harvesting systems has their own specific demand for varieties. Cane varieties should also qualify sugar factory characteristics pertaining to milling and processing problem of sugar industry. In the eve of variety development for specific objectives, economics has a dominant role to play at the farm and the factory. Economic factors demand maximum production per unit area at the lowest cost. Cane varieties should produce higher yields with irrigation and fertilizer use efficiency grown in natural diseases and pests free environment. Economic factors also demand high sucrose contents for production of high sugar yield with the lowest manufacture cost in the factory. Progressive increase in high sugar yields is a big challenge in view of day by day increasing costs of production. This challenge can be met only by genetic changes, and these can be brought either through conventional breeding or bio-technology. So as to achieve high yield potential with desired economic characters the main task of cane breeder is to produce new combinations of genes, which interact with their environments including different soil types and agricultural practices.

Sugarcane is grown in different environments of climate, soil and cultural conditions and may be exposed to diseases and pests. Breeding is required for increasing genetic yield potential as well as to sustain the ill effects of yield limiting factors. According to Evens (1980), cane breeders should emphasize on four broad aspects of cultivation.

i. Selection for higher yield potential under favorable conditions and adaptation to local environments

ii. Sustainability to continually changing agronomic and management practices.

iii. Resistance to diseases and pests
To have cultivars of desired characters genes bearing required traits have to be incorporated through sexual reproduction. If desired combinations are not achieved through conventional breeding, new horizons of genetic engineering may be approached. A systematic breeding program include selection of parental lines, study of cross compatibility, effective crossing techniques, growing fuzz and the selection criteria and evaluation for different environments.

**Main Features of Breeding Program**

**Collection and maintenance of germplasm**

A breeding station should have an adequate source of germplasm for crossing. In order to develop new superior varieties, it is imperative to collect and maintain germplasm of wide genetic diversity. This includes:

a) Representative clones of different Saccharum species and related genera, so as to incorporate desired characters through crossing and back crossing.

b) Cane varieties of different origin including local adapted varieties and the exotic varieties.

Variety introduction is an important component in cane breeding programme. New varieties are introduced keeping in view various considerations (Miller, 1994).

1. The varieties to be introduced from a country of similar latitude and altitude, matching specific conditions of soil type, rain fall pattern, crop growth season and diseases.

2. The station is growing varieties or parental lines similar to those adapted in local conditions.

3. The varieties to be imported which possess the traits desired to be incorporated in the local cultivars.

4. To import varieties of unknown characters and parental attributes should be the least resort.

**Choice of parents**

In a cross breeding programme great emphasis has to be given to selection of parents. While selecting parents, the breeder should be clear about the aims and objectives, whether to introduce genes for resistance of some economic characters or for quantitative improvement of varieties. The parents marked have to be used to generate genetic variation. The efforts have to be concentrated on crosses that stand the highest probability of producing elite genotypes for production of commercially acceptable varieties.

For a cross breeding program parents are selected either on the basis of their own quantitative or qualitative characters or considering their inheritance capabilities to produce better than average population of seedlings. The parents that develop successive generation having exceptional combinations of desired genes are preferred. Improved parental clones are preferred as these clones presumably have linkage blocks much favourable for the environment; the program is served (Berding and Skinner, 1987).
However, exceptionally outstanding parental material is sometimes deleted that proceed to higher selection stages but never help select commercial strains. Nevertheless, to classify parents on their ability to produce elite clones would be a long and expensive exercise. The program to classify and select disease resistant parents may take 8-10 years and it may take further 10 years period for crossing and selection of a resistant commercial parent (Benda, 1987).

Choice of parents generally depends on phenotypic and genotypic expression of their characters they display. The criteria of selection may be the agronomic and morphological traits, disease reaction, flowering behaviour and the breeding performance for specific characters. Progeny tests of genotypes in advance selection lines ascertain the stability of the character. Trial crosses can indicate usefulness of parents through selection ratio of seedling population. Superiority of parent can be adjudged from the performance of selected progeny clones. A large selection rate in different selection stages, years and locations assure the performance of crosses. Complete record is to be kept for selection rate and selection ratios in different stages. The one practical method followed is evaluation by comparing the frequency with which the progeny of the specific parental varieties reach the select list in relation to the total of original seedlings population.

A repetition of crosses beyond quite low limits is not advocated; greater advantage may be expected from new parental combinations than from crosses reported many a times. However, certain proven crosses can be repeated for some times with advantage.

While selecting the parental lines there could be a number of options (Miller, 1994)

1. Choice could be for the current commercial varieties, the best available in the stock.
2. Promising varieties currently being evaluated in selection stages
3. Foreign introduction with specific genetic traits (diseases resistant, fibre content, sucrose content etc) needed in future varieties.

In breeding programme at Canal Point, within five years after crossing, superior selections are used as parents for the next generation

**Crossing Methods**

**Selfing:**

Selfing is a big tool for breeding to develop pure lines for the purpose of heterosis. But sugarcane is heterozygous in nature with large chromosomal combinations, selfing, in true sense is not possible. In sugarcane improvement program more emphasis is made to enhance genetic variability for selection of elite clones. Modern commercial varieties of sugarcane are complex inter specific hybrids; their inbred population may continue to show a considerable degree of variation. Nevertheless, progenies of self in sugarcane have less genetic variability and reduce the chance of large variants in a seedling population. In-breeding has been used just to concentrate genes of desirable character or increase homzygosity of genes for more simple inherited characters like sugar contents. Selfing has also been a practice to ascertain the degree of self-fertility.
Open pollination-field crosses

The method was adopted in earlier days of cane breeding. Desirable male and female parents were planted in close by rows and cane fuzz was collected in open. It allows the natural choice of crossing with ample chances of pollen contamination from other parental lines grown in the area. In this case only female is identified. Plants developed by such crosses in Barbados were called Barbados natural hybrids (BNH). In India such crosses are called general crosses (G.C). Nevertheless, there are a few options to this method. Female parents are placed in between desired male parents on both sides. To ascertain the effectiveness of the cross the fertility of male and pollen sterility of pistil plant may be assured. And to further assure the cross, the arrows may be covered in a cloth bag to avoid contamination.

Poly-cross

In this method, sets of different female varieties are pollinated with a set of different male varieties. Grouping of genetic combination is made on the respective female parents within poly-cross. Thus one female arrow is crossed with mixture of pollen from a number of male tassels. Selected female varieties are placed in an area. Two or more tassels of a number of elite male parents are placed at random along side the female to all possible combinations among the selected parental lines. It helps cross a large number of varieties, in a short time of general combining ability, at minimum expenses. The main object is to widen genetic base by diversity of cross-pollination. In this case only female parent is known. Nevertheless, the male parents and the pistil parents have to be chosen on the basis of superiority for one character or the other. The pollen fertility, self-sterility of pistil plant and the combining ability have to be tested before hand. Seed of each tassel is to be harvested separately. Poly crosses have been used most often in tropical breeding stations, because both male and female varieties are usually fertile and male sterilization is not practiced.

Poly crosses produce higher number of seedlings then from bi-parental crosses due to higher pollen shading (Nuss, 1979). The method has the limitation that due to random pollen source, a high selection rate from a poly-cross can not be repeated.

Area crosses

In this method a single out-standing male parent is used to pollinate a number of self-sterile female varieties. This is a sort of bi-parental crossing and is more efficient in utilizing the male parent and is less costly.

Bi-parental crosses

The method is widely used by cane breeders. Known male and female parents are placed in pollen proof enclosures. The degree of male sterility and pollen fertility should be known to assure a good cross. In tropics, the female has to be emasculated through hot water emasculation treatment to induce male sterility, while in sub-tropics; cold temperature during tassel development effectively causes male emasculation of unprotected tassels. Tassels to be used as male parents are protected from low night temperature b moving them into the crossing chamber.

The technique is applied for making combinations of most desirable parents with the
expectation of producing superior progeny. It also helps to make special crosses to introduce un-adapted germplasm into the breeding program. However, compared to poly-cross, bi-parental crossing technique is more expensive and time consuming. It may be emphasized that superiority of male and female parents provides no assurance of superior progeny as a whole or individual elite clone. It is in fact the combination of gametes of both the parents that may or may not lead to produce outstanding progeny. In bi-parental crosses expectation may not come true, and uncertainties are faced in each cross, as desired clones cannot be predicted in a progeny. The only way to produce superior clones is to exercise a large number of crosses among promising parents to make wide diversity of combinations. Choice of parents is important with background information as transmission of characters into progeny clones.

**Recurrent selection**

The technique involves the use of specific combining ability for a particular character, like high sucrose contents and earliness. It is crossing among agronomically excellent parent with difference in a particular character. When progeny shows a large rating of a particular character the cross is repeated. Reciprocal recurrent selection is also done, to avail the chance of incorporating character of both the parents, in progeny. The proven parents, which produce superior progeny, have to be identified before hand (Heinz and Tew 1987). During selection record is kept on the number of the seedlings selected for specific parents in F1 through F6 selection stages. A selection ratio is calculated between stages and their parents with the poor records are discarded. This is taken to be the modified recurrent selection program. According to Heinz and Tew (1987) 200 seedlings grown from a poly cross could give satisfactory trial test.

The method is best utilized at the US Sugarcane Field Laboratory, Houma, Louisiana (Breaux, 1984). Bi-parental crosses producing seedling population with high selection rate for good juice quality are repeated each year. With this character in view elite parents are ear marked and are consistently used in crosses. The progeny clones bearing high sucrose are further used in inter crossing to produce still another improved cycle. The successive use of this technique for a number of years has brought considerable improvement in juice quality. The fifty years research at Louisiana indicates that Brix and sucrose have high heritability and there has been no close negative association between sucrose content and cane yield (Breaux, 1987).

**Proven crosses**

Efficiency of bi-parental crosses lies in the selection of parents and the knowledge of the inheritance of character to progeny lines. The parents showing better selection ratio to the crosses giving advanced lines are better than those having lesser selection ratio, so the above average selection rates is further exploited by growing large progenies. However, test crosses can be run before going for larger crosses. Some parents may have lesser selection ratio, but produce most outstanding clones, are not rejected and are maintained to avail of the chance to some degree. The parent used in several crosses and has shown outstanding performance in a number of crosses are preferred during selection. A 40 % increase in the average sucrose content of sugarcane cultivars has been achieved through 5 cycles of recurrent selection beginning in 1920 ‘s’ (Legendre and Burner, 1997).
Family selection

The principle behind the family selection is to find families that contain a higher proportion of potential commercial crosses and not to produce progenies having some individual outstanding clones. The performance of a particular cross is checked in successive selection stages. The proven status of a cross is assessed by relating the selection results for the whole population of crosses planted in the same year and a cross ratio analyses is made. The ratio is calculated using the most advanced stage reached by that cross series (Berding and Skinner, 1987). Improvement in population can be made by careful selection of crosses as well as by family selection for crosses that have above average rates.

Assessment of variability

A commercial sugarcane variety being heterozygous and polyploid in nature possesses high variability. During the course of cross breeding genetic recombinations occur at meiosis, which further increase the chances of chromosomal pairing to further exploit the variability pattern. Accidental loss or gain of chromosomes at meiosis also increases the chances of variability in sugarcane. Once variability is expressed in progeny and clones are selected for a given environment, they retain their characters. Although the genetic base may be stable for a highly productive variety for the moment, it is highly vulnerable to uncertain changes in the environment it is grown. The demand for new variable emerge with changing environment which could be emergence of new diseases, pests, changes in ecological conditions influenced by moisture stress, salinity, water logging, changes in cultivation practices, the mechanization demand for erect-ness and easy trash-ability and industrial demand for hard and soft cane. Thus new requirements need to widen the genetic base by introduction of further variability in the available germplasm. Thus cane breeders lay emphasis to exploit phenotypic variability in different environments through genotypes x environmental interaction. And, this is possible by testing large cross combinations. The genetic base should not be made static by using a small set of parental combinations years after year. It is exploiting the same variability again and again. This chance has to be magnified by further widening the genetic base which needs to make new crosses to screen desired progeny to select for desired characters.

Keeping in view the objectives of the program and the extent of variability desired to introduce in the cross, the breeders has now to chose the parents for cross combination. The choice may be for a recurring selection cycle or introducing some exotic lines may further open the genetic base. The genetic base may further be widened through early generation inter-specific hybrids or their back crosses in the crossing program. The performance of families or individual crosses has to be assessed through progenies up to fourth or later selection cycles.

The assessment of cross combinations depends on the progeny size and the selection criteria. For best selection maximum possible number of crosses should be conducted and a reasonable size progeny has to be raised to collect reasonably correct data information. Too small or too clumsy progeny size is not desirable. And the citeria for cross assessment is either the selection rate or statistical variance (Breeding and Skinner, 1987).
Inter specific hybridization

Most of the existing sugarcane hybrids have been derived through inter-specific hybridization involving two or more species of Saccharum, with the predominance of S. officinarum and S. spontaneum. Main objective behind the hybridization has been to improve for yield and quality and impart hardiness in commercial cultivars against various soils moisture and environmental stresses.

Nobilization

The term ‘nobilization’ refers to inter specific crossing of wild forms of S. Spontaneum, S. barberi and S. robustum with S. officinarum varieties normally called the noble canes. The varieties of S. officinarum are almost the sole source of genes controlling sugar contents. While wild forms contribute traits for ratoonability and vigor and increased adaptability to stress. The hybrid so developed is then backcrossed with original noble genotype to predominate yield and quality characters. Since noble canes generally lack vigor and resistance to a number of serious diseases, the inter-specific crossing work produced good commercial quality varieties with considerable resistance. Java, producing PoJ 2878 and India for developing Co 205, has been pioneer in nobilization of sugar cane plant.

In nobilization process, back-crossing made headway in progressive improvement in sugar recovery in derivatives of S. sinense and S. robustum. Backcrossing is also resorted to for diluting considerable characters of wild species carried over to hybrids. Some obstructions are sometimes observed in inter specific recombination as genetic elimination, zygotic elimination, pleiotropy and linkage. Chromosomal imbalance may often leads to male sterility. It is for this reason that S. officinarum is used as pollen parent in backcrossing. Other difficulty is that only a small number of noble canes flower profusely.

The inter specific hybridization has been used successfully to broaden the genetic base of sugarcane. This base broadening helped the selection of suitable genetic trait from a large seedling population obtained through successive crossing and back-crossing work. The genetic base established in the initial hybridization work has been continuously used for the last six-seven decades. The consistency in achievements suggests the search to further genetic diversity to coup the need for new arising problems in cane and sugar production. Therefore, efforts of the breeders are to collect and maintain wide variety of germplasm of different origin. A large combination of crosses and back crosses with in-depth study of cytogenetics and genetics and morphological expression of varieties in different environments help select elite clones of desired traits.

Practical Approach to a Cross Breeding Programme

A cross breeding programme can be run under natural or artificial flowering conditions or both. Before the crosses are performed it is essential to have infrastructure and environments available for cane flowering and then study the flowering behavior of cane varieties. Cane varieties differ in flowering behavior and may have the following peculiarities.

Varieties do not flower at the same time even under the most favorable conditions. This
characteristic of varieties requires specific photo-inductive regimes to hasten or delay the flowering so as to synchronize flowering time for crossing among desired parents. The photo-inductive regimes of varieties have also to be determined to induce flowering in non-flowering varieties.

Development of tassels from boot and opening of anthers is of great consideration for breeders. In some varieties anthesis begins soon after the emergence of the tassel from boot, while in other varieties may be delayed for one to more days of arrow emergence. And in some cases anthesis fails to occur in fully expanded arrow. Pollen viability of varieties has also to be ascertained for determination of male or female sex. In a successful cross breeding programme among desired parents, male and female fertility in flowers has to be assured. It has been established that stigmas are, most the time, receptive while male organs are more sensitive to environments. The low temperature during flowering season poses problem of low pollen fertility and poor seed viability.

**Infrastructure for cane breeding**

In the countries with climate quite conducive for cane flowering and where diurnal temperature remain within 20º - 30ºC, cross breeding is practiced under field conditions. Countries located on latitude ranges of 5 – 15º N or S provide favorable temperature conditions during flowering time; Coimbatore (India) and Mauritius may be referred as an example. However, under conditions of natural flowering in open fields, day length is shorten by enclosing the tagged field plants with black colored mats enclosure (Coimbatore). The day length is extended by giving extra light through illumination in the field (Mauritius). These practices are done for synchronization of flowering time.

In the cold climate where flowering is scarce and seed viability is problem due to low temperature, viable see production is achieved under artificial conditions in photo-thermal houses. The photo induction requirement for flowering are met under photoperiod houses and seed viability is obtained under glass house conditions. Cane breeding station at Louisiana (USA), Marenja (Australia), Natal (S. Africa), Taiwan (China) and Alexandria (Egypt) have very successfully carried out their sugarcane crossing programme in photo-thermal houses.

The photoperiod houses are to provide photo-treatments to cane varieties according to their photoperiod requirements that help induce flowering in non-flowering varieties and hasten or delay flowering to synchronize crossing period. At Louisiana there are six bays of photo-treatment, each having the size of 26' (l) x 13' (w) x 24' (h). Each photo-treatment bay has 3 rail carts, each designed to hold 18 can cultures. Rail carts roll out or in the bay as per treatment requirements.

The crossing glass/green house measures 51' (L) x 35' (w) x 24' (h) and is designed with aluminum crossing cubicles on side walls. The cubicles (5' x 3') accommodate crossing without pollen contamination. Day and night temperature is maintained at 30ºC - 23ºC with 75 % RH. At low temperature pollen grains are sterile; they may not open or abort. To have good fertile pollen, anthesis should occur at very favourable temperature with minimum and maximum ranges of 23-30ºC, respectively.

In Louisiana the cane varieties to be grown for photo-treatments are planted in 10 gallons capacity cans (Annon, 1982). The planting media is composed of sand, field soil and
compost in 1 : 1 : 1 ratio. The plants grown are well nourished with frequent N fertilizer application. When the plants are fully developed N application is checked. As the plants complete their vegetative growth are subject to photo-treatments from 1st June up to September 15 as per required light treatment. From 1st June to July 12 plants are subject to daily light of 12 hrs 30 mins. From July 13 to September 15 the daily light is gradually shorten by one minute and thereafter the plants are subject to natural photoperiod. Only sun light is used as the light source for photoperiod. Different bays have difference of one week late or early exposure to light.

By the termination of photo-treatments plants are shifted to breeding glass house. The plants on showing the symptoms of boot formation are marcotted for development of aerial roots. Marcotted stalks are used for making by-parental or poly crosses. Marcotting is done in caned stalks however expected flowering stalks in open fields may also be marcotted and brought to crossing house for cross breeding. Such stalks may be used as good male parents.

Selection of male or female parent

Selection of sex in parents is based on the extent of anther dehiscence and pollen fertility. The anthers may be fully opened, or small, shriveled and yellow coloured. Usually, if the anthers are plump, purplish or brownish in colour and exude pollen from both sides, the variety is used as male. And, if the anthers are yellow, shriveled, small and devoid of pollen, the variety is used as female. In some cases variety is self incompatible for seed production. The male sterility may be genetic due to abortive pollen or may be environmental to check dehiscence in low temperature. This is an important study and should be made to keep the parent as a male or female in a cross.

In the case of genetic male sterility there is incompatibility of chromosomes complements and pollen developed is aborted. In such cases varieties are good female parents. In the case of environmental sterility, some pollen may be produced but anthers do not dehisce and pollen is not released. In this case sexual position of parent varies with the season, parent may act as male fertile in one season and sterile in the other.

Depending on varieties, the male fertility varies from 0 – 100 %. According to the classification of Rao and Rao (1972), inflorescence with 30% open anthers, shriveled and yellow coloured is selected as male sterile pistil parent. If open anthers are 50% or below, plant is fit for use either as male or female parents. The variety could be used as male parent if above 50% anthers are open and are fully plump, brown or pink in colour. Clones having pollen fertility of less than 30 % can be considered as female parent (Natrajan et al, 1983). In Brazil, parents with 5% fertile pollen are considered female, 5-20% as weak male and could be used as female, above 20% fertile pollen are considered male parents (Fasihi, 1979).

The desired male and female plants are placed in cubicles designed along the walls of the glass house. Female plants are in pots, while the male stalks are either marcotted or are in Hawaiian acid solution. They are so placed as to keep the male tassel a little above the female and are covered with muslin cloth. Each day morning the male is given a slight jerk to shed pollen on female tassel. It takes about 8 – 10 days for complete anthesis of male tassel. Female tassel is then wrapped in craft paper bag till maturity of the arrow in situ.
Photo-period House for photo induction treatment for cane flowering

Cane flowering varieties placed in preservative solution stationed in a crossing chamber (after Hogarth and Allsopp, 2000)

Cane arrows placed in a glass house
Hybridization Techniques

Gradual development in cross breeding techniques in sugarcane adopted by different research centers has been reviewed by Ethiragan (1987). In the earlier years of cane breeding, open pollinated arrows were collected without choice of parent or control of pollination. Selections were made from seedlings just to exploit the heterozygosity of cane through natural cross-pollination. In Barbados the varieties so developed were termed as BNH (Barbados natural hybrids). Later developments were:

a) Female and male around to be bunched together to affect natural crossing.

b) Planting the male and female plants in particular rows in isolated area, male to be planted on both sides. Arrows of both the parents are bagged together to allow crossing. Some types of mats placed aside to avoid contamination of foreign pollen.

c) Bringing together arrows of desired parents planted in adjacent rows and then closed by cloth bags surrounded by a pole.

d) Female arrows left in the field enclosed in the bag. In the evening fully emerged male arrow is cut, placed in kettle of water and tied with female arrow in the bag to affect crossing next morning with expected pollen shed from the spikelets. Fresh arrows are sacrificed each day.

e) Panicle branches from the male arrows containing mature spikelets ready for anthesis, are plucked shortly before sunrise, rolled in newspaper and brought to the pollen collection room. Spikelets are spread on the paper, moisture if any is absorbed by a blotting paper and then heated under 400 W HPL lamps. Due to warm environment pollen is shed in an hour’s time and collected on glazed paper. The pollen is hurriedly taken to the field and dusted over receptive stigma of female arrow, already covered by cloth lantern. Ladder is used as an aid in pollination. This operation is repeated for 7-8 days till the blooming of female arrow is completed.

f) The male varieties grown in the field may be used as pollen donor varieties. The spikelets are collected and brought to the laboratory, for pollen collection and then pollen dusting on female flowers in acid solution or marcotted stalks.

Bringing fresh male tassel from field or collecting pollen each day so as to cross female flowers is cumbersome and inefficient. The crossing techniques have now been completely modified and made more scientific to assure pollination and seed setting efficiently. Male sterile female parents and male fertile parents are selected and cross-pollination is made possible by using different techniques. The crossing procedure vary with different countries; some stations rely upon acid solution technique for longevity of flowering stalks, some stations have adopted marcotting technique, while in others excised marcotted stalks are used in conjunction with acid solution (Ramdoyal et al, 2003).

Solution technique

A technique to preserve the male tassel was developed in Hawai (Mangelsdorf, 1953). Through this technique the cut male tassel stalks with two or three inter nodes are placed in acid solution. The tassels remain alive for a number of days to release pollen from
anthers. The constituents of the solution used at Canal Point and Mauritius are given as
under.

**Canal Point**

Sulpher dioxide (SO\textsubscript{2}) : 180 ppm Dissolved in high quality water  
Phosphoric acid (H\textsubscript{3}PO\textsubscript{4}) : 108 ppm. Produced by reverse osmosis

Crosses maintained in acid solution are kept in 19 liter rubber containers. 
Solution is over flown three times per week and replaced with fresh solution.

**Mauritius**

SO\textsubscript{2} : 100 ppm dissolved in ordinary tap water  
H\textsubscript{3}PO : 50 ppm  
H\textsubscript{2}SO\textsubscript{4} : 25 ppm  
HNO\textsubscript{3} : 25 ppm

Potassium metasulphite is used as the source of SO\textsubscript{2} in place of gaseous SO\textsubscript{2} The solution is changed every three days during the pollination phase and every four days during the maturation period.

The procedure for the use of this technique described by Miller (1994), Ramdoyal and Domaingue (1989) and Romdoyal et al, (1995) is given as under.

The solution is prepared a fresh and put in 10 liter plastic buckets. Seven or eight 1.5 meter cane stalks with tassels are placed in solution. The arrowing stalks selected as parent are cut between 8 and 12 AM, most of the leaves are detached and stalk placed in bucket containing solution. These are then carried and transported to crossing chamber and placed at the racks planned for crossing. The pH of the fresh solution is maintained at 2.3 and as the pH rises to 3.0, the solution is changed. While changing the solution, care should be taken that the base of the cane stalk is re-cut slightly.

By this technique the life of male tassel is increased and cut stalks remain alive for a long time. With their cut ends dipped in solution, the tassels of most varieties complete their blooming in a normal manner and remain alive until the seed is ripened. It takes a period of three to four weeks from the commencement of blooming. For active life of the tassel the environment must be humid and wind free. The author has observed that in less humid windy environment leaves wither and cane stalks loose their turgidity due to high transpiration.

The technique is being used successfully in Australia. The solution technique could not get popular in USA. Some varieties are sensitive to the solution (Dunckelman and Legendre 1982). In India as well, the solution rapidly turn toxic and panicle branches get dry (Balasundaram, 2005).

**Marcotting / Air layering**

Flowering stalks, both male and female, after cutting from the field, can be kept in isolated space for ease in crossing. The roots are induced in two or more nodes on above
ground standing cane stalks, in fields or in pots, by surrounding them with suitable rooting media. After roots are developed the stalks are severed below the rooted media and are brought to crossing chamber, arranged to stand on rakes for allowing normal crossing on blooming of tassels. Marcotting is done almost 4-6 weeks prior to emergence, before shortening of top leaves (Ramdoyal et al, 2003).

The technique was first developed in Coimbatore (Venkatrama and Thomas, 1927) and was called as tile pot technique. The technique was later improved by using polythene sheet and sphagnum mass for rooting media by providing favourable environment of temperature (22°C) and humidity (80%), (Dutt and Hussainy, 1950). The rooting media used for marcotting vary with breeding stations.

- **Mauritius**: Mixture of soil + saw dust + bagasse (1 : 1: 1) (Degroot and George, 1962)

- **Louisiana**: Water soaked sphagnum mass (Dunckelman and Legendre 1982)

- **South Africa**: Vermiculite + composted bagasse (Redshaw, 1998).

In Louisiana, rooting media is filled in tube like role prepared around cane stalks by wrapping 61cm x 61cm -10mm polyethylene film role. The role after filling and tightening make a tube size of 13 cm dia., within 15 cm between upper and lower ends. The media is watered once a week through a small hole on upper side (Dunckelman and Legendre, 1982).

The author, during his visit to Baton Rouge, Louisiana (1990) further observed that the marcotted stalks were kept in small water channel in a glass house (Malik, 1990). The lower end of the marcotted stalk is dipped in water and the water is frequently replaced a fresh. It is to cover the risk of withering in flowering stalks.

At Louisiana, marcotting is done one month in advance of tassel appearance (Anon, 1982), while in S. Africa cane stalks in crossing chambers are marcotted two months after the date of initiation (Redshaw, 1998). At Canal Point, cultivars used to produce tassels are grown either in pots or in the field; the stalks are marcotted 8 weeks prior to anthesis and flowering stalks are cut from field pots shortly after the on set of anthesis. The author has observed that the marcotting done just at boot stage produce good root system. In some countries cane stalks are marcotted at the first sign of flowering. Marcotted stalks produce on an average about twice as much seed per tassel as do acid solution maintained tassels (Miller, 1994).

The countries using marcotting technique include Bangladesh, China, Columbia, India, Indonesia, Mauritius, S. Africa, Thailand and USA.

**Cross Breeding Techniques Used in Different Countries**

The information on crossing programme and techniques compiled by Ramdoyal et al (2003) is reproduced in Table-4.06.
### Table 4.06 Basic features of sugarcane crossing programme at various cane breeding stations*

<table>
<thead>
<tr>
<th>Particular</th>
<th>Austria</th>
<th>Barbados</th>
<th>Brazil</th>
<th>India</th>
<th>Indonesia</th>
<th>Mauritius</th>
<th>South Africa</th>
<th>USA (Canal Point)</th>
<th>USA (Louisiana)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>17º 12' S</td>
<td>13º 13' N</td>
<td>13º 55' S</td>
<td>11º 1' N</td>
<td>8º S</td>
<td>20.14º S</td>
<td>29.49º S</td>
<td>26º N</td>
<td>30º N</td>
</tr>
<tr>
<td>Longitude</td>
<td>145º - 45 E</td>
<td>60º 00 W</td>
<td>39º 08' S</td>
<td>77º E</td>
<td>113º E</td>
<td>57º 29 E</td>
<td>31º 01 E</td>
<td>81º W</td>
<td>91º W</td>
</tr>
<tr>
<td>Parents used</td>
<td>630</td>
<td>506</td>
<td>723</td>
<td>100-126</td>
<td>146</td>
<td>247</td>
<td>400</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>Flowering</td>
<td>Natural &amp; Artificial</td>
<td>Natural &amp; Artificial</td>
<td>Natural</td>
<td>Natural</td>
<td>Natural</td>
<td>Natural &amp; Artificial</td>
<td>Natural &amp; Artificial</td>
<td>Artificial</td>
<td></td>
</tr>
<tr>
<td>No. of crosses/year</td>
<td>1500</td>
<td>797</td>
<td>1477</td>
<td>400-600</td>
<td>2000</td>
<td>2600</td>
<td>1300</td>
<td>1400</td>
<td>300</td>
</tr>
<tr>
<td>Inter-specific crosses (%)</td>
<td>&lt; 50</td>
<td>17</td>
<td>2</td>
<td>Yes</td>
<td>2</td>
<td>8</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bi parental crosses</td>
<td>80</td>
<td>11</td>
<td>43</td>
<td>Mostly</td>
<td>40</td>
<td>46</td>
<td>70</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>Foreign Varieties used (%)</td>
<td>19</td>
<td>6</td>
<td>24</td>
<td>Few</td>
<td>30</td>
<td>39</td>
<td>10</td>
<td>Few</td>
<td>Nil</td>
</tr>
<tr>
<td>New local parents</td>
<td>12</td>
<td>19</td>
<td>48</td>
<td>15 – 20</td>
<td>30</td>
<td>61</td>
<td>40</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Proven crosses</td>
<td>13</td>
<td>10</td>
<td>4</td>
<td>20 – 30</td>
<td>42</td>
<td>4</td>
<td>few</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Proven parents (%)</td>
<td>68</td>
<td>20</td>
<td>6</td>
<td>30</td>
<td>32</td>
<td>18</td>
<td>20</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
## Cane and Sugar Production

<table>
<thead>
<tr>
<th>Particular</th>
<th>Austria</th>
<th>Barbados</th>
<th>Brazil</th>
<th>India</th>
<th>Indonesia</th>
<th>Mauritius</th>
<th>S.Africa</th>
<th>USA (Canal Point)</th>
<th>USA (Louisiana)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying</td>
<td>13°C 20% RH</td>
<td>Hot air dehumidity</td>
<td>Hot air silica gel</td>
<td>35°C 48 h</td>
<td>Sun dry dehumidit y</td>
<td>Hot air silica gel dehumidit y</td>
<td>Hot air silica gel</td>
<td>Hot air 35°C</td>
<td></td>
</tr>
<tr>
<td>Defuzzing</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Seed storage</td>
<td>-21°C</td>
<td>-51°C</td>
<td>Alum. bag 0°C</td>
<td>-20°C</td>
<td>-20°C</td>
<td>Alum. bag - 21°C</td>
<td>-18°C</td>
<td>Plastic</td>
<td></td>
</tr>
<tr>
<td>Storage length - years</td>
<td>&lt; 10</td>
<td>25-Jan</td>
<td>3</td>
<td>5</td>
<td>2 - 4</td>
<td>3 - 5</td>
<td>1 - 20</td>
<td>1 – 5</td>
<td></td>
</tr>
<tr>
<td>Seed moisture %</td>
<td>5%</td>
<td>6 - 11</td>
<td>4</td>
<td>7</td>
<td>15</td>
<td>12</td>
<td>11</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Seedlings *</td>
<td>85,000</td>
<td>N.A</td>
<td>400,000</td>
<td>N.A</td>
<td>1,200,000</td>
<td>100,000</td>
<td>180,000</td>
<td>150,000</td>
<td>150,000</td>
</tr>
<tr>
<td>No. of years for selection *</td>
<td>10 - 12</td>
<td>10</td>
<td>10</td>
<td>15 - 18</td>
<td>15</td>
<td>10</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of commercial ratoon *</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>6-7</td>
<td>4</td>
<td>2 – 3</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Ramdoyal et al (2003)*
Variety Selection Procedure

Growing Cane Fuzz

Cane seed usually called “fuzz” is very fluffy and delicate. Nature has provided it hair for wide dispersal through air. The fuzz is usually sown as such along with hair; the seed having low viability (Lesser then 30 seedlings per gram) should better be de-fuzzed to avoid thick placement of seed. Thick mat is a barrier in proper contact of roots with growing media, thus tiny plants die due to poor nourishment. Thick mat also encourages development of harmful microorganisms to depress growth. The de-fuzzing practice considerably reduces the volume of seed for sowing, as well as proper storage. While de-fuzzing some seed may be damaged and viability is some what affected. Nevertheless, with proper care taken in de-fuzzing, the injury to de-fuzzed seed is not that significant compared to seeding in a mat (Breaux and Miller, 1987). Cane seed is very delicate and need great care in its sowing, selection of media, temperature and humidity of the environment.

Planting media

The seed is very sensitive to soil salinity. Thus the pH of the planting media should be almost neutral, with pH less than 8 and EC to be less than 1.0. The soil medium should be porous with coarse structure with complete nutrient availability. Friable organic soils can meet these requirements. If such type of soil is not available, desired media should be prepared by mixing loam soil with organic matter compost and some loosening agent.

The author has been planting fuzz on 10”-12” raised beds in well-drained alluvial soil. Bed size of 75 x 50cm is kept according to convenience in handling, sprinkling and furrow irrigation in latter stages. If the soil is not of requisite porosity, top 5cm of bed is dressed with specially prepared media containing loamy field soil + sand + well rotten compost in 2: 2: 1 ratio. The soil and sand is sieved and media is thoroughly mixed. The compost is prepared from berseem, cane trash and farm yard manure in 1: 0.5: 1 ratio, allowed rotting and decomposing for 3-4 months. Biofertilizer prepared from sugarcane press mud and stillage water has also given good results to replace compost.

For sowing fuzz in trays planting media need special attention. In CTC, Brazil, media is prepared from a mixture of filter cake, bagasse and horse dung. The media is fumigated with methyl bromide (Mechado et al, 1987). At Canal Point as well methyl bromide sterilization is mostly adopted (Breux and Miller, 1987). Soil media in flats is sterilized in airtight chambers or under sealed plastic covers, sealed tightly at the ground. The fumigant is used @ 0.68 kg per m² of soil or 0.68 kg of fumigant for each 70 standard size seedling flats (35 x 50 x 10 cm). The fumigation is followed by 4 to 14 days of aeration before sowing. At sugarcane Res. Sta. St. Gabriel, Louisiana, a sterilized mixture of soil + sand +organic matter in 6: 6: 1 ratio is used (Quebedeaux, 1992). The media may also be steam sterilized. Voluminous autoclaves have been designed that sterilize the media along with flats. In India, usual media is horse dung, silt and sand in 3 : 3 : 1 ratio, and the mixture is sterilized in autoclave (Babu, 1990).
Fuzz sowing

Sowing on beds in open field demand very favourable weather with temperature around 30-35° C. Temperature higher than 35° C and dry winds depress germination rate and cause mortality of tiny seedlings. Rapid fluctuation in diurnal temperature and lack of humidity depress growth. Persistently favourable weather is essential for good initial growth. Temperatures lower than 25°C depress growth of seedlings and promote infection by pathogen.

To obtain good germination and healthy initial stand it is preferred to grow seedlings in specially built seedling houses where desired temperature and humidity is maintained. A constant temperature of 30-35°C is the most important single factor for successful germination of fuzz, and humidity of the environment should not drop below 60% (Breux and Miller, 1987). Light is essential for good growth of young seedlings. Any form of shading is undesirable during early growth of seedlings. Even the low light intensity is sometimes limiting due to cloudy weather. In open field conditions, partial shade may be provided to save from scorching heat when temperature exceeds 38°C.

In seedling houses fuzz can be grown in any size of the trays, however 35 x 50 x 10cm is considered the standard size (Breux and Miller, 1987). Flats could be made of wood, metal or plastic. Galvanized metal flat may show zinc toxicity, but problem can be avoided with asphalt varnish coating.

While sowing seed the fuzz should best be treated with fungicides. The author has used Topsin or Benlate (0.2% solution) with best results. The fuzz is wrapped in muslin cloth and dipped in the fungicide solution for two minutes. It is gently squeezed to drain of water and then kept for a while to air dry excessive moisture. It is then evenly spread on sowing beds or flats. It is gently pressed on media, very lightly covered with dusting soil media. Water is sprinkled to drench the surface. The beds or flats should then be covered with polyethylene sheet to keep the environment moist till germination is complete. But if there is risk of rising temperature during sunny days, polyethylene cover should be removed during daytime and fine sprinkling is repeated if felt necessary. Soon after germination the cover is removed to expose seedlings to full light.

Germination

Seed germination starts in about 60-70 hours and normally completes in five days. Growth is very slow in first two weeks and this is the stage that needs utmost care to save the seedlings from pathogen attack and various stresses. Poor drainage most often induces the chances of "Damping off" disease in excess moisture which may kill hundreds and thousands of seedlings all of a sudden. After germination the seedlings should be sprayed with fungicide solution twice a week. As the plants come in three-leaf stage in almost three weeks they are hardy enough to resist the diseases. For proper nourishment the seedlings should be sprayed with NPK or any suitable nutrient media in very light dose, without risk of injury to tiny plants.

Initial growth and vigor of seedlings is greatly affected by seedling population per unit
area. Over-crowding of seedlings results in weak and thin seedlings and increases the probability of mortality from fungal diseases. A seedling density of 300-800 per standard size flat is usually maintained (Breux and Miller, 1987). The seed quantity per tray or per bed may be worked out through germination test of fuzz in laboratory.

Diseases of seedlings

Seedlings are vulnerable to pathogen attack soon after germination. Dense populations of seedlings have more chance of attack than a sparse population. Pathogen species mostly reported to attack at very young age are 'alternaria', helminthosporium, pythium, rhizoctonia and drechslera. The author has observed effective control of seedling disease by spray of Benlate or Topsin in 1:3000 solutions. Finaminosulf @ 500 ppm has also been reported to be used alone or mixed with carboxin @ 15 ppm for control of pithium (Breux and Miller, 1987). Spray of “MEME” at planting has shown effective control of seedling blight by Drechslera Sp. Seedling mortality by damping off can also be controlled by spray application of a mixture of vitavax @15 ppm and Dexon @ 30 ppm (Agnihotri et al, 1976)

Seedling diseases occur suddenly and cause serious damage even during fungicide application. The best way is prevention than cure. The media should be sterilized, over crowding should be avoided, drainage should be ensured and water not to stay any moment and fungicide spray be applied as routine on proper schedule, before any disease symptoms appear. In case of attack the affected plants should be rouged out and infested pots/ trays are placed aside.

Transplanting

Transplanting methods vary at different breeding stations, depending upon the climate, mechanism involved and the seedling population. After raising the seedlings in beds or trays, these may be transplanted directly in the field, when fully established, or may be transplanted in phases. In a heterogeneous population, each individual seedling is an
independent genotype entity and must be given uniform environment to avoid unnatural competition. Therefore transplanting in phases is preferred, where the seedlings are singled out in pots.

**Single out**

In 5-6 weeks, seedlings are at 4-6-leaf stage, 5-7 cm in growth size and can be singled out. Plants in flats/beds are densely populated and compete with each other for growth. If not singled out weeklings are eliminated for want of light and space and only stout plants predominate. To give equal chance for light and nutrients the plants are singled out. Different procedures have been adopted at various research stations. In Louisiana, plants are singled out at 5cm distance in specially prepared plastic strays. When fully established these trays are loaded on especially designed rakes and seedlings are mechanically transplanted in the field. In Mauritius seedlings are singled out in RCC block containing 8 or 12 hollow spaces of 10 x 20cm each per seedling. The author has adopted the system of transplanting in 10 x 10cm earthen pots or 10 x 20cm polythene bags filled with suitable planting media. Earthen pots give high percentage of survival and can be re-used. Black plastic parts are also used at some stations. Seedlings are well established in pots, in about a month before transplanting in field.

Before transplanting the leaves above crown spindle should be trimmed off to cut down transpiring surface. Soon after transplanting, pots should be kept in cool and humid place under shade or in a green house, till fully established. Exposure to bright sun and hot winds may depress growth or reduce survival rate. The plants should be provided full sunlight, soon after they recover from shock of transplanting.

**Field nursery**

The best period for transplanting seedlings in field, in Pakistan conditions, is September-October or February-Mid March. Before transplanting the leaves above crown should be trimmed off. Seedlings are transplanting at 120 x 120cm or 150 x 60cm from row to plant distance. At SRS, Baton Rouge, Louisiana, the row to plant space is maintained at 180 x 40cm (Dunkelman and Legendre, 1982). A standard commercial variety is also planted as
check for every 15 or 20 seedlings. Soon after transplanting the seedlings have to be irrigated. The seedling clones, as established, grow fast, produce tillers as per capacity of the clone and complete cane formation till June.

Selection of Clones and Varieties

Selection criteria

Sugarcane is heterozygous in nature and because of recombination of various characters, desirable or undesirable in the seed; the seedlings obtained are mostly unlike their parents. For a variety to be of value, it must have a pre-dominance of desirable traits combined in satisfactory manner. But due to large chromosomal combinations the chance of obtaining such an elite clone is one out of thousands. Therefore, seedlings have to be grown in a large number, so that the law of chance could select a few elite clones.

High yielding seedlings appear as chance segregates and their superiority is due in large measure to heterosis. It has been observed that some times best parents are varieties, which would themselves, never succeed in cultivation. Heterotic effect accounting for excellence of commercial varieties are not due solely to simple dominance, but to a particular gene balance in the process of chromosome recombination in sexual reproduction. Favorable combination may appear or may be lost in chromosome segregation. Selection of parental combination is highly important for transmitting desired traits in progeny lines. Desirable phenotypes are very rare indeed and have to be closely searched from a seedling population. Effect of genotype x environment interaction on the selection of phenotype in given environment has to be thoroughly studied.

Selection Program

Single Plant Selection

The size of the seedling population and the number of first clonal selection that can be handled commonly judge a selection programme. Seedling selection rate varies at different stations depending on the germplasm.

The seedling population of a parent / cross shows a large variation from plant to plant and need a critic eye and sense of judgement for selection of an elite clone. Selection of plant based on some quantitative and qualitative characters is made through phenotypic expression in a given environment. The growth, tillering, stooling, cane height, girth, inter-node pattern, erect-ness, toughness Vs brittleness, pithiness and diseases and pests infestation are the main characters under study. Data of required characters are recorded on grade (0-9) basis. The brix taken by hand refractometer is the main criteria of quality evaluation at this stage. The selected clones should be superior to or equal to the standard variety. The selected clones should not fall too far below the standard variety.

In economic crop production varieties must have good ratooning potential. In most of the cane breeding stations first plant crop of field nursery is harvested without selection and clones are kept ratoon. First clonal selection is made in ratoon crop and it helps to evaluate seedling clones with additional character of ratooning. At single plant stage 10-20% of seedlings are selected by rejection of absolutely useless material. The selected clones are evaluated in a series of selection stages till the variety is awarded with number for commercial propagation.
Assigning seedling number

The selected seedling clones are assigned serial number starting from one ‘1’ each year. The ‘Number’ carries the origin of the parents along with the prefix of the year. As for example, CPD 2001-1; CP denotes fuzz parent from Canal Point, 1 means seedling number during 2001, and ‘D’ indicates the name of station where the seedlings are selected which is Dewan Farooque Sugarcane Research Institute, in this case, and so on. Parentage of parents involved in the cross of clone is recorded. This number persists in various selection stages till it fortunately reaches the stage when the variety number is finally assigned to the clone.

Subsequent selection

Stage –I

Selected seedling clones are planted in single rows of 5 meters. In single line Nursery the material may be as large as 2000 or even more. For handling a large number, row length may be reduced. Efforts have to be made to provide uniformly fertile soil and equal inputs to the entire field. A standard variety is planted after 15 to 20 clones to differentiate the environmental variations in the same field. It also helps in statistical analysis of the data. Observations are recorded on phenotypic expression of visible characters of growth, stooling habit, mill-able canes, girth, erect-ness, pithiness, foliage habit, diseases and pests; characters are mainly graded. Brix reading of clones give the quality comparison with the standard variety. Screening is designed to select superior clones to improve average value of whole population and at the same time avoiding the planting of too many poor varieties in next stage. Usually 10-20% of clones are selected.

Stage –II

The clones selected from stage-I, are planted in 2 rows x 5m long. This stage includes one or two standard varieties replicated at uniform intervals. Observations are made on desired quantitative and qualitative characters. The weights of mill-able canes are recorded to estimate per cane weight of each clone.

Stage –III

The clones selected from stage-II are planted in plot size of 3 rows x 8m long with two replications. Selection is made on desired characters including cane yield and laboratory analysis of cane juice for the first time.

Stage –IV

At this stage the varieties have to be finally evaluated for preliminary out field tests at grower’s field. The plot size is increased to 4 rows x 10 meters length. The numbers of varieties included in the trial are reduced and are planted in appropriate statistical design, simple Randomized Complete Block Design (RCBD) or Latin Square. Data on one plant and one ratoon is recorded for various quantitative and qualitative characters with detailed cane juice analysis. The varieties are also subject to replicated disease nursery for inoculated disease evaluation. Seed of promising varieties is also increased for next-year out field zonal testing with growers.
Disease Nursery

Varieties are planted in replicated trial with plot size of 2 rows of 5 meters length. Separate trials are carried out for smut, red rot, and most susceptible variety is kept as standard for comparison. While planting the sets are dipped in spore suspension of disease. For red rot, the disease debris is also applied in furrows. At later stages cane stalks are also inoculated with pathogen spores through plug method and observations are recorded.

Stage-V

The stage follows the same experimental design with testing varieties at ten to fifteen locations in different ecological zones. Varieties selected from stage IV are planted at the research station as final variety trial and the trials repeated at grower’s field as out field trials.

Out Field Trials

Genetic performance of varieties has to be evaluated in different environments of climate and soils. A variety to be stable for a number of years must be exposed to varying environments for which it is expected to be released. It is the genetic x environment interaction that ascertains the suitability of a variety for a particular region. Replicated variety trials are conducted keeping two or more local commercial varieties as standard. The trails help evaluate the variety performance in different soil and climatic conditions, as well as give feedback about their adaptability with the growers conditions. Data on one plant and one ratoon are recorded. The adapted varieties are finally selected and assigned varieties number.

Assignment of variety number

It is the serial number of the varieties finally selected at this particular station, with prefix of research station brief, and the year of selection. The variety number also denotes the origin of the seed/ fuzz as for e. g BF 90-162 where ‘B’ stands for Barbados (origin), ‘F’ for Faisalabad (the research station) and ‘162’ is the serial number of variety finally selected so far. If some exotic variety has been acclimatized and finally selected, as a matter of principle, its number or name is not changed and is released as such.

Stage –VI

The most promising varieties confirming their adaptability with data on diseases and pests tolerance are put to national uniform variety trial (NUVT). The trial includes the varieties from different research stations in the country. The same set of varieties is repeated at all the research stations with the same statistical design and layout with uniform input conditions. As the crop matures the team of experts visits the experiments at all locations and gives remarks on the performance of the varieties in different conditions.

Variety Selection Program in Different Countries

After the stage of raising seedlings from cane fuzz, the clones pass through various
selection stages from single stool to non replicated small and large rows, replicated preliminary and final trials, disease nurseries and finally out field trails in growers field. During each stage of selection the varieties are evaluated for various quantitative and qualitative characters and data are recorded and preserved in computers. Data are also invariably recorded for ratoon crop in different trials. The procedure followed is almost the same in various breeding stations, with the difference of plot size or the number of years the variety is evaluated in a single trial or replicated trials. The sugarcane variety selection system followed in Mauritius and Louisiana is given in Table-4.07 and Table-4.08. The sugarcane selection schemes followed in some leading cane breeding stations are reproduced in Table-4.06. The data in Table-4.06 further indicates that it takes 8 to 18 years for testing varieties before release for commercial cultivation in different countries. Breeding stations in some countries give more emphasis on ratooning and studies on genetic x environment inter-action. To stabilize the characters the information is collected on the effect of favorable and unfavorable environments in the same location as well as different locations. In case the selection cycle is cut short it may increase the chance of variety decline in fields in short span.

Inheritance of Sugarcane

Owing to the high polyploid number and hetraploid chromosome constitution of most varieties inheritance in sugarcane do not follow simple Mendalian laws on crossing. Most of the economically important characters like growth habit, yield, juice quality and drought resistance are quantitative in nature, being controlled by multiple genes or polygenes. Where the number of polygenes involved is large it is difficult to distinguish the variation caused by the effect of genotype or caused by environment alone. Linkage also comes in the way of obtaining a combination of desirable genes with the corresponding elimination of undesirable genes. However, polygene inheritance of important quantitative characters may permit the transgressive segregation as a result of which the progeny clones may be superior to both the parents especially in the yield of cane and sugar. Values of heritability have been worked out for several characters and genotype environmental interactions have been largely studied. Indications of maternal and paternal influence in the transmission of some characters have also been reported.

Field nursery

The best period for transplanting seedlings in field, in Pakistan conditions, is September-October or February-Mid March. Before transplanting the leaves above crown should be trimmed off. Seedlings are transplanting at 120 x 120cm or 150 x 60cm from row to plant distance. At SRS, Baton Rouge, Louisiana, the row to plant space is maintained at 180 x 40cm (Dunkelman and Legendre, 1982). A standard commercial variety is also planted as check for every 15 or 20 seedlings. Soon after transplanting the seedlings have to be irrigated. The seedling clones, as established, grow fast, produce tillers as per capacity of the clone and complete cane formation till June.
Table 4.07 Sugarcane variety selection system in Mauritius Sugar Industry Research Institute, Mauritius.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Number of new varieties</th>
<th>Plot size</th>
<th>Harvest data and selection criteria</th>
<th>Disease and pests screening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedlings</td>
<td>100,000</td>
<td>-</td>
<td>Over all vigour visual selection</td>
<td>-</td>
</tr>
<tr>
<td>Clonal nursery single clone</td>
<td>15,000</td>
<td>3 m x 1 row P</td>
<td>Vigour Agri. characters Brix</td>
<td>Visual observation of diseases &amp; pests</td>
</tr>
<tr>
<td>Single line Nursery</td>
<td>3,750</td>
<td>5 m x 1 row P</td>
<td>Agronomic trails, Brix, cane yield, Brix yield</td>
<td>Visual observation of diseases &amp; pests</td>
</tr>
<tr>
<td>Group trial</td>
<td>750</td>
<td>5 m x 2 rows P + 1R. 3 locations Rep. 3 x 3, 4 x 4, 5 x 5</td>
<td>Agronomic trails, Brix, cane yield, Brix yield</td>
<td>Diseases &amp; pests</td>
</tr>
<tr>
<td>variety trials</td>
<td>40</td>
<td>10 cm x 4 rows P + 1,2,3 R 4 locations RCBD</td>
<td>Agronomic trials, cane yield, sugar contents, sugar yield</td>
<td>Studies on diseases tolerance</td>
</tr>
<tr>
<td>variety trials</td>
<td>20</td>
<td>10 cm x 4 rows P + 1,2,3 R 4 locations RCBD</td>
<td>Agronomic trails, Brix, cane yield, sugar contents, sugar yield + profitability</td>
<td>Studies on diseases tolerance</td>
</tr>
<tr>
<td>Out field trials</td>
<td>4 - 5</td>
<td>10 cm x 6 rows P + 1,2,3,4 R 12 locations RCBD</td>
<td>Agronomic trails, Brix, cane yield, sugar contents, sugar yield + profitability</td>
<td>-</td>
</tr>
<tr>
<td>Selection cycle</td>
<td>Commercia l variety release</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Malik, 1998
Table 4.08 Sugarcane variety selection programme at USDA-Agric. Res. Station, Houma, Louisiana

<table>
<thead>
<tr>
<th>Stage</th>
<th>Number of new varieties</th>
<th>Plot size</th>
<th>Stalks per variety for analysis</th>
<th>Harvest data and selection criteria</th>
<th>Disease and pests screening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seedlings 1st year</td>
<td>200,000 to 400,000</td>
<td>-</td>
<td>-</td>
<td>Over all vigor</td>
<td>Visual only</td>
</tr>
<tr>
<td>Seedlings 2nd year</td>
<td>100,000</td>
<td>Single plant 16” x 1 row 1 R.</td>
<td>5 (for seed)</td>
<td>Observation in 1st ratoon growth, vigour, erectness, absence of pithiness, plant density, Brix, natural freedom from diseases &amp; pests</td>
<td>Visual natural freedom from diseases &amp; pests</td>
</tr>
<tr>
<td>First clonal trial 3rd year</td>
<td>6,000 to 8,000</td>
<td>6’ x 1 row P + 1 R</td>
<td>10 (analysis sucrose)</td>
<td>Same as stage III plus sucrose analysis &amp; estimated yield of cane &amp; sucrose unit area</td>
<td>Ratings of major diseases/pests taken &amp; noted in field book</td>
</tr>
<tr>
<td>2nd clonal trial 4th year</td>
<td>1,000</td>
<td>16 ft x 2 rows P + 1st R.</td>
<td>15 (sucrose analysis)</td>
<td>same as stage IV</td>
<td>Same as stage IV plus single plot (16 ft) dip inco. Smut trial + borer trial</td>
</tr>
<tr>
<td>Replicated nursery 6th year</td>
<td>100</td>
<td>16 ft x 2 rows 2 Rep. P + 1st &amp; 2nd R. 2 Locations</td>
<td>15 (sucrose analysis) entire plot for yield analysis</td>
<td>Plots mechanically harvested for yield estimates milling quality, cold tolerance, maturity testing</td>
<td>Same as stage IV plus 2-Rep. smut trial &amp; mosaic spread test 2 Reps. For borer trial</td>
</tr>
<tr>
<td>In field testing 7th year</td>
<td>40</td>
<td>16 ft x 3 rows 2 Rep. P + 1st &amp; 2nd R. 2 location</td>
<td>15 (sucrose analysis) entire plot for yield analysis</td>
<td>Same as stage V but multi location average yield estimates</td>
<td>Multi-location disease ratings survey of borer damage</td>
</tr>
<tr>
<td>Out field testing 10 to 15</td>
<td>32 ft x 3 rows 3 Rep. 1P + 3 R</td>
<td>Same as in stage VI</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Selection cycle</td>
<td>13 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Malik, 1990
**Variety Selection for Specific Characters**

Cane varieties have a leading role in enhancing sugar yields per unit area. A review of the Canal Point Sugarcane Breeding programme spanning a period of 33 years (1968 – 2000) reveals that 69% of the total gains in sugar yield was attributed to breeding varieties with high cane yield and rich in sucrose contents (Edme et al, 2005). The cane fuzz is to be produced from preplanned crosses for required objectives and ecological conditions. The breeder has to visualize the phenotypic expression of transmission of characters in a seedling population in a given environment. Heterozygosis with a large number of chromosomes has made genetic make up of the plant very complex and gene re-combinations are so numerous that chances of sorting better than standard are quite a few. Gene for one character may be linked with other gene on a locus. It has been established that to develop an elite clone for one character, say sucrose, the chance of selection is 1: 360,000 (Stevenson, 1955). The breeder should have a clear-cut objective in view while selecting progeny.

**Cane yield**

Higher sugar yield per unit area is the ultimate aim of all cane-breeding programs and for this cane yield and sucrose contents are the most important component. Number of stalks per unit area and weight per cane are two main components of yield. Stalk population is governed by germination capacity and tillering, while stalk weight by its thickness and height and these are hereditary characters. Cane yield is a polygenic character; multiple genes are involved controlling cane height, thickness, tillering, germination and internodes pattern. By and large plant characters like root system, leaf growth, vigor, lodging etc all in one form or the other affect yield.

The primary selection is always based on vigorous growth and high tillering capacity of plant. In the initial selection stage of seedlings cane yield is correlated with some yield contributing factors like growth, vigor, leaf area, tillering, cane thickness and cane height. The stalk number and thickness are more associated with cane yield than other characters (Mariotti, 1972 and Khairwal and Babu, 1976). In single line Nursery, individual cane weight, cane thickness and number of canes per stool may help estimate cane yield. In later stage yield is precisely determined from cane weight recorded from replicated plots. Selection for specific objectives of tolerance to adverse soil, drought and lodging has to be done in later selection stages. In earlier studies by Barber (1916) some plant parts were correlated with cane yield and are reproduced as under.

- Stalk thickness positively correlated with cane weight and negatively correlated with tillering.
- Leaf width positively correlated with stalk girth and cane weight and negatively corrected with tillering and sucrose in juice.
- Leaf length negatively correlated with sucrose in juice.

In the present day selection program followed at research stations, good numbers of millable canes with good ratoon-ability are the main criteria of primary selection. Yield of cane is also influenced by fertilization, resistance to climatic adversities,
resistance to pests and diseases. Generally primary selection should be done in good soils at high level of fertilization and soil moisture; varieties showing efficient utilization of water and fertilizer be selected. The clones that show fast growth in initial stage of plant development, crop should stand without lodging and respond favorably to cultural conditions and mechanization should be selected.

**Cane juice quality**

The genes responsible for sucrose are inherited from S.officinarum. In the early history of cane variety development sucrose contents in cane have been improved by recurring selection and back crossing with high sugar varieties. Even now, to develop high sugar varieties, parental lines for crosses are chosen that transmit quality characters to progeny clones. Through recurring selection donor parents are selected that have more chances of transfer of quality traits to the seedling population. Recurring selection helped develop parent stocks showing Brix value rang of 23.2 to 24.9 % in Barbados (Kennedy, 1997). Progress has been made still further, selecting parental lines having juice Brix of 30.1 %, sucrose contents of over 25 % and juice purity of over 90 % (Horn and Ram, 2004).

Sucrose content in cane is a quantitative character and is polygenic in inheritance. Several characters are related to juice quality in cane. Variation having good mill-ability and high sugar contents are preferred. The characters desirable for good mill-ability are moderate hardiness of rind, good fibre length, longer inter nodes and low fibre-sucrose ratio. High sucrose and purity are desirable with low milling losses.

The variety to possess high quality juice should have high sucrose, high purity, low reducing sugar and low starch, gums and amino acids. The presence of higher non-sugar compounds pose problems with the clarification process. Attention should be paid to fiber contents and juice extraction of cane. A 12% fibre is ideal for better sugar yields. Low fibre makes the cane too soft and has adverse effect on crushing, while higher fibre extracts low juice. However, higher fibre in canes withstands the crop from lodging and plants also resist the attack of borers. However, a balance in cane quality and morphological characters of cane has to be maintained.

Juice quality is essentially a relative character; where expression is controlled by a strong and very evident variety x environments interaction. Other factors affecting the variety differences on juice quality are time of maturity, nutrient status of soil and plant, soil and plant moisture content, date of planting etc. Even where favorable genes are present, good juice quality will not develop in the absence of appropriate growth and ripening conditions. Differences in varieties are more pronounced in early season, therefore variety selection for this character should best be made early in the season.

There is no morphological character correlated with richness of juice and there is no definite association between cane quality and cane weight, thickness, tillering and erectness. Progeny tests have to be employed to evaluate their parents as a source of high sucrose transmitter genes. Use of high sucrose noble varieties as male parents has often given good results.

In earlier selection in seedlings and may be in single line Nursery, where clonal population is high, single stool Brix content is reasonably dependable criterion for juice quality. In late stages of selection, however, complete laboratory analysis may be
followed to reach at a cane quality.

**Disease resistance**

The yield and quality losses due to diseases amount to millions in a crop year. Losses due to some diseases are quite visible like red rot, while some diseases do not depict clear symptoms but are of great economic significance, like RSD. The occurrence of losses due to diseases can be minimized by a number of variety development strategies.

(a) Cultivation of disease resistant varieties.

(b) Cultivation of disease tolerant varieties. These varieties are known to yield economic returns even though are infected with the disease to some degree. However, the variety should always be kept under strict observation that the disease effect is not overlooked for a long time. If crop remain unchecked the infection level may be increased to threaten the crop economy, or may become a source of infection for other tolerant varieties. Change in a race of pathogen may develop disease susceptible strains to cause severe losses in time to come.

(c) Cultivation of susceptible varieties in climatic regions, where chances of disease spread is minimal. Pathogen alters disease expression due to radical changes in climate and cultural practices. In Pakistan L 116, susceptible to red rot remained a major quality cane of southern Punjab and upper Sindh, for almost two decades. Similarly the variety BF 162 highly susceptible to rust and moderately susceptible to red rot has been a leading variety of southern Punjab, covering almost 75% area of cane. Sugar mills growing this variety had exceptionally the highest recoveries in the province (Malik, 2000). Production potential of this variety is risky in lower Sindh and northern Punjab due to conditions required for rust proliferation.

Adjustments in planting time i.e. shifting in planting from autumn to spring also evade the incidence of disease spread due to non-prolific weather in later case. Thus lifecycle of pathogen and environment interaction are of great consideration both by breeders and pathologists. However, sudden changes in weather and environment may increase the chance of disease spread. It is always safe to avoid the spread of such variety as a major variety in risky environments.

(d) Cultivation of varieties where disease can be kept under control by chemical, biological and mechanical means. Some diseases can be safely controlled by heat therapy and chemical treatments and by following proper crop rotation. Hot water treatment and farm hygiene’s are most effective tools to control RSD (Leverington, 1987).

Out of the aforementioned disease control strategies, the most economic method is to release disease resistance varieties. Cane breeding has a dominant role for developing suitable crosses and screening and selection of resistant clones. But resistance must not be achieved at the cost of yield. Therefore attention has to be focused on the introduction of parents contributing genes for resistance/ tolerance. Before working on disease resistance information should be made available on area under susceptible varieties, degree of disease infestation in the area, expected potential losses to be occurred and the
available stock of resistant strains with research station. Information on extent of inheritance of the disease helps selecting suitable parental lines. Experience with diverse diseases has shown that crosses of resistant parents tend to have more resistant offspring’s than crosses of susceptible parents (Benda, 1987). Inheritance for resistance to one disease is independent of the resistance to the other disease, and the inheritance of resistance appears to be independent of the inheritance of the components of yield (Breaux and Fanguy, 1985; Wu, Heinz and Mayer, 1983). Frequency of resistant clones in progeny of crosses determines the effective parental combination.

Types of disease resistance

In sugarcane two types of resistance may be recognized:

**Physiological resistance:** Where living cells suppresses or prevents the development of pathogen.

**Morphological resistance:** Where the structure of tissue is such that the development of pathogen is prevented or retarded mechanically.

Former is more important and is attributed to the presence of phenolic compounds in resistant varieties. In morphological resistance the number of vascular bundles, which are continuous through the node, is less. Though such varieties may be susceptible, the attack of pathogen is confined to the initially infected inter nodes. The disease may not seriously injure the varieties that have high degree of physiological resistance, though they possess a large number of continuous vessels. Thickness of epidermis cuticle and rind may also confer to resistance to the entry of pathogens. However, there is no apparent association between the degree of susceptibility to mosaic and morphological character of cane. A few genes contribute the resistance to mosaic; resistance is dominant and is transmissible from parent to progeny.

Pest resistance

Many plant characters have been associated with resistance to pests especially borers. They ate, for example, leaf surface, width and erectness of leaves, leaf hardiness, mid rib, dry matter in the leaf spindle, length, of leaf spindle, rind hardiness, wax coating of stalk, colour of stalk, leaf sheath-tight or loose, fiber content, plant height, stalk diameter, amount of pith and juice quality. Varieties having hair on leaf sheath and high fibre contents show varying degree of tolerance to pests. Resistance may result from unattractiveness of leaf for egg deposition, inability of young larvae to become established, high fibre, which hinders feeding of borers. Pest tolerance and ability to produce good yield in spite of pest infestation are favourable characters.

Cane varieties in various selection stages are evaluated against pest infestation under natural field condition. Varieties susceptible or resistant to various pests are graded in 0 – 9 rating in earlier stages of selection. In advance selection stages data on actual pest attack and their effect on yield and quality are recorded.

Lodging resistance

Lodging can damage the full-grown crop, provide favourable environments to development of diseases and pests and deteriorate the juice quality. For better yield and
recovery good sugar varieties should withstand lodging under high fertility and optimum moisture level. Varieties having high fibre contents and vigorous root system resist lodging. Varieties may be selected which do not show much yield and recovery losses even on lodging. Lodging tendency may be noted whether cane is trailing, just bending down or up rooting on lodging. Seedling clones are selected which have erect habit of growth. Cane shoots of some clones are spreading in initial growth stages, but erect later on. The erect growth pattern in the very initial stages is preferred.

**Resistance to frost and drought**

Wild canes of *S. spontaneum* and indigenous varieties of *S. barbieri* and *S. sinense* show tolerance to cold and occasional frost. Combining these characters in *S. officinarum* has given good result.

**Resistance to water logging**

Certain clones of *S. spontaneum* are able to withstand water logging for long periods. Such clones may be successful as parents for inducing this character in commercial varieties. Tolerances to water logging are characterized by production of large matrix of fibrous roots extending from base of stem to the surface of water.

**Varieties for mechanical harvesting of cane**

Mechanization in cane culture demand specific varieties, which allow the effective working operation of machinery in the field without damage of cane stalks. For evolving such varieties the following characters have to be incorporated in breeding program.

- Varieties having thick erect cane and tolerant to lodging
- Self-striping habit having low trash to cane ratio
- Uniform growth and cane height
- Stout stalks without brittleness

**Varieties for problem soils**

Cane productivity is increased by improving physical properties of soil and meeting its fertilizer demand, but sometimes it is not economical to ameliorate many problem soils. Solution to this problem lies in the evolution of varieties that sustain sugar yield level under problem soils. Day by day increasing population pressure on soils has tempted the growers to bring marginal areas under cultivation, which result in drop in average yields. The crop productivity can be sustained on a reasonable level by bringing genetic improvement.

The soil problems mostly encountered in crop productivity are:

**Saline sodic soils**

Cane varieties react differently to saline conditions. Some mineral deficiency occurs in saline soil and varieties show different response to deficiency levels. Suitable varieties can be selected that sustain growth and yield at varying salinity levels.
**Water logging**

There is great variation in tolerance to water logging in the Saccharum complex and also among commercial varieties (Roach and Mullins, 1985; Yang and Chen, 1980).

**Sandy soil**

In Sandy soils plants grow rapidly until the freely available water is depleted and subsequently water deficit leads to severe stress, resulting into the death of poorly adapted cultivars. Stress tolerant varieties are able to grow rapidly during the period of abundant water supply and still, survive the ensuing period of stress, if it occurs.

Stress tolerance refers to the ability of sugarcane clones to survive and grow productively in a moisture stress. The feature of stress can be categorized as stress avoidance and stress tolerance (Moore, 1987). The stress avoidance is due to morphological modification in plants like small sized leaves, extensive root system, cuticular wax or thick epidermis. The stress tolerance occurs when plants are able to prevent or decrease the injuries caused by stress. Usually stress avoiding but tolerant plants are generally lower yielder under optimum conditions (Moore, 1998). Stress tolerance is a complex phenomenon governed by a number of biotic (pathogen, weeds, insect pests etc) and physio-chemical (temperature, moisture, chemical, mechanical) factors.

Good productivity, under stress conditions, can be achieved either by improving cultural practices to evade the effect of stress or by developing varieties resistant to stress. Though rapid yield increase can be obtained by the former method, but input resources may not be assured all the times. For long term measures it is always economical to rely on better genotypes. For that purpose characters specific to resistance should be ascertained in a variety. Adaptable varieties showing avoidance/ tolerance to stress should be earmarked and then used in cross breeding for manipulating genes to transfer of specific character. Stress avoidance traits more likely result in reduced yield potentials than the escape or tolerance traits (Moore, 1998). Avoidance traits allow the surviving cells to remain in the un-stressed state by reducing the area exposed to the stress. Which in turn can lead to reduced photosynthesis resulting in low yields? Escape mechanism keeps the surviving cells in the unstressed state by allowing the plants to complete its life cycle before the onset of stress. For instance early maturing varieties can give better sugar yield before the onset of cold stress. In tolerance mechanism cells remain alive and productive while being exposed to the stress and potential yield loss is low (levitt, 1980 and turner, 1979).

**Bio-technology for Sugarcane Improvement**

Genetics and breeding has been a basic tool for improvement in sugarcane plant. In the past century, tremendous improvement in yield and quality has been noticed. Besides much potential yet left in traditional breeding and selection methods, the point seem to have reached to somewhat static or sustainable yield. The slow progress in the near past further questions the scope of genetic transformation. Genetically, sugarcane faces complex problems in conventional breeding due to a large chromosome numbers, polyploidy and linkages. Quantitative characters are mostly controlled by many genes and that linkages pose problems in inheritance. Desired combinations of characters are
not always possible and it takes years to induce desired traits and exploit variation in millions of seedlings. Increasing population pressures with increasing production cost demand some spectacular improvements to develop superior genotypes without much loss of time. In this context biotechnology has appeared as the most productive seen of 21st century. Application of tissue culture technology at collulose level and molecular biology at the gene level has provided new opportunities for producing superior genotypes in crop plants. Genetic engineering has opened the scope to transfer the properties of single gene from one organism to the other. It is even possible to synthesize genes producing desired character. Biotechnology has two fields including the simple use of tissue culture and sophisticated approach of genetic engineering/molecular biology.

Tissue Culture

It is a novel technology for micro-propagation of existing varieties as well as to create improvement in existing varieties. Micro-propagation of existing varieties is the most popular and widely adopted technology. Through this technique disease free varieties can be propagated throughout the year, while variety improvement is done through inducing somaclonal variation, somatic embryogenesis and haploid production.

The plantlets are developed from callus of plant tissues or individual plant cells. The callus is an unorganized mass of plant cells developed as a result of cell division over the surface of cut end of explant. The callus can be initiated from almost any sugarcane tissue e.g shoot and root apical meristems, young leaves, root band, young node, rachis of immature inflorescence and pith parenchyma (Liu, 1981). Callus lack morphological differentiation. The shoot and roots are then differentiated to plantlets in specific nutrients and other substances under suitable growing conditions. Success of tissue culture depends on aseptic condition of the environment, type of explant selection and use of specific media for callus formation and plant and root differentiation.

Comprehensive studies on tissue culture have been made in Pakistan. The apical meristem and dormant buds are mostly used in tissue culture technique in sugarcane crop (Sarwar, 1984). Being covered by leaf sheath bud scales are usually free of infection. As such short tip culture can successfully be applied for elimination of seed born diseases. The technique is extensively utilized for micro-propagation of healthy seed. The callus culture technology helped in eradication of mosaic virus in cane varieties Col 54, L 116 and BL 4 (Mirza and Shaheen, 1987). It is reported that propagation of disease free healthy seed increased yield and quality of cane (Siddique, 2000). Meristem tip culture alone is quite efficient in cleaning mosaic, smut and RSD from affected plants. By this method about 400,000 healthy seedlings can be produced in 6 months (Naik, 2001).

Micro-propagation:

It is true to type propagation of selected genotype using in vitro culture technique. Shoot tips of healthy plant are taken; sterilized and outer whorls are removed and inoculated in basal medium. After 45 – 50 days of growth, shoots are transferred to the modified MS medium benzyl amino purine to produce axillary shoot. It is the sub-cultured and transferred to rooting medium (Jalaja, 2000).

Micro-propagation plants are healthy, disease tolerant and are high yielding (Santana, 1991; Ziminez et al, 1991). Temporary immersion bioreactor has been developed that
facilitates, higher shoot formation at low cost (Rodriguez et al, 2003). This technique increased shoot multiplication to 1: 100 in 45 days.

Meristem culture technique for micro-propagation is also helpful in producing plantlets free of sugarcane mosaic virus.

**Genetic variability through tissue culture**

This is a modern branch of science where in living cells are modified in vitro (laboratory) condition to create variability beyond sexual limits. In sugarcane work was initiated by Heinz and Mee (1969), who demonstrated that plantlets could be developed from tissue on a defined medium in glass tubes. Originally technique was utilized to propagate thousands and millions of plants, having similar characters in a short time. With advancement in technology new strains are now developed which are often genetically and morphologically different from donor plants (Heinz, 1987). Reports on systematic breeding efforts on tissue culture are available from USA (Heinz, 1987), Taiwan (Liu, 1981, 1890) and India (Sreenivason and Jalaja, 1983, Prasad et al, 1987). The biotechnology includes tissue culture, haploids, protoplasts, DNA restriction enzyme fragment polymorphism, and gene splicing and monoclonal anti bodies (Heinz 1987).

**Direct regeneration**

It is the regeneration without the involvement of an intermediate callus phase and plants regenerated are genetically identical to the parent plant. Direct shoot and root formation takes place directly from leaf explant without callus intervention (Jawahrial et al, 1994). Another system of smart sett technology is developed at BSES, Brisbane, where in pieces of leaf tissues are prepared and placed in plant growth regulator media that results in the small plants regenerating directly from the surface of the leaf material (Lakshmanan et al, 1999). In this process seedlings are ready for planting in 12 – 14 weeks (Jason et al, 2003). The process is fast, takes short time in culture and sub-culture and has high multiplication rate with very low somaclonal variation.

**Somaclonal Variation**

Callus induction and subsequent shoot differentiations was first reported by Heinz and Mee (1968). The initial site of callus cells in young leaf and sub-apical meristem explants was identified by Liu et al, (1982) and developed several high yielding and high sucrose callus derived plants. Callus culture can help to rectify specific defects of widely adapted varieties. Very high yielding variety rejected due to specific defect can be improved by correcting defect through callus culture without disturbing the genetic balance of a genotype. Somaclonal variation noticed in the callus derived plants of sugarcane varieties was utilized to develop smut resistance plants without adversely affecting other desirable traits. Through this technique some varieties were developed which were of great economic significance with respect to rust tolerance (Peros et al, 1994), red rot resistance (Singh et al, 2000) and salt tolerance (Khan et al, 2004).

**Cell Culture**

It is a subsidiary branch of tissue culture. Single cells for culture are isolated from callus or mesophyll. The cells are usually obtained by placing a piece of callus into a liquid medium and shaking with orbital shaker until the media become cloudy with suspended
cells. The cells are then isolated and grown in liquid media. The cells from mesophyll are isolated enzymatically or by grinding. The method for plant regeneration from embryogenic cell suspension and protoplasts was standardized on CoL 54 at Faisalabad (Aftab et al, 1996; Aftab and Iqbal, 1999). The production of synthetic seed by encapsulating either somatic embryo or vegetative parts like shoot tips has received great attention. A method for regeneration of sugarcane from encapsulated somatic embryo has been described by Naik (2001).

Liu (1990) induced mutation by adding colchicine in cell suspension culture. The mutants selected through somaclonal variation showed improvement in stalk density; stalk height and sucrose contents, over its donor parent. The mutant TCS-3070 showed an increase in yield of cane and sugar by 8% and 13% respectively over the donor variety F160. Some plants from tissue culture were resistant to Fiji disease. Cell culture in coupling with the application of mutagens produced plants, which were tolerant to salts and resistant to herbicide toxicity. A nitrate reductase deficient (NRD) cell line and plants were produced which show lesser requirements for N source.

**Protoplasts**

Protoplasts in culture solution can regenerate cell walls and divide into cell clumps. Under appropriate condition they can fuse and combine. They can take up microorganism and organelles as well as foreign generic material like DNA into genes. This protoplasm fusion technique helps in incorporating the genetic material and provides the means of bringing characters of two species together, which are otherwise incapable (Liu, 1981). It is a very valuable tool to transfer genes from one-species/cultivars to the other.

Improvement in sugarcane is made by wide hybridization among different species; crosses among species like Rinition arindonaceum, Sacharum narenga and Sclerastachya fusca have the subject of interest to cane breeders. But most often crosses among these species show problems of sexual incompatibility and sterility of hybrids. To overcome this difficulty somatic hybridization could be accomplished by fusing together protoplasts of donor plants (Sinae, 1992). Thus genes from different species could be introduced to develop new varieties with desirable traits.

Associative N fixation (Rhizocoenosis) is assuming great importance to reduce the cost of fertilizer. It has been observed that free N fixing organisms “Azospirillum brasilense” parent in roots of sugarcane, can be grown in callus culture of sugarcane. Regeneration of sugarcane from protoplasm provides opportunity for somatic hybridization (Heinz, 1987).

**Anther Culture**

The conventional methods employed by breeders for haploid production are very cumbersome and laborious. With the introduction of tissue culture methods excised anthers and isolated pollen can be induced to form haploid embryos and or plants (Liu, 1981). Haploids provide the fastest way to develop homozygous lines for use in F₁ hybrids.

Homozygous diploids can be generated from haploids by colchicines treatments. Thus haploids have potential in mutation breeding. Pathogen resistant lines and in the eradication of virus, which is not pollen transmitted can be isolated by anthers when
excised. Liu (1981) was of the view that success from anther collection is not much assured as young anthers contain a high concentration of phenolics and thus cause death of the isolated anthers. This problem can however, be overcome by cutting the whole of spikelets in liquid medium.

**Limitation in tissue culture**

Tissue culture technique is being used in cane improvement due to genetic changes in callus. But the problem in tissue culture breeding, as with other mutation program, is that the induced genetic change is undirected, and most often the tissue culture derived clones are inferior to the donors (Liu, 1981). The variation usually originates from the deletion or addition of a new chromosome or portion of one, the mutant plant usually resembles the donor variety in all but a few characters. Therefore one has to be very careful in selection of desired strain. For screening an agriculturally useful genotype, the tissue culture desired population must be large enough to improve the probability of finding an altered genotype. Due to morphological resemblances most of the phenotypes are usually ignored. Nevertheless, disease tolerant strains can easily be detected. It is why most of the work repeated is confined to selection of disease resistant strains.

Biotechnological approaches have demonstrated variability in specific traits and this is a great innovation in the field of genetic and breeding. Since planned cross breeding program is possible in conventional breeding, the new biotechnology does not replace the conventional methods of variety improvement. However, new sources of variation are very valuable when integrated with conventional breeding to achieve further demand for variety improvement (Heinz 1987).

**Use of Chemical and/or Physical Mutagens**

Three mutagens i.e, colchicine, EMS and gamma rays have been used for the purpose of increasing the mutation frequency for a given character. By using colchicine chromosomes number increased three times from its donor, were stunted and lacked vigor (Liu et al 1977).

EMS solution produced new derivatives but without noticeable changes in agronomic characters (Liu and Chen unpublished data)

**Gama rays.**

The mutagen demonstrated conspicuous alteration in agronomic character. Nevertheless the new plants were shorter and thinner than its donor plants. As for practical use of ionizing irradiation in *saccharum*, detection of mutated plants is tedious and often much more difficult.

As in other crops irradiation or chemical mutagens may be used to advance mutation in sugarcane, there by increasing genetic variability (Price and Warner, 1960). Actually genetic variability in sugarcane is already vast and difficulties are encountered in recognizing variability, particularly mutants affecting quantitative characters, is very great. Therefore mutation breeding is not much advantageous over conventional breeding.
Molecular Biology

Biotechnology incorporation of molecular approaches offers new horizons to facilitate conventional breeding. New molecular tools have made the cytogenetic analysis more precise and practicable. Molecular markers / genetic markers has helped in elimination of chromosomes and species-specific DNA markers can be used to determine mode of chromosomes transmission and identify hybrids in certain crosses (Legendre and Burner, 1997). Through DNA marker, selections of hybrid progeny lines can be made in initial seedling stage that save much of time in selection of superior germplasm.

Though high ploidy level of commercial varieties and quantitative nature of most economic traits have cloned genes, question the large-scale use of genetic engineering in sugarcane improvement. Nevertheless, its use can not be denied in obtaining transgenic sugarcane lines resistant to pests, diseases and herbicides, salt and drought stress resistance and fibre characters.

Molecular markers and genomes for sugarcane variety improvement

Genomic research in sugarcane has played great role in understanding the structure of genomes. This has been made possible with the development of molecular markers which include Random Amplified Polymorphic DNA (RAPD), Amplified fragment length polymorphisms (AFLPS), Restricted fragment length polymorphisms RFLPS) and simple sequence repeats (SSRS). These markers have been used to clarify phylogenetic relationship, documentation of varieties, assessing genetic diversity, developing genetic maps, detecting major genes and to resolve complex genetic traits (Selvi, 2005). These have greatly improved the knowledge on sugar genomics to classify characterized genes that can be tested for their association with economically important traits.

Finger printing

Molecular finger printing of varieties and germplasm has the importance in variety protection, identifying duplicates and germplasm. In this context some micro satellite markers have been used on international level to identify varieties.

Molecular markers for introgression

Genetic improvement of sugarcane is principally through introgression of other species with S. officinarum. Identification of hybrids based on morphological traits is very difficult; as such molecular markers are valueable to identify hybrids and introgression programmes. For this a number of species and genus specific markers have been identified.

Genome mapping

Mapping studies have helped in the identification of structural differences between species and their hybrids. Chromosomal rearrangements observed between genomes have helped in identification of chromosomal pairing. Some quantitative traits have also been mapped that affected sugar yield, stalk weight and fibre etc.

Molecular diversity and phylogenetic relationship

These markers have been used to find actual genetic relationship of a clone with its
Various techniques of gene transfer and expression studies in sugarcane have been reviewed by Naik (2001). These include:

1. Expression of electroporated DNA (Hauptmaun et al., 1986)
2. Use of tissue for electroporation in embryonic calli of cane (Arencibia et al., 1995)
3. Micro-projectile bombardment for gene transfer into intact sugarcane cell (Franks and Birch, 1995)
4. Electroporation and transient expression of genes in sugarcane protoplasts (Rathen and Birch, 1992)
5. Regeneration of sugarcane plant protoplasts (Gupta, 1995)

**Development of transgenic plant by tagging specific genes**

Conventional technology of cane breeding has made considerable improvement in yield of cane and sugar. It is due to evolution of varieties with high biomass and sugar contents as well as by overcome of constraints in production due to environmental stresses, pests and diseases.

Cane hybridization system may produce a superior clone with good sugar yield and tolerance to pests and diseases. However, developing a variety combining all the superior qualities is impossible due to the complexities of the genetic make up of the plant. The improved variety though superior in yield and quality may lack resistance to disease or pests. The genetic transformation technique offers the opportunity to cover the deficiency in an elite variety by introducing the specific gene for development of transgenic plant.

Considering the ethanol production from sugarcane, this crop was termed the bio-fuel. But the improvement in biotechnology has opened the horizon to a bio-factory for the production of value added products like bio-plastic and pharmaceuticals.

The main objective of mapping is to tag genes of desired traits for manipulation in cane improvement. In sugarcane genetic mapping is very complex. Therefore, use of molecular marker in genetic analysis of agronomic traits has so far been limited. However, such studies have been made for traits bearing single gene as in some of the sugarcane diseases. Some resistant genes are being exploited for disease resistance (Daugrois et al., 1996, Rossi et al., 2003). The molecular markers have been used in mapping fibre content (Msumi and Botha, 1995), and development of transgenic plants for resistance against eye spot disease (Mudge et al., 1996), mosaic virus, rust resistance, smut resistance (Raboin et al., 2003) and borer resistance (Ford et al., 1994).

Genes are now being discovered that are responsible for physiological functions of cane plant. Genetic engineering methods have been developed for production of transgenic plants containing sucrose phosphorylase gene. Experiments are under way to trace the genes responsible for photo-phosphirelation, carbon assimilation for photosynthesis and sucrose metabolism (Barry et al., 1998, Carson and Botha, 2000, 2002). A patent has been obtained for increasing plant growth by introducing gene for carbonic anhydrase (Elisen,
Genomic studies in Australia have been done on stem tissue actively accumulating sucrose in sugarcane (Casu et al, 2003, 2004).

Some cane variety have ‘nif’ gene which help fix nitrogen from the free living and symbiotic microorganism and then make the crop self reliant for ‘N’ requirements. These bio fertilizer are reported to benefit cane crop with a minimum of 30-40kg N/ha (Naik, 2001).

Some of the important cane breeding stations are enlisted as under:

**Sugar cane Variety Selection Programme in different Cane Growing Countries**

<table>
<thead>
<tr>
<th>Country</th>
<th>Station Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Bureau of Sugar Experiment Station (BSES), Meringa</td>
</tr>
<tr>
<td>Barbados</td>
<td>West Indies Central Sugarcane Breeding Station</td>
</tr>
<tr>
<td>Brazil</td>
<td>Camamu Breeding Station (Copersucar, Camamu)</td>
</tr>
<tr>
<td>India</td>
<td>Sugarcane Breeding Institute (SBI), Coimbatore</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Indonesian Sugar Research Institute (ISRI), Pasuruan</td>
</tr>
<tr>
<td>Mauritius</td>
<td>Mauritius Sugar Industry Research Institute (MSIRI), Mauritius</td>
</tr>
<tr>
<td>S. Africa</td>
<td>South African Sugar Association Experiment Station (SASES), Durban</td>
</tr>
<tr>
<td>USA</td>
<td>Sugarcane Field Station (SFS), Canal Point, Florida: Sugarcane Research Center (SRC), Houma, Louisiana</td>
</tr>
<tr>
<td>China</td>
<td>Tainan Sugarcane Breeding Station (HSBS), Hainan</td>
</tr>
</tbody>
</table>

**Morphological and Botanical Characters**

Once a variety is developed cane breeders record its agricultural characters for its growth and morphological behaviors. The variety has to be described for botanical characters for its identification. Different systems including botanical, anatomical and morphological characterization of varieties have been developed for variety identification. Botanical description is the easiest and economical method employed in field conditions. Some of the parameters have been correlated for growth, yield and recovery of a variety and some relate to tolerance to frost, drought, lodging and cane pests. To ascertain a plant character specific to a variety a minimum of 30 cane stalks should be observed. Brief account of various characters is outlined in this section.

**Morphological characters**

Much work has been done on botanical classification of cane in earlier history of cane development (Artschwager, 1939, 1940; Artschwager and Brandes, 1958; Skinner, 1972 and Moore, 1987). Various plant characters are morphologically described as under:

a. **Leaf:** Cane leaf includes leaf blade, sheath, dewlap, ligule and auricle.

i) **Leaf blades:** They are characterized for their size including length, width and leaf carriage. Size differs with soil fertility and favorable or un-favorable growth.
Length: (varies from 1 to 1.5 m); 0 (short) – 9 (long)
Width: 0 (narrow) – 9 (broad): < 4 cm: narrow
> 4 cm: medium
> 6 cm: broad

Carriage: 0 (erect) – 9 (drooping):
upper most leaves with visible dewlap

Colour: Lamina colour may be light green to dark green and may have purple
cast.

ii) Leaf sheath: The leaf sheath wraps the internodal section of cane.
Leaf sheath collapsing may be loose or tight. It may be glabrous on the
adaxial side and often hairy on the abaxial size.
Sheath may have hair and varieties are identified on the basis of hair
group.
Sheath may have spines on abaxial surface, more so on upper side.
Spines may persist or disappear in advance plant age.

iii) Dewlap: It is on the junction of leaf blade and the leaf sheaths; the outer
surface is deltoid or squarish and gives mobility to leaf blade.

iv) Ligule: It is a membranous appendage at the junction of the blade and sheath.
It may be of four types, linear (strap), deltoid (triangular), crescent or bow shaped
(ARTSCHWAGER AND BRANDES, 1958).
v) **Auricles**: The auricles are 'ear shaped' appendages located at the acropetal margins of the leaf sheath. They differ in presence, size, shapes and type of insertion on the sheaths. Nine forms of auricles have been reported by Artschwager and Brandes, 1958. Length may vary with different leaves of the same cane. Auricle may be present on one side or both the sides of the sheath.

![Different shapes of auricles](image)

**Cane stalk:**

The cane stalk varies in length and girth depending on favourable or unfavourable growth environments.

**Colour:** Colour varies with age and exposure to light. Lower portion of cane stalks at about ten months of age when exposed to extreme environment may get colour. Colour of their internodes which could be creamy white, greenish, yellow, brown and purple red. Colour is due to anthocyanin pigment in the rind section of cane stalk. Colour may be greenish, turning to purple or red on exposure to light. Cane stalk may have wax coating, discolouring the internodes.

i) **Cane thickness.** It varies with variety and growing conditions. Under normal growth conditions, the thickness standards used are:

- **Thin/Slender:** Less than 2.00 cm;
- **Medium thin** = 2.0 – 2.5 cm
- **Medium:** = 2.5 – 3.00 cm;
- **Medium thick** = 3.0 – 3.5 cm
- **Thick:** = 3.5 cm and above

iii) **Internode:** Internodes are distinct unit of cane stalks between two leaf scar portions of cane and are classified into six shapes.

**Inter-node structure**

- **Splits:** The rind surface of internodes may have one, two or even more longitudinal.
- **Cracks.** The splits may be deep or shallow, long or short.
**Ivory markings:** They are longitudinal thin cracks just in the epidermis region. They appear as thin lines, long or short and are several in number.

- **Weather markings:** Internodes may have dull gray irregular patches due to reaction of weather recorded as: Present, often present or absent.

- **Bud groove:** Often depressions are noticed on the internode just above the bud and these are known as bud grooves. They may be long or short, deep or shallow.

- **Node:** Node is a joint portion of internodes on a cane stalk and is composed of growth ring, leaf scar and root band.

- **Growth ring:** It forms the boundary between the node and the internode above
Cane Breeding

It is a narrow band and is devoid of wax. It has shiny appearance. It is characterized as narrow or wide, swollen or even.

- **Leaf scar**: It is leaf sheath scar and is the point of attachment of leaf sheath to the internode.

- **Root band**: It is the basal portion of internode and composed of rows of root primordial; bud is also located in this portion. Root primordia appear as small circular dots and are the points of root emergence. The root eyes are arranged in 2, 3 or more regular rows or may not have any symmetry referred to as staggered.

- **Bud**: This part of the internodes sprouts to develop a shoot of the new plant. It varies considerably in size and shape. Eight shapes have been described by Artschwager (1940), while Skinner (1972) has simplified to just three forms as round, ovate and pointed. Buds may be confined in root band or extend above the root band. Bud may limit itself to remain within growth ring or may protrude above it. Some varieties have space between bud and the leaf scar called cushion.

![Bud Shapes](image)

Different forms of bud patterns, (after Dillenijn, 1952)

![Bud Shapes](image)

Different shapes of sugarcane buds
Period and stage suitable for plant characterization

The variety for plant characterization should be of an age of about 10 months. The crop should be mature and plants characters should be recorded before the crop is exposed to cold chilling period. The plants for characterization should be selected from quite healthy disease and pest free crop. The following plant parts may be collected.

Leaf characters:
Third unfurled leaf from top internodes and nodal part:
- Top most joint having 1st, 2nd dried leaf
- Splits, ivory marks.
- Top most joint having 1st, 2nd dried leaf
- Bud: Top most buds covered under 1st, 2nd dried leaf

Morphological characters

From planting to its maturity sugarcane passes various phases of growth including germination, tillering, vegetative growth, cane formation and maturity. The qualitative and quantitative performance of a variety has to be assessed during each phase of plant development. Cane varieties have to be selected based on phenotypic expression of desirable characters. Various growth parameters are measured, counted or rated under standard procedure of 0 (desirable) to 9 (undesirable grade). The following characters are generally considered while ascertaining characters of new cane varieties.

Germination: Number of sprouts as percent of buds planted; Germination rate percent, shy or fast. Periodic data recorded after cane planting.

Tillering: Number of shoots per basic plant germinated. Shoots arise from underground section of node on primary germinated shoot. The tiller development continues as primary, secondary or tertiary and so on, till leaf canopy completely covers the ground. Periodic data of tiller production recorded after the germination is complete. Tillering may be poor or profuse, late tillers/water shoots.

Growth: Plant growth may be slow or fast, thus the leaf canopy cover is early or late. The growth of cane stalks may be actually measured at periodic intervals, weekly, fortnightly, or monthly. The plant to be measured is tagged; a peg is dug along site to be the basal point for subsequent measurements. The plant height is measured from the base to the first visible dewlap on the top portion of plant.

Stool: Stool is composed of cane stalks in a bunch. Stool may or may not have a uniform growth of stalks and is graded as low, medium or high uniformity.

Tops: Heavy top: > 10-12 leaves; light: < 10 leaves in a stalk.

Trashing: Leaves of a mature stalk may remain firmly attached or may abscise. So, the leaf sheath may be free trashing, tight sheath or clinging type.
**Cane height:** Measured from basal joint at soil surface up to the top most first exposed dewlap.

**Cane thickness:** Measured by vernier caliper from the central internodes.

**Cane formation:** Number of cane stalks developed from tiller shoots. It could be early or late; good or poor.

**Maturity:** Assessed by hand refractometer Brix data or a thorough laboratory analysis for Brix, Pol, Purity, Fibre, Pol : fibre ratio and glucose/ non sugars

**Ratooning:** Sprouting of stubble may be : slow, vigorous / weak, heavy/ poor

**Lodging:** The cane stalks could be erect, semi-erect or lodging type.

**Mechanized harvesting:** Cane stalks should withstand lodging, should remain erect and should not be brittle.
Cane Cultivation

Factors of Plant Growth

The factors that control growth of plants consist of water, air, nutrients and mechanical support. Soil is the main agent in supplying whole or in parts all of these factors except light. The soil has very specific physical and chemical properties, which accelerate or retard plant growth.

Sugarcane Soils

Soil is the medium of plant growth. It is the upper most biologically active part of earth crust. Soils are formed by a slow natural action of weathering agencies where by the parent material, the rocks, are broken down to very small particles and appear as weathered minerals on earth surface. The parent material, animal life and decomposed organic compounds decide the character of soil. Volume compositions of a typical soil is

- Mineral matter : 45-50 %
- Organic matter : 1-5 %
- Non solids or pore spaces : 50 % (air:25 % and water: 25 %)

Mineral matter is in a fine or coarse state of sub-division of sand, silt and clay particles, including oxides and carbonates. The size, shape and geometry of soil pore, controls to a large extent retention, availability and rate of water movement. Plants take the mineral-matter and nutrients while come in solutions form.

The organic matter is composed of a variety of plant and animal life, in addition to earthworms, rodents and other microbes. The soil is a living body full of activity and not just a mixture of sand and clay.

Ideally air and water occupy almost equal space; air is pocketed in bigger pores and water in smaller pores. Soil pores form the soil atmosphere that contains the oxygen, carbon dioxide and other gasses. These gasses are not in gaseous state but are adsorbed with water in humid form. Carbon dioxide is produced as a result of respiration by roots and soil microbes, and the percent volume of the gas is much more than that present in the atmosphere. Plant roots and soil organisms in turn need oxygen incorporated in soil through gas exchange during cultural operations and other aerobic conditions.

The composition of soil is not static; some of its components are liable to change. Mineral matter show very little change, organic matter can be increased, maintained or depleted depending upon the organic manure added to soil or rate of its decomposition. The air-water can change any time or moment.
Physical Properties

Physical properties include soil texture and structure.

**Soil texture**

The soil texture is determined by the relative proportion of the mineral particles of soil, classified into sand, silt and clay based on their particle size. The physical features of these soil gradients are as under.

**Sand:** sand may have very coarse particles of 0.2 to 2 mm or a little fine with particle size of 0.2 to 0.05 mm. One gram of very coarse sand (0.2 – 2 mm) count about 1000 particles and has surface area of only 0.0035 m². Sand particles are very loose and do not hold together. It holds a little water and the nutrients are easily leached. Such soils are well aerated and drain very fast. They are easy to cultivate.

**Silt:** Silt soils range between sand and clay with particles size of 0.002 to 0.05 mm. The particles stick together and can hold some water and nutrients. Silt soils compact quite easily.

**Clay:** clay constitutes very fine particles of less than 0.002 mm dia. One gram of clay contains approximately 90 billion particles with surface area of about 800 m². Clay has large effect on chemical and physical reaction of soil. Clay soils are usually fertile, but are poorly aerated and waterlog easily. They can absorb large amount of water, are sticky and exhibit high degree of plasticity when wet and form hard clods when dry. They are difficult to cultivate.

**Loam:** The soils that have more or less equal proportion of sand silt and clay are called loams. The relative percentage composition of these soil gradients is further classified into sandy loam, loam and clay loam soils.

The sandy loam or clay loam is conditioned when sand or clay predominate in the composition as the case may be.

Physical properties of soil play important role in soil productivity through:

- Intake and flow of water.
- Availability of moisture storage capacity.
- Movement of air and heat.
- Mechanical impedance to root development and seed emergence.
- Ease with which the soil can be tilled.

Soil texture has great importance with respect to absorption and retention of water for crop use. Water in soil is contained around soil particles as a film of water. Since clay particles have large surface area and are many more than sand particles in a volume of soil, absorb much more water than sand. Clay soils have high storage capacity of nutrients with low leaching characters. Sandy soils have large pores, have lesser surface area and drain out the water rapidly.

The water to be held by soil particles is called its **water holding capacity**. And each soil
type has fairly well defined way of holding and retaining water it receives through irrigation or rainfall. Only a part of water is held around soil particles and the rest is lost as free drainage.

The capacity of soil to hold water against gravitational flow is called the **field capacity**. Water at field capacity is the maximum amount of water the soil can hold. It is the point of saturation of soil with respect to holding water. **Wilting point** is the term used for the lower end of the available water, below which plants have problems in extracting water from soil and start wilting.

In fact all the water absorbed by soil is not available for plant use. It is the difference in the water at field capacity and the wilting point. And this range of available water differs with soil types. Clay soils have larger water holding capacity. They absorb water very slowly and retain a large volume of water. Water is tightly held around clay particles and soil release a little for actual crop use. As such their wilting point is also high. Clay soils besides holding more water, pose water management problems, due to lesser water availability, poor drainage, poor aeration, poor root development and poor uptake of moisture. A rough estimate of water holding capacity of various soil types is shown in Table-1.

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Field capacity</th>
<th>Wilting point</th>
<th>Available water for crop use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy soil</td>
<td>10</td>
<td>04</td>
<td>6 %</td>
</tr>
<tr>
<td>Clay soil</td>
<td>45</td>
<td>34</td>
<td>11 %</td>
</tr>
<tr>
<td>Loam soil</td>
<td>34</td>
<td>16</td>
<td>18 %</td>
</tr>
</tbody>
</table>

Sandy soils have larger pore particle size, lesser pore spaces, as such hold much less water than clay soil. Most of the water absorbed is lost by deep percolation. Very little water is held by sand particles as crop available water. Since sandy soils loose more water through leaching, are also more prone to nutrient losses. So these soils have water and fertilizer management problems.

Considering water intake, water retention and water availability to plants, loam soils are the best. The loamy texture combines the water holding capacity and cation exchange capacity (CEC) of the clay, with good drainage and porosity of the sand and help good aeration and root growth.

**Soil structure**

It refers to the arrangement of soil particles (sand, silt and clay) into aggregation. The degree of aggregation depends upon texture, organic matter, cultural operations and the climate. Crumb-granular structure is the best for crop production.

**Chemical Properties**

Soil is a storehouse of certain nutrients; adsorption and release of all macro and
microelements is taken up in soil. The clay particles and humus is the seat of such activities. The nutrients are fixed or released due to cation exchange capacity of soil, to which pH has an important role.

**Soil pH**

It is the most important indicator of soil health. The pH is the degree to which the soil is acidic, alkaline or neutral in chemical reaction.

The soil pH is a guide toward good nutrient management. As the pH influences the fixation and release of nutrients for plant availability and the activities of microorganism, some nutrients are in available form at low pH, while others are made available at relatively high pH.

**Organic matter**

The soil health is to be measured by the amount of organic matter it contains. For better crop production the organic matter in soil should not be less than 1%. In some cane growing countries organic soils are reported to have organic matter of 2 to 4%.

1. The organic matter helps to create friable consistency, improve soil structure and increase water-holding capacity.
2. It acts as a source of plant nutrient, and provides energy to the soil microorganisms. It is a seat of electrical charges to hold nutrients through cation exchange capacity (CEC).
3. Fertilizers and water use efficiency is enhanced in organic soils.
4. The soils with low organic matter are sick soils.
5. The soils in Pakistan mostly contain 0.3 to 0.5% organic matter. Good yields cannot be expected from these soils, unless organic matter improved.

**Sugarcane soils**

Sugarcane is a long duration exhaustive crop and requires heavy fertile soil. Heavy fertile soil is one that provides all essential nutrients to the plant in very favorable environment of soil pH, soil temperature, moisture and organic matter and support the plant during its crop cycle. Soil is ameliorated to create favorable environment for crop growth including the development of roots. Sugarcane is grown on a variety of soils with texture ranging from rough sandy loam to heavy clay. Ideally sugarcane soils are deep, well drained, and well structured sandy loam to clay loam with an adequate amount of organic matter. The soil should have crumb structure and reasonably friable.

Better yields can not be predicted from very sandy or clay soils and marginal areas. Sandy soils are problem soils with respect to irrigation and fertilizer management. These soils though are easily workable but are very expensive to maintain. They can’t be regarded productive due to poor retention of water, heavy requirements of irrigation water, and leaching of nutrients. The clay soils on the other hand are intractable requiring heavy cost of cultivation. These soils have impenetrable nature, and pose problems both on wetting and drying with respect to poor drainage, and cracking. All the important cane yield-contributing parameters of bud emergence, tillering and root development are
suppressed in clay soils.

Good production can be predicted from loam soils. With good management condition sandy loam and clay loam can give profitable crops. Sugarcane soils should be easily workable to give crumb structure and fine tilth and loam soils present these characteristics.

Sugarcane has deep root system with main bulk of roots (75%) concentrating in 25-45 cm depth and considerable volume penetrate to deeper regions. If soils are worked deep bulk of roots penetrates to deeper layers in search of water and nutrients. Therefore soils with deeper zones are considered the best. Deep soils with good sub-soils are preferred for cane cultivation.

Marginal lands with problems of salinity and water logging are not suitable for good cane and sugar yields. Sugarcane does not thrive well in high pH soils. The pH of 8.2-8.5 is just marginal, and 8.5-9.0 is lethal for crop growth. Before planting cane, such soils should be reclaimed. Heavy clay soils and soils in low-lying areas pose serious problems of water logging. Soils having poor drainage and improper-aeration check activities of microbes and intake of nutrients. Root development is checked in waterlogged conditions; therefore these are sick soils for cane cultivation. For establishing a good crop stand good drainage has to be assured during full crop season from planting to maturity.

Though soil texture can’t be easily changed but soil structure can be improved by proper cultivation practices, crop rotation and frequently incorporating organic matter.

**Land Preparation**

The good land preparation changes the physical state of soil to an ideal environment for seed germination and root growth. If not, the soil will be either too loose or too compact, the surface too finally grumbled or too cloddy in poor growing condition. Principle of land preparation is to prepare it to a fine tilth to favour the rapid intake of moisture, easy sprouting of buds, free penetration of roots and help release the nutrients for establishing a vigorous crop stand. Soil conditions have to be accelerated by improving soil organic matter, stirring the soil down for moisture penetration and root development. Good drainage has to be assured and the soil has to be cultivated to give it a crumb structure.

Amongst field crops, sugarcane has heavy bio-mass and vigorous deep root system that require land to be prepared to deeper horizon. Sugarcane is a long duration crop that occupies the soil for over 12 months, and considering its subsequent two or more ratoons, land preparation is needed once in 3-5 years. Thus good land preparation would predict good plant and ratoon crops, and poor preparation would always be a crop burden on land. The extent of land preparation depends on weather conditions, crop rotation, soil type and type of farm machinery available with the growers. Different steps/ cultural operations involved in land preparation are mentioned as under:

**Soil organic matter**

Good cane yields are conditioned by organic matter in soil. Organic status of soil should be
maintained by adding farm yard manure or filter press cake in soil and growing green manure crop in rotation with sugarcane. The manure or filter press cake should be incorporated in soil well in advance of planting time. The green manure crop should be buried in the soil 4-5 weeks before planting. It should be irrigated to allow thorough rotting.

**Uprooting/destruction of stubbles**

In case the sugarcane has fallow sequence or sugarcane follows the green manure crop, the rotavator should be used to shred the stubbles of cane into pieces. In the absence of a rotavator, stubbles may be uprooted by disc plough or mould board plough. Next run of a disc harrow would break the stubbles into pieces for thorough incorporation in the field. In case the soil turning plough or rotavator is not used disc harrow may serve the purpose, but it would require two or three runs for proper churning and incorporation in the field.

**Weeds eradication**

Land preparation during fallow period is important with respect to weed eradication. Noxious weeds especially rhizomatous grasses are best controlled during dry summer. The fields should be repeatedly cultivated to dry out nuts and rhizomes exposed to sun. Where necessary root mass and stollens should be collected and burnt. Soil turning ploughs dig out the rhizomes to facilitate collection and drying. This eradication time if not properly availed would promote rhizome developments in subsequent period of cane growth.

**Tillage operations**

The requirement of cane field, for deep ploughing or shallow tillage depends on soil type and farm machinery in use. A good yielding crop of cane has a well established root system with maximum root zone to a 45 cm depth. For proper root penetration and water infiltration, soil has to be initially worked to a depth of 45-60 cm. Deep tillage becomes essential when cane crop has passed 3-5 years of ratoon cycles. During this period, irrigation gradually suppresses the soil particles. Repeated movement of farm machinery during inter-row cultivation operations and during harvesting, soil gets compact and requires deep ploughing to raise good yields of subsequent crop.

Most sugar producing areas that contain organic soils possess good physical condition, are fertile and roots extend easily to deeper depth, and there is no need to waste energy and power to till the soil deep. Deep tillage operation is necessary where under lying sub-soils are infertile, relatively hard and check root growth to lower horizon. Under such conditions shallow tillage encourage shallow rooting, check infiltration of water to deeper layers, therefore crop suffer badly under drought conditions. In hard impermeable soils shallow tillage often leads to poor cane yields.

Besides the cultivation, to obtain a fine tilth, soils should be ploughed to a depth of active root zone i.e. 30-45 cm depending upon the nature of soil. Sandy loam and loam soils are easy to work, while clay and clay loam soils are hard to operate. Heavy soils need more attention to loosen to deep layers to facilitate deep root penetration as well as retention of water to deeper zones. However, the tillage operations have some norms. Long term intensive cultivation may make the soil very fine to disturb the crumb structure. Excessive cultivation increase soil degradation and increase bulk density that would
affect water retention. It is a critical factor in maintaining soil productivity. Since, cane fields are planted only once in every 3-5 years, they require sub-soiling prior to ploughing in order to attain the desired depth of tillage. Without previous sub-soiling, the large disc plough will not penetrate to deeper layers and make only shallow cut.

Out of the various implements available, disc harrow operates to 12-15 cm depth. Cultivator works to 15-20 cm, disc plough can work to a depth of 30 cm; the chisel can tear down the soil to 45-cm depth, while sub-soiler can go as deep as 50-60 cm depth. In some countries, however, disc ploughs and rippers are available to work the soil to 100-110 cm depth, but these need heavy power tractor.

**Breaking hard pan**

Sometimes constant shallow ploughing for a long time creates hard pan. A constant working depth of bullock driven simple plough (‘Hal’) or disc harrow could create hard pan. A hard pan is also created by regular deposits of calcium salts at a certain depth of plough-share. These pan layers restrict the development of roots in upper zone only; thus development of plants is checked after 4-5 months of growth period. To attain good crop growth throughout the active growth period, these hard pan layers must be broken by sub-soiler or chiseling of sub-soil. Sub-soiling/ripping after 3–5 years of crop cycle is very important to break open the compact layers formed during inter-row cultivation and harvesting operations. Number of cultivation operations needs wisdom and experience. Sandy loam or loam soils that have light profile may not require that extensive ploughing.

The development of secondary roots is of utmost importance for giving the plant adequate areas of surface contact. Under conditions of deep fertile soils with desirable physical properties, the root system becomes well developed to depths of 150 – 180 cm or even more. Whereas, under compact soil conditions with limited aeration, root system is practically devoid of the secondary branches. Under conditions of excessive moisture, from rain or over irrigation, crop develops quite week roots systems. Therefore, field operations causing critical compaction or puddling the soil must be avoided.

**Seed bed preparation**

This is the stage of land preparation just prior to cane planting. Important points to be considered in seed bed preparation are:

1. The soil should be tilled to a desired depth. The well prepared soil should have a granular structure for proper aeration and root penetration.
2. Soils should not be worked when wet, or in dry state.
3. The soil should be worked over for sufficient time from first plowing to planting so that the weeds and grass population is eradicated.
4. The soil should not be "over-worked"; preparing too fine a seed bed is as undesirable as inadequate preparation.
5. Foremost attention should be paid to keep the level of soil surface uniform.
6. Post planting traffic in the field should be kept at minimum level.
Cane and Sugar Production

Cultivator

Land leveller

Disc plough

Disc plough

Sub-soiler in use

Chisel
Mechanization in Cane Culture

Sugarcane is a long duration crop producing huge biomass and roots penetrate deep into soil where there are no physico-chemical limitations. To produce this quantum of biomass, crop needs certain level of land preparation to provide and optimum environment for plant growth, root development and soil and water conservation to economize resources. This could be done through traditional cultural practices using manual operations and livestock at the farm or through partial or complete mechanized culture. All the leading cane growing countries have mechanized their farm operations. Mechanization in cane culture has increased the efficiency of farm operations manifold. It has helped bringing large areas under cane plantation and has helped in maintaining its productivity through high soil working efficiency in deep ploughing, leveling, green manuring, and timely operations in planting, fertilization, irrigation, weed control and ratoon management.

Machinery used for various farm operations

Different types of heavy and light equipment are used with different objectives at various stages from land preparation and planting to harvesting cane. Main stages for the use of farm equipment are:

1. Land preparation
2. Seed bed preparation
3. Cane planting
4. Post planting care of crop
5. Inter-row cultivation
6. Plant protection
   - Weed control
   - Pest control
7. Harvesting stage
   - Harvesting of crop: Manual v/s mechanized
   - Haulage and transport cane to the factory
8. Ratoon management
   - Stubble shaving
   - Trash management
   - Inter-row cultivation
9. Cane stubble eradication
   - Destruction of stubbles
   - Land preparation for replanting or during fallow

A Package of Farm Equipment

A complete package of mechanization observed in USA, Australia, South Africa and such other countries include equipments for all the operations of land development, cultivation, seed bed preparation, planting, inter row hoeing, weeds and pests control spray operations, cane harvesting and haulage to sugar factory. Different types of models of equipments have been introduced by various companies like HODGE in Australia. A complete set of equipment from land preparation, planting to harvesting being marketed
Reversible disc and mould board ploughs
Field rollers, levelers and laser land leveler
Cultivators
Disc harrow, heavy (dia. 910 mm) or light (dia. 610 mm)
Weed rake, trash rake
Cane planter- Billet or whole cane planter
Fertilizer distributor with double row cultivator
Rotary weeder
Herbicide, pesticide applicator
Stubble shaver
Rotavator
Cane harvesters: Whole stalk harvesters or chopper harvesters with small and large cane loading bins and transport mechanism

Field operations with heavy farm equipment need appropriate power of tractors from 25 to 250 HP. In Pakistan though not made common, locally designed equipments are available which include sub-soiler, chisel, disc plough, mould board plough, cultivator, leveler, semi automatic cane planter, ridger cum fertilizer applicator and inter row cultivator. Stubble shaver, Disc ratooner/inter row disc cultivator has also been designed for multi functions operations of stubble shaving, hoeing, earthing up and trash management. The farming system is thus semi mechanized according to the farm resources and available know how.

Use of heavy machinery for deep plowing including the sub-soiler and disk plow should be critically visualized considering the nature of soil, the previous crop grown and the moisture status of the soil. For example clay and heavy soils respond to deep tillage, while light textured soil do not; deep alluvial organic soils may not respond to sub-soiler. However, when a hard pan exists near the surface, sub-soiler is essential to shatter this layer for deep root penetration. Sometimes repeated shallow ploughing for years also creates hard pan, which has to be broken.

Shallow tillage encourages shallow rooting resulting into poor yields. Shallow tillage reduces infiltration of water to deeper layers therefore the crop suffers badly under drought conditions. When cane fields are planted after 3-4 years of ratoon harvests, they require sub-soiling and deep ploughing in order to attain desired tillage depth. Without previous sub-soiling and chiseling, disc plough may not penetrate to desired depth. To plow the soil deep or shallow and number of working have to be judged critically by the grower himself. The observations and experience of the grower should decide the essentials of a good seedbed. Usual practices of seed bed preparation in different regions are referred as under.
Australia: A minimum of seven passes of different implements required to prepare a seed bed (Jacquin & McIntyre, 1993)

Kenya: Pair of disc gangs, two mould board plow and four disc colters mounted on tool bar (Musonge et al, 1994)

Mauritius: Five passes of disc harrow: two light disc harrow followed by two heavy disc harrows and a final one with light disc harrow. Equipment used to chop stubble includes light disc harrow, chisel and rotary hoe. Best results are obtained with the rotary hoe, use of chisel with two passes of light disc harrow also give good results (Jacquin et al, 1996).

Main considerations for profitable farm mechanization

Farm machinery is very expensive item and its cost is a major component of the total farm budget. Economics of cane production lies on the efficient use of machinery with maximum output per unit time and cost involved. The use of farm machinery should itself be taken as a profit or loss entrepreneur. The proprietor of the farm should have close watch on each and every aspect of the farm machinery utilization at the farm. The system should not only meet its cost, but should give considerable profit margin to the organizers with appreciable increase in overall production of sugarcane.

Key points of cost effective mechanization

1. Maximum use of machinery.
2. Minimum reliance on farm labour
3. Field efficiency to achieve the highest output under ideal conditions.
   a) Planning for machinery use and effective farm operations
      • Actual need of the operation
      • Selection of the machinery for specific task
      • Time schedule for each job
      • Optimum time of operation: Save time for maximum effective use of machinery
   b) Reliability of the machine
      a) Farm layout
         1 Field sizes, roads, routs, watercourses and irrigation systems have to be pre thought
         2 Farm size has great effect on economic efficiency of mechanization
         3 Operational costs are high on small farms than on large farms
         4 Smooth and large plots with no obstacles
         5 Longer working length of the field and minimum short rows
6 For smaller farms facility of hiring services can strengthen cane mechanization

b) Operator’s performance

1 Responsible well trained operator to be preferred over cheap and poorly trained operator.

2 Operator can significantly control the repair cost.

c) Cost effectiveness

1. Cost of machinery and cost of operation per unit time.
2. Number of times the operation is perform
3. Availability of repair and spares and the cost involved
4. Availability of technical services
5. Economics of ownership cost of machinery v/s hiring charges.

Limitations in mechanized cultivations

It is beyond doubt that mechanization in cane culture has contributed high working efficiency per unit time. Machinery has fully matched the output of cane field to the milling requirements of sugar industry. It has relieved the organization of any risk of labour force.

Complete mechanization accommodates complicated machinery from automatic cane planter to complex combined harvesters. This requires thorough technical knowledge on the use of the equipment, availability of work shop, repairs and spares should also be assured. While planting, inter row space has to be confined to the machinery track. The mechanization requires well planned large block of land and wide row tracks for convenience in machinery operations. The row widths are maintained according to design of the machinery. The 1.5 to 1.8 meters is the usual row distance observed in various countries which have adopted mechanized culture.

Mechanization has contributed to its high efficiency with best yield production potential and economic returns. However, with all these benefits heavy farm equipment and complex machinery have been developed which has with time exerted adverse effect on sustainable productivity with respect to low plant density, soil compaction, poor root growth and stool damage.

Gradual increase in row spacing has resulted in poor plant geometry, which does not intercept all the available light, water and nutrients (Bull and Bull, 2000).

Mechanization has lead to considerable crop losses due to, improper adjustments between row spacing and machinery track, stool damage, soil compaction and soil degradation.

The intensive use of machinery for land preparation, cultivation and harvesting operations results in subsoil compaction. A relationship of yield decline with time has focused with the change in soil chemistry, biology, microbial biomass and soil organic carbon status, and physical degradation of the old land (Mc Garry and Bristow, 2001).
Mechanization in mono culture results in soil degradation process in cane productivity including 'P' fixation, salinization, soil compaction, surface crusting, intake rate decline and hard pan in sub soil layers (Meyer and Van Antwerpen, 2001; Henry, 1995). Mechanical compression on soil particles may reduce the pore spaces, upset the movement of water, and check the root development resulting into impaired growth of cane.

Rate of root growth is affected by poor aeration condition, reduced pore size and mechanical impedance. Roots readily grow in well drained soils with desirable pore size: otherwise root tip needs extra energy to push soil particles aside to overcome penetration resistance (Vepras and Miner, 1986). Roots are unable to grow through hard pan characterized by high mechanical impedance (Trouse, 1983).

Compaction is normally accepted as an unavoidable consequence of mechanized operation in cane fields. Compaction has to be considered as a factor to be managed as a part of crop production system. The following management alternatives have to be considered to eliminate compaction effects.

1. Row space should match the tracks of the machine.
2. Traffic load on soil may be reduced by combined field operations.
3. A minimum cane yield decrease of 10% was due to inter-row compaction, and a maximum of 42% was observed where there was direct damage caused by traffic over the stool (Torris, et al., 1990).
4. Direct stool damage should be avoided by controlling the traffic on right paths.
5. Damage caused by machine traffic becomes worse under wet soil conditions. Harvesting in wet weather may require the use of tracked equipment to reduce field damage.

**Land preparation**

Land preparation starts with deep ripping followed by deep plowing in barren land and eradication of stubble in ratatoon field. Seed bed is prepared by running heavy and light disc and cultivator a number of times till desired tilth is achieved. In all these operations thorough attention is to be focused on soil type, moisture contents and prevailing weather conditions.

Mechanical stool eradication for destroying stubbles is effective only in dry weather. The most effective implement for uprooting stubble is mould board plow. Stool eradication can also be done by shallow operations of discs. The objective is just to cut and invert the stubble. One more discing 1-2 week later usually kill all re-growth. Disc plow or harrow are not that effective and may miss part of stool.

The main objective of plowing and cultivation of sugarcane soils is to destroy an old crop and to prepare a weed free seed bed before planting a new crop.

Some growers consider deep tillage to be an integral part of land preparation. Certain soils may require deep tillage, but generally this expensive operation is neither necessary nor cost effective. Traditional land preparation system, which use many passes of heavy
equipment, are not generally cost effective. Normally deep tillage is not justified, and number of operations can be eliminated without affecting crop yields and net profit adversely.

In one of the comparative studies deep plowing (920 mm) and sub-soiling (250 mm) were compared with conventional tillage operations. The yields of plant and ratoon crop indicated that there was little advantage in plowing or sub-soiling to a depth greater then 200 – 250 mm (Moberly, 1972). Less expensive equipment used at the correct time may be equally effective (Meyer, 1991). It was concluded that the extra expense of tillage was not warranted unless specific soil problem exists.

The most important aspect in working efficiency is the timing of operation and selection of the most effective implement for a particular soil.

Each tillage operation must have a purpose, to shatter a compact layer, break the hard pan or to pulverize the soil to a fine tilth. Operation to till deeper than needed, to prepare a finer seed bed than required or extra working to make the soil compact, while disturb the soil texture for cane growth, make operation expensive.

After soil has been loosened by tillage operation, further operation should be avoided to a minimum as tracks or wheels can the soil compact. Cane rows must have a bed of loose soil permeable to air, water and roots to grow without mechanical impedance. For inter-row cultivation, suitable row distance may provide a path for machinery track.

Attention is now being focused to change inter row distance to minimize the soil compaction and bulk density of soil with a little change in machinery design within the 1.5 and 1.8 meters inter-row spaces. In some other studies dual rows planting at 0.5 m apart in mounds of 1.8 meter centers is considered economically better over single, triple and quad rows and increase plant density per hectare, limit soil compaction, promote soil health and deeper root growth. This planting system matches the current harvester track width and requires minor modification to equipment (Bull et al, 2001).

**Minimum tillage**

The concept of modern cane culture is that the tillage should be carried out when absolutely necessary. Excessive tillage operations bring faster break down of organic matter in soil. The Queensland Sugar Industry believe that the least tillage restore the chemical, physical and biological properties of soil (Garside et al, 2000). According to them regular tillage brings degradation of soil organic matter maintained by trash blanketing and legume fallow. For the sake of good soil health very little tillage is carried out in ratoon where retention of trash as green trash blanket has become an established practice. Monoculture, excessive tillage, low input of organic matter and high input of nitrogen fertilizer help develop unhealthy soils. Minimum tillage of two to three shallow cultivations has been considered enough to realize high yield of cane and sugar (Ricaud, 1971, Glaz, 1989; McIntyre and Berbe, 1989). However, facts remain that soil types, soil condition, soil fertility and weed infestation has to be kept in view while deciding to follow least tillage operation or to give thorough ploughing to the soil.

The concept of minimum tillage aims at reducing the tillage operation required for acceptable seed bed. In one of the techniques only the strips of land meant for cane rows
are cultivated. After the harvest of cane, the inter-row spaces are once tilled, and furrows are made for cane sett placement manually or by machine. The cane stubbles are then churned and shredded with rotary hoe and it involves minimum soil disturbance. The technique is quite effective in sandy loam soils, however, loam and clay loam soils need some inter-row cultivation to obtain suitable seed bed. Heavy clay soils are not suitable for this method.

The trials conducted in Mauritius indicated that minimum tillage resulted in better yields, but the advantage of the technique decreased with increasing number of ratoons (McIntyre et al, 1984). The higher yield was attributed to lesser deterioration of soil structure, incorporation of organic matter provided from the old cane stubbles left in situ and retention of moisture. Glyphosate was used for control of weeds. Strip tillage resulted in saving between 44 - 56 %, compared with conventional tillage technique practised in Hawaii (Jakeway, 1982). Only 44 % of the total field area is prepared. It helps reduce traffic in cane field with minimum compaction. No negative effect on yield was noticed. Fifty percent reduction in cost in minimum tillage compared to conventional system is also reported in Australia (Holmes and Verri, 1988).

**Soil moisture**

For effective use of heavy implement soil moisture status is of immense importance. Loose sandy loam or organic loam soils are easy to work and do not pose much problem if are partially or semi dry. Repeated working the soil in dry state may produce fine dusty condition but this practice permanently damages the soil structure. It tends to create crust on wetting. All types of plowing operations should be performed when soil is slightly moist. The best tilth is achieved when the soil is at optimum moisture content. Working the soil when it is wet make it compact for root development and bud emergence. Ploughing the wet soils tend to become puddle during cultivation operations and on drying turn into hard clods. The clods formed in heavy puddled soil are not easily broken down to Crumb State. Working such soils increase the number of supplemental tillage operations which increase working cost many fold and even then proper tilth may not be achieved.

**Leveling**

Leveling is the most essential operation in land preparation. After the field is properly shaped it is leveled to attain a smooth surface. The leveling provide enormous benefits in the form of uniform flow of water, high water use efficiency, uniform penetration of water in soil, better control on water distribution, better drainage, reduced soil heterogeneity followed by uniform germination and stand of crop.

Considering the nature of unevenness of the field, slopes and heights, and earth and fill status, the grower has to select the kinds of implement for appropriate operation. For large cuts and fill, scrappers pulled by tractors and front blade, may be needed for a moderate localized leveling. Simple blade/land planner would be enough for minor leveling, and for giving a uniform touch field leveler would be required.

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moderate localized leveling. Simple blade/land planner would be enough for minor leveling, and for giving a uniform touch field leveler would be required.

![Land leveller](image1)

![Lazer leveller](image2)

The use of blades and leveler are the conventional approaches. Precision land shaping has now introduced technique of laser leveling in modern cane culture. The laser tower, usually on a mobile trailer is set into the field and the emitter is programmed to beam a signal along predetermined grades. The receiver's mounted in the scrapers automatically control the cutting and later releasing of soil. This is now the best system for a uniform leveling. The leveling may be done to achieve zero grade or 2 – 5 cm slope to either of the direction considering the flow of water. Precise shaping by laser leveler would be followed by pre-plant smoothing of field with a land plane or leveler. Precise leveling may take some time and may involve some capital investment but it is a permanent operation and has long term pay pack.

**Cane blocks and size of borders**

For efficient use of heavy farm machinery large working blocks in cane fields are required. Time and energy is un-necessarily wasted in small land units and also the land is not precisely worked upon. Proper lay out of the farm is an integral component of land development. The farm should be divided into large blocks to facilitate the free working of the machinery so that there should be minimum turns during land preparation. Large working blocks also help in effective use of tractor and equipment in post planting operations for hoeing, weed control, earthing up and harvesting. Lay out of the field should include a network of roads and water channels for convenient movement of machinery. In squares and rectangles system of Pakistan lands, if not 300-meter length, the minimum working length of block should be 150-meters. The scientific approach is to make blocks keeping into consideration the infiltration rate of soil.

**Planting Time**

Planting time is influenced by suitable temperature for germination of buds. Good germination is obtained at temperature around 27°-32°C. Thus any season of the year that coincides with favourable temperature for germination is suitable for planting. In countries located in equatorial regions of the world, the year round temperature range is 25°-30°C, so cane crop can be successfully planted in any month of the year. In tropical
regions and beyond tropics as such planting time is mostly confined to spring and autumn months of the year, for rest of the period extreme weather conditions are observed with temperature too high or too low for germination.

In Punjab province of Pakistan, cane is mostly planted in spring; first fortnight of March is the optimum period of planting. However, planting can be initiated by middle of February and time can be extended to end of March. Weather conditions regulate actual planting time. Winter season may terminate earlier or spring rains may extend cold weather. Growers have to use their wisdom to predict the weather and complete planting in time. Untimely planting has detrimental effect on germination, yield and quality of cane. Studies carried out on different planting times indicate that Cane yields in September-October planting (90-88 tha⁻¹) are significantly higher than rest of the planting dates. Yield is considerably reduced in winter planted crop (66-72 tha⁻¹). Yield increase is again noticeable in February- March planting (78 tha⁻¹), followed by drop in yield to 66, 53 and 24 tha⁻¹ in April, May and June planting, respectively (Table-5.02).

<table>
<thead>
<tr>
<th>Date of sowing</th>
<th>Cane yield t ha⁻¹</th>
<th>C.C.S % cane</th>
<th>CCS t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 September</td>
<td>90.00</td>
<td>10.59</td>
<td>9.53</td>
</tr>
<tr>
<td>15 October</td>
<td>88.11</td>
<td>10.41</td>
<td>9.17</td>
</tr>
<tr>
<td>15 November</td>
<td>75.54</td>
<td>10.24</td>
<td>7.73</td>
</tr>
<tr>
<td>15 December</td>
<td>72.27</td>
<td>10.07</td>
<td>7.28</td>
</tr>
<tr>
<td>15 January</td>
<td>66.79</td>
<td>9.90</td>
<td>6.61</td>
</tr>
<tr>
<td>15 February</td>
<td>78.08</td>
<td>9.73</td>
<td>7.60</td>
</tr>
<tr>
<td>15 March</td>
<td>77.14</td>
<td>9.56</td>
<td>7.37</td>
</tr>
<tr>
<td>15 April</td>
<td>66.00</td>
<td>9.38</td>
<td>6.19</td>
</tr>
<tr>
<td>15 May</td>
<td>52.98</td>
<td>9.22</td>
<td>4.88</td>
</tr>
<tr>
<td>15 June</td>
<td>23.97</td>
<td>9.04</td>
<td>2.17</td>
</tr>
</tbody>
</table>

* Fasihi et al, 1974

Better yields in autumn and spring are due to more favourable temperature, while extremely high temperatures in May-June dry out the soil and depress germination of seed setts. Late planting also results in weaker plant stand as well as marked reduction in growth period.

An average of 30 different zonal centers indicate that September planting gave 36.85% increase in yield and 9.63% increase in sugar recovery over March planting (Table-5.03). Enhanced yield of September planting over March have also been reported by Fasihi et al. (1970) and Yadev (1991). In some other studies where September cane gave 26% increase in yield compared to March planting, cane population was higher by 10.06%, cane height by 11.97%, cane thickness by 5.61% and per cane weight by 27.39% (Fasihi et al, 1970).
Table-5.03 Yield and quality performance of September and March planting (average of different climatic regions of Punjab)*

<table>
<thead>
<tr>
<th>Test Sites</th>
<th>Month</th>
<th>Cane yield &lt;sup&gt;t ha&lt;/sup&gt;&lt;sup&gt;-1&lt;/sup&gt;</th>
<th>CCS % cane</th>
<th>CCS t/ ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average of 30 plots in 5 regions</td>
<td>September</td>
<td>106.25</td>
<td>12.30</td>
<td>13.07</td>
</tr>
<tr>
<td></td>
<td>March</td>
<td>77.64</td>
<td>11.22</td>
<td>8.71</td>
</tr>
<tr>
<td>Difference %</td>
<td>36.85</td>
<td>9.63</td>
<td>50.00</td>
<td></td>
</tr>
</tbody>
</table>

*(Fasihi and Malik, 1989)

Planting season has pronounced effect on tillering. Autumn planting avails of longer growth period, therefore, produce more tillers than spring planting (Fasihi and Malik, 1974; Verma and Yadava, 1986). In spring crop, tillering phase is almost completed by the month of June. Later tillers, if produced develop into suckers, while in autumn crop this phase is completed by the end of March. After the tillering phase is over the crop gets into cane formation phase. As such in autumn planting, period of cane-formation prolongs to develop heavy and vigorous stool.

Cane yield reduction from delayed planting could be compensated by increase in seed rate so as to make up plant population, but still further delay can in no case match the optimum planting time (Table-5.04).

Table-5.04. Response of different seed rates to various dates of planting*

<table>
<thead>
<tr>
<th>Seed rate DBS/ ha</th>
<th>Cane yield &lt;sup&gt;t ha&lt;/sup&gt;&lt;sup&gt;-1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>March 1st week</td>
</tr>
<tr>
<td>75,000</td>
<td>108.35</td>
</tr>
<tr>
<td>125,000</td>
<td>113.93</td>
</tr>
</tbody>
</table>

*Fasihi and Malik (1989)

In NWFP, frost is a usual feature in winter that spoils the buds. As such most of the cane area is planted before frost occurrence. If cane is planted in September, the young germinated shoots are affected by frost. Therefore, cane is mostly planted in late October and November, seed remain dormant in soil and sprouts out as winters are over.

In Sindh province, planting time varies with regions and availability of irrigation water in canals. In lower Sindh, winter is somewhat mild, as such autumn planting is extended till mid November. The growth of germinated shoots is relatively less affected by mild winter temperature; as such, prolonged growth period tantamount to higher yields. Higher cane yields of lower Sindh than other regions are due to longer growing cycle of the crop. September planting generally gives 20-30% higher yield of cane than spring planting, but in lower Sindh the growth is not much checked during winter, yields are further stimulated. Since upper Sindh experience extreme weather like Punjab, main planting is done in spring season and a small area is covered in autumn.

Spring planting hardly provides an active growth period of 8 months, while growth period of autumn-planted crop is extended by about 3 months in Punjab and NWFP and almost 5-6 months in lower Sindh. The cane growing regions of the world that avail of
favorable growth period throughout the year are known to produce good yields.

Autumn planting has pronounced effect on cane juice quality. Longer crop duration provides more time to develop healthy and heavy stool. It helps in earlier growth of cane plants, earlier cane formation and better development of assimilates and their storage in cane stalks. Maturity is relatively induced earlier. Delayed planting has drastic effect on sugar recovery and sugar yield per unit area (Table-5.02).

Autumn planting has a considerable edge on spring, with respect to yield and recovery of cane. Nevertheless adaptability varies with regions depending on cropping pattern, economic factors and climatic features. In Punjab, NWFP and upper Sindh, multiple cropping suits the economics of growers. Autumn cane however, is to be planted at the cost of some “Rabi” crops. Unless inter cropping is done, growers don’t consider sole crop of cane as economical. So hardly 5-7%, of the cane comes under autumn planting. Autumn planting in NWFP is due to typical climatic features, that the cane crop is to be secured from frost. In lower Sindh, autumn planting is the general practice of growers. Further there are large holdings, and sugarcane has been adopted as a mono-crop. Besides higher yields of autumn planting, irrigation is the main constraints of restricting planting in September-October. Irrigation water in non-perennial canals is generally available up to October. Growers get a little supplies of irrigation water in spring.

Some times better remuneration from cane crop due to higher cane prices compared to other commodities, growers bring more area under cane and extend planting to the month of May. Such situation arises when cane is planted after wheat harvest, but cane yield is badly affected (Table-5.05). It is not economical to grow cane in May. Germination is extremely low, tillering is depressed and population of mill-able stalk and per cane weight is much reduced. A yield reduction of 49.5 % has been reported in summer cane (Yadava, 1991). It has however, been recommended to minimize yield losses by following a cane row distance of 60 cm to have maximum plant population.

<table>
<thead>
<tr>
<th>Particulars</th>
<th>March</th>
<th>April</th>
<th>May</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st week</td>
<td>3rd week</td>
<td>1st week</td>
</tr>
<tr>
<td>Germination %</td>
<td>44.85</td>
<td>50.60</td>
<td>32.40</td>
</tr>
<tr>
<td>Cane yield t/ha</td>
<td>95.69</td>
<td>96.68</td>
<td>83.37</td>
</tr>
<tr>
<td>Deviation %</td>
<td>+ -0.0</td>
<td>-0.01</td>
<td>-12.37</td>
</tr>
</tbody>
</table>

Fasihi and Malik, 1989

**Table-5.05 Effect of dates of planting on germination and yield of sugar cane during spring**

**Seed Cane**

In sugarcane, ‘sugarcane seed’ refers to the true seed (fuzz) collected from cane arrow and is valued by breeders, while seed cane is the term used for the cane setts, the nodal portion of cane stalks that contain the buds or eyes. It is the healthy bud that sprouts to develop a shoot. The quality of planting material, the seed cane, determines the germination rate and subsequent crop growth.
**Germination**

A bud is an embryonic shoot consisting of miniature stem with small leaves in the form of scales. Before germination buds are in a dormant stage and are protected by fibrous scales around. As the germination starts buds develop into spike like sprouts prior to the extension of leaves. Germination of buds is the transition from the dormant into the active stage, which is preceded by changes in food constituents and by the activities of enzymes and growth regulating substances in the cuttings. Maximum germination and vigorous shoot would occur when both internal and external factors are optimal. Sprouting of healthy buds is associated with development of roots from root primordial. Germination rate is influenced by inherent capabilities of varieties and the environments in which the seed sets are grown. Germination rate is of great economic significance to good yields as it establishes the basic stand of the crop. Generally, under favorable field conditions germination could be as high as 70-75% in autumn planting and 45-50% in case of spring planting. Germination is reduced to 30% in winter and only 24 – 10%, during May–June months. Some varieties may have lesser germination, and poor quality seed may germinate as low as 15-20% or even less. Similarly, under favorable conditions germination is complete in 25 - 35 days, while under un-favorable conditions it may be delayed as much as 70 - 80 days. As such, a number of factors affect germination.

**Factors Affecting Germination**

**Cane varieties**

Cane varieties show some degree of variation in germination rate and speed of germination. Thick cane stalks and cane with robust buds have better germination (BL 4) with fast growth than thin cane and smaller buds (L 116 and CP 43-33). Soft canes have good germination than hard fibrous canes. Germination in CoL 54 and Triton is rapid, where buds start sprouting in 10-12 days, where as sprouting is delayed to about 20 days in CP 43-33.

**Temperature**

Temperature is the main factor affecting germination. The temperature range of 34-37°C is considered optimum for germination (Humbert, 1968). The germination is hampered at temperature below 20°C and above 43°C (Verret, 1930). When the temperature remains below 18°C for several days seed often rots before establishing a stand. However, varieties have different optimum and minimum temperature for normal function of root system. Nevertheless, warm moist soil is desirable for rapid germination and early growth of all varieties.

Under Pakistan condition, spring (February-March) and autumn (September- October) period provide the ideal temperature for planting cane. Since September-October period provides consistent long duration of optimum temperature, germination rate is high and is completed within 25 - 35 days. If planting is delayed till late autumn, germination is delayed and is considerably low due to low temperature. Cane planted in November, sometimes remains dormant till late January. Under conditions where spring planting is followed by sudden rise in temperature, germination is drastically affected.
Moisture

For good germination, soil should be in optimum moisture condition of field capacity. Very excessive moisture creates the problem of poor aeration and lack of oxygen for respiration of roots. In fact both moisture and aeration are closely related. Soil moisture is greatly influenced by soil type and water application. Heavy clay soil creates inundation condition with very poor aeration on application of heavy irrigation. While sandy soils loose moisture soon? Sandy loam soils are ideal to retain optimum moisture and air. Improper leveling also pose problem of excess or low moisture.

Moisture in seed setts matters much for germination of buds and roots development. To start with, primary shoots meet their moisture requirements from the moisture in cane setts. If cane stalks get still, gradually loose their moisture and fail to meet the water needs of emerging roots and shoots. Studies conducted on the use of steel cane as seed material indicates significant reduction in germination, cane stalk density and the yield of cane. The loss in yield corresponds to the staling period, which is 10.76 % for 6 days staling and 22.70 % for 12 days staling (Table-5.06). For planting stale cane, it is advisable to soak the seed for a few hours.

Timing of first irrigation to a plant crop is very critical. Planted seed cane during warm weather, if left un-irrigated in soil, rapidly dehydrate and loose potential for germination and root development. Germination losses are more in top seed and at relatively higher temperature (35-40ºC). Under delayed irrigation conditions, soil borne fungi infect the tissues of moisture stressed seed.

### Table-5.06 various yield contributing characters affected by staleness of seed*

<table>
<thead>
<tr>
<th>Character</th>
<th>Seed staling days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Germination %</td>
<td>49.89 a</td>
</tr>
<tr>
<td>Cane density ha⁻¹</td>
<td>85.27 a</td>
</tr>
<tr>
<td>Cane yield t ha⁻¹</td>
<td>111.15 a</td>
</tr>
</tbody>
</table>

* Aslam et al (2001)

Fresh v/s stale seed cane

Moisture in seed setts also matters much. For planting stale seed cane it is advisable to soak the seed for a few hours.

Age of seed crop

Young succulent stalks prove better seed material than old hardened stalks. Therefore, seed taken from an 8-10 months aged crop is better than from a long duration plant or ratoon crop.

Seed portion

Top portion of cane stalks is more succulent, soft and well nourished than the lower parts,
is therefore best for use as seed. Buds from top section sprout faster than the lower portion. In a study cane setts from top portion gave significantly higher germination than middle and bottom stalks (Ayub et al, 1988). Since lower portion contains higher sugar contents, this can better be utilized for crushing, while 1/4th or 1/3rd top portion of immature cane stalks can be used as seed cane. When planting and harvesting proceeds at the same period, this practice gives considerable saving of crop for seed. During winter, tops with 6-8 buds may be buried in a soil pit to preserve as seed, for later use in early spring; while the lower portion of cane stalks may be supplied to mills for crushing.

**Sett size and bud position**

Two and three budded setts are ideal for optimum germination compared to larger seed pieces (Ali, 1990). It also depends on bud portion of cane stalks, difference in germination would be less in upper setts having smaller inter-nodes than in lower stalks having longer internodes.

Three budded setts are reported to be the best for optimum germination (Yadav, 1991). One budded set might give good germination under ideal condition, but are more vulnerable to environmental stresses. Primary shoots developed from two or three budded setts are more vigorous than from one budded set. There is experimental evidence to show that three budded setts gave 16% higher yield than single bud setts (Kakde, 1985).

In case of longer setts, upper positioned buds sprout faster than lower positioned buds and difference in growth remains to affect yield. Further, that longer sett is liable to be up rooted during inter-row cultivation operation.

In studies carried out at Faisalabad, two budded setts gave significant increase in plant population and cane yield over single nodes and bud chips (Fasishi and Malik, 1986). The buds of one budded placed upward gave 72.2% germination than the buds placed side ways (69.43%), and downward (23.61 %), (Fasihi and Malik, 1992). The buds positioned downward always give poor germination and much delayed emergence of shoots.

Planting longer seed pieces, even the whole cane show considerable differences in sprouting of upper and lower buds. Buds on upper portion of cane stalk sprout first followed by lower buds. Suppressing sprouts of lower buds is due to hormonal effect (Dille Vign, 1952). As such due to late sprouting of lower buds, initial vigour of sprouts is markedly affected. In regions with short growing season this phenomenon suppresses tillering and yields. However, in case of long duration crop season, late emergence makes up the plant population to compensate the yield. In some countries it is found convenient to plant whole cane stalks, but cutting it into small pieces while walking along cane rows.

**Nutritional status of seed setts**

Seed setts should have sufficient nutrients to sustain growth of new seedlings until they develop their own root system. Setts from healthy vigorous crop give more germination than from malnourished, weak and poorly grown crop. Crop supplied with adequate irrigation and fertilizer not only gives better germination, produces vigorous shoots. Better germination of top seed pieces and immature cane is stated to be due to higher nitrogen contents. For having better sprouts, last dose of fertilizer to seed crop may be applied nearly 30 days prior to its harvesting (Black Burn, 1984). In some countries the
cane scheduled for use as seed is usually fertilized 4-6 weeks prior to cuttings. The pre-
fertilized seed germinates rapidly after planting and results vigorous healthy shoots
(Humbert, 1968).

**Sheath cover**

Generally leaf sheath protects the buds from injuries of various types and mechanical
damage during harvesting and seed transport. If not de-trashed, leaf sheath may pose
barrier in emergence of buds and development of roots. Tight sheath exerts more
depressing effect than loose sheath. If conditions for germination are very favorable loose
sheaths may not exert any significant effect. However, in un-favourable environment of
soil temperature, moisture, aeration and soil structure, sheaths check emergence and
sometimes delay germination or rotten the seed pieces before the buds sprout. Leaf sheath
should better be removed than to take risk.

**Diseased seed**

Cane diseases not only affect germination; diseased seed is a carrier of the disease to infect
the following crop. Failure of germination is sometimes due to rotting of cane setts caused
by soil inhabiting bacteria and fungi. If due to low temperature or excessive moisture,
conditions are not conducive to active growth of buds, the soil organisms invade the setts.
Before the buds activate, infected cane setts are rotten. To secure good germination seed
setts have to be treated with suitable fungicide like, Aretan, Agallol, Benlate, Topsin-M.
These fungicides also save the seed from soil born diseases. Hot water treatment is reported
to control RSD and grassy shoot disease (Srinivasan and Rao, 1968).

**Hot water treatment**

The first requirement for production of healthy cane is the use of healthy seed. The
disease infected cane is often overlooked and results in infection of plant and ratoon crop.
The selection of a clean source of planting material is one of the important methods for
the control of cane diseases. One aspect is to discard infected plant material. Still some
diseases fail to show clear symptoms, as external symptoms of RSD are usually not
obvious and require special techniques and knowledge to be familiar with the disease.
Sometimes plant material gets contaminated in large area but disease free seed is not
available all around. This calls for the need to treat the seed with hot water.

Various forms of thermo-therapy have been evaluated as a means of controlling some
cane diseases like chlorotic streak, downy mildew, leaf scald, mosaic, RSD, red rot, smut,
grassy shoot and white leaf disease.

Thermo-therapeutically methods include hot air, aerated steam and hot water treatment.
The hot water treatment includes (Cullen and Evans, 1985):

- Long hot water treatment for RSD and smut control
- Short hot water treatment for control of chlorotic streak
- Serial-hot- water treatment for mosaic control

All these methods have their application in specific cases. As hot air treatment is less
damaging to young immature plants. Aerated steam is capable of utilizing higher
temperature and longer treatment times for control of RSD and mosaic. Special steam chamber is to be desired for raking individual stalks on rakes. However, difficulty is encountered in uniform heat distribution in the chamber.

Hot water treatment has proved an established practical method with uniform temperature control for treatment of RSD, leaf scald and smut. Single treatment should be preferred over long hot water treatment to avoid bud injury. To avoid bud damage correct time and temperature has to be maintained as uniformly as possible. Inadequate time and temperature combinations tend to escape the plants from correct heat therapy.

Post treatment care involves the sterilization of cane cutting equipment. Unhygienic condition may re-infect the seed for further contamination.

The best procedure in hot water treatment is to treat the seed at sugar mills level and to grow it at sugar mills farm under supervised planting system. The seed so propagated may be distributed to growers next season. In case some disease contamination is observed the disease infected plants may be rouged out of the seed plot.

Hot water or hot air treatment improves germination by killing the pathogen, activating the nutrients and also by softening the bud scales. Hot water treatment to setts of RSD affected variety NCo 310 at 52°C for 20 minutes improved germination by 24.23% over untreated setts. Hot water treatment for longer duration (50°C for 2 hour) had drastic effect on germination (Gul, 1990). The hot air treatment of whole cane stalks was also reported to improve germination (Shukla et al, 1979). Hot water treatment is also known to alter the effect of Hormone (top dominance) as buds of whole cane treated with hot water germinate uniformly.

**Damaged seed**

Seed could be damaged due to a number of reasons:

- Frost occurrence damages the seed buds due to frozen tissues.
- Lodged cane is also liable to be damaged either due to bud sprouting or rotting of cane stalks.
- Stale, dry cane has poor germination and extent of loss depends on the nature of dryness of buds and cane stalk
- Seed cane could be physically damaged due to friction to buds during transportation or during peeling of the trash with sharp sickles.

**Seed placement and soil cover**

Soil cover is a little bit of firm packing of soil, on seed setts, done with manual hand/ foot operation, by running over of wheels or drums on cane row by light tractors. It helps push soil around seed setts to cover nodes with root primordial. It should be firm, not compact, to remove air pocket. Seed placement and soil cover relate to the preservation of moisture around seed pieces, saving seed from vagaries of temperature extremes and mechanical pressure on seed setts. The seed planted in deep trenches and furrows is to be given a shallow soil cover. In dry planting, irrigation is to be delayed till germination; seed cover should be thick enough to conserve moisture for pretty long duration. A 5-8 cm soil cover
would preserve moisture to give satisfactory germination. If all conditions for germination are favourable, light cover is enough but if moisture is to be a limiting factor thick cover ensures good germination. However, soil type and its preparatory state are of prime importance. Hard clay soil needs less cover to avoid mechanical pressure than sandy loam soils where in bud emergence is no problem. Germination is always less in unprepared soils with smaller clods, as it loses moisture soon and bud emergence and root development is checked.

Under late autumn planting, temperature becomes a limiting factor, for which light cover is advocated to expose the seed pieces to sun heat. In case of planting late in spring, when temperature gets high, thick cover should be applied to avoid sun drying on surface layers. While applying thick cover, it should be ensured that the soil is well pulverized, is in good tilth and contains enough moisture.

**Seed Health Programme**

Seed health affects germination, speed of emergence and vigour of sprouted shoots. Since germination affects the basic stand of the crop, it is an economic factor. Sugarcane seed is the costliest component of the production cost of sugarcane. It accounts for almost 20-25% of total cost of production of cane crop. For attaining good germination, utmost care has to be taken in selection of seed crop. Seed crop should be healthy, nutritionally vigorous, erect standing and free of pests and diseases. Seed could be selected from top portion of cane stalk, or soaked to compensate staling losses. In usual farm operations, such precautions are considered unusual and one feels inconvenience. In general, practice, it becomes difficult for a grower to take all the precautionary measures in selection of healthy seed from the main crop. The best way is to grow a healthy crop specifically for seed purposes. There could be two devices for a seed health programme.

- Growing seed nurseries.
- Propagation of seed through tissue culture

**Growing seed nursery**

The grower should use his vision for seed requirements of the following year crop. The seed crop needed the next year is planted in separate nursery. For this purpose following measures are to be taken:

- Land for seedbeds is selected from the nutritionally rich fields.
- Land is well prepared and added with FYM/Press Mud.
- Seed cane is taken from a healthy crop and is treated with fungicides like Benlate, Agalol, Areton and Topsin-M etc.
- High seed rate is used to achieve thick plant population.
- During the course of crop growth, the cane field is kept free of weeds and pests.
- Crop is supplied with adequate irrigation and fertiliser. The last dose of fertilizer may be applied nearly 30 days prior to harvesting.
All precautions are taken to save the crop from lodging.

All these measures help provide healthy seed for ensuing crop season. To make the seed free of some of the fungal diseases and RSD hot water treatment is the usual feature of seed care in some of the advanced counties. In India hot water treatment plants are manufactured by some factories and supplied to sugar mills. These are fixed or mobile Moist Hot Air Treatment Plants (MHATP), having the capacity of treating 1000 Kg to 2000 Kg seed per operation. These plants are operated in sugar mills. The seed is treated and planted at sugar mills farms and there from the healthy disease free seed is supplied to growers.

**Propagation of seed through tissue culture**

This is the latest technique for propagation of disease free seed. The buds being covered by leaf sheath and scales are usually free of infection. As such, shoot tip culture is successfully applied for elimination of seed born diseases. The technique is extensively utilized for micro-propagation of healthy seed.

![Cane seedlings (plantlets) raised through tissue culture, being grown in a temperature control fibre glass house](image)

The callus culture technology helped in eradication of mosaic virus in three cane varieties CoL 54, L116 and BL4 (Mirza and Shaheen, 1987). It is reported that propagation of disease free healthy seed increased yield and quality of cane (Siddque, 200). The author during his ex-Pakistan tour observed that the technique is being effectively and extensively utilized in China and India for propagation of healthy seed.

In Pakistan, Shakrganj Sugar Research Institute, Jhang has taken up work on micro-propagation of new cane varieties developed at the Institute. The technique is useful not only for micro-propagation of healthy seed but also for rapid release of new cane varieties.

**Seed Rate**

Plant population in a cane field is regulated by seed rate, its germination and tillering capacity of varieties. Seed rate is a basic unit that has empirical importance in
establishing a basic stand of crop. In establishing a good crop stand foremost
cornerstone consideration has to be given to a right quantity of quality seed. Optimum seed rate
develops a good number of initial shoots to develop desired cane stalk population. The
seed rate depends on variety, planting season soil types, seedbed preparation and planting
methods.

In India, the amount of seed corresponds to 30,000 three-eye buds or 50,000 two eye-bud
setts ha⁻¹ (Hunsigi, 2001). For wider row planting (1.5 m apart rows) in USA, 3.5 - 4 ton
ha⁻¹ is usually applied when planting is carried out by machine. Higher seed rates (6-8 t
ha⁻¹) are essential as the setts are then placed with less precision (Blackburn, 1984). Cane
planting in Australia is fully mechanized, where whole stalk planter require 3.5 tonnes
of cane ha⁻¹, while billet planter would need higher seed rate of 7.5 tonnes cane ha⁻¹ with
billet length of about 300 mm (Hogarth and Allsop, 2000)

Low seed rate would have low plant population thus affecting the yield of cane. Therefore, the seed should always be in optimum rate. A cane stalks population of
100,000-120,000 ha⁻¹ or 10 to 12 per sq. m. is considered ideal for good crop yields
(Hunsigi, 2001). To obtain this stalk density the following seed rate is recommended for
optimum conditions of planting in Pakistan. The seed rate may be measured on the basis
of cane weight or seed set count per unit area of plating.

Cane weight basis: 7-10 tons ha⁻¹.
Cane setts counts: 60,000-75,000 double budded setts ha⁻¹
or
40,000- 50,000 three budded sets / acre

As a layman advice and easy to measure, single row of over-lapping setts give
generalized measure for 3 feet row distance, and more or less two rows of setts placed
end to end give required weight or volume for planting in 4 feet row distance
furrows/trenches.

- Incase of thin slender cane stalks seed rate would be lower in weight compared
to thick cane stalks. Thus the seed rates of thick and thin cane varieties would
vary accordingly.
- The lesser seed would be used for cane with short inter-nodes than longer inter-
nodes.
- Delayed planting reduces germination due to low temperature in late autumn
and high temperature in late spring. In both the cases the seed rate should be
increased by 25 to 30 percent.

Cane stalk population at maturity depends on germination, tillering and shoot mortality
occurring under different environmental stresses. Considering an average germination of
50 % and average tiller count of 2.5 per germinant, mill-able stalks would account for
about 105,000 ha⁻¹. This is the case for a thick cane variety BL 4, planted in March; the
variety planted in September would have more germination rate and more tillering hence
more plant population. Similarly varieties with high tillering capacity may have more
plant density over 150,000 plants per hectare.
Method of Planting

Planting methods vary in different climatic regions, soil conditions, soil types and the advances attained in cane culture. Planting methods affect growth of plant and ease in after care in inter-row cultivation, hoeing, earthing up and plant protection operations especially weed control. In developing countries manual planting is in vogue using bullock power and in part tractors for field operations and furrow making, while, in advance countries, planting is fully mechanized.

Manual Planting

Moist “Wattar” planting

After the land is finally prepared for planting, it is irrigated. And, as the field comes in field capacity or is properly moist, it is well pulverized using disc harrow and cultivator followed by planking. Furrows are made to 15-20 cm depth and seed setts are planted. The setts are then covered with moist soil by planking to have 8-12 cm compact surface over setts. The next irrigation is delayed till completion of germination. To have good germination the field should be well pulverized to a fine tilth and the moisture should be preserved to its optimum.

This method is more useful in early planting during February or late autumn during November. The method is not suitable for planting during hot weather, as soil looses its moisture soon, which affects germination. The methods are best suited to good loam soils that retain good moisture; hard, clay soils do not suit for this method. The seed soaked for about 24 hours ensures good germination.

Dry furrow planting

After seedbed preparation, the field is planked and shallow furrows (15-18 cm deep) are made at suitable row distance. The seed setts are placed in furrows and are given very light soil cover (2-3 cm). The field is then irrigated. During hot weather, irrigation may be repeated to ensure prolonged retention of moisture in soil. As the soil comes in proper moisture condition, the inter-row space in furrows is cultivated with suitably designed cultivator, planking is then done to compact the surface to preserve moisture.

Soil moisture is a key factor to pick right stage of cultivation and moisture preservation.
Cane and Sugar Production

Cultivation at wetter stage hardens the soil to make a surface very compact to suppress germination. Cultivation in over dry conditions digs out pebbles that dry out soil moisture, which too hampers germination.

This planting method can best be applied in loam soils. The hard clay soils would not create fine tilth for preserving moisture; there is more chance of puddling on inter-row cultivation. Such types of soils suit more to trench planting.

**Trench planting**

In well-prepared seedbed, 20-25 cm deep trenches, at 90, 120 or 150 cm row distance are made with the help of a ridger. Narrow row spaces will make shallow trenches while wider row spaces can make deep trenches. For good trench formation, the soil should be worked deep and well pulverized. After trench formation the furrow surface should be loose and friable. On less permeable soil trenches are made shallow that the seed could be placed on loose friable soil. Hard surface hampers the root penetration in soil. For dual row planting in trenches at 120 cm space a ridger has been designed that prepares two small furrows (10 – 12 cm apart) in the bottom of the trench (Fig-----). Two rows of seed sets are placed in this furrow and are given light soil cover. Irrigation water is applied in the trenches. Field is given light irrigation at 10-15 days interval as per water requirement of the field. As the germination is complete and tillering start, inter-row ridges are cultivated to fill in the trenches gradually. When crop grows further and leaf canopy covers the inter-row spaces, next run of ridger make new trenches and simultaneously earth up the cane rows.

In trench planting, field has to be irrigated at desired frequency to achieve good germination. Therefore, the irrigation water supply has to be assured for successful rising of crop. Repeated irrigation, at the very start of the crop, encourages weed growth; therefore, the techniques require pre-emergence effective herbicidal control.

The chief advantage of trench planting is that cane gets a good anchorage and does not lodge. The plants are earthed up, which besides proper anchorage to stools against lodging, help prepare new trenches for irrigation. Water can be made to flow through trenches without submerging the field especially during July- August when flood
irrigation followed by speedy winds tends to lodge the crop. The technique is reported to save water with additional yield of cane over flat/ furrow planting (Hunsigi, 1993).

**Slant planting**

In areas of high rainfall, in clay soils and in water logged conditions “slant” planting can be adopted (Hunsigi 1993). Three budded setts are planted, 2-5 cm deep, either on the top or on the side of the ridges. The setts are inclined on an angle of about 45°, so that one bud is buried in the soil and two buds are exposed. The exposed buds germinate. When excessive water recedes sett is pressed horizontally in soil, so that germinating shoots develop roots and plants get established thereafter.

**Side planting**

In saline soils of relatively high pH, germination is a great problem. In such conditions, trench planting is done, but with a different technique. Two budded setts are horizontally placed on the side of the trenches just 4 or 5 inches down from the surface. The water is passed through the trenches. The salts move on to the surface of the trenches and don’t accumulate in root zone. As such bud sprout and plants get established without many problems.

**Spaced transplanting technique (STP)**

Single eye cuttings with many special treatments have been used in Java and many other cane producing areas to increase the seed supply of a new variety at a rapid rate (Humbert, 1968). The technique is reported to be the most efficient for rapid seed multiplication (Srivastava et al, 1981). A settling nursery is established in an area 50 m² (5 X 10 m) with small plots of 1 m². About 30,000 single eye setts are vertically pegged in well-prepared plot incorporated with FYM or press mud. The buds with root band remain above the soil surface, and are covered with cane trash or rice straw as shade from sun. The setts are sprayed with hand sprinkler to keep the buds moist. The buds sprout and nursery is ready for transplanting in 3-6 weeks depending upon ambient temperature. The settlings are transplant at 90 cm X 60 cm row to plant distance.

For ease in transplanting, holes be made in furrows at 15 cm with wooden pegs. The settling is pushed vertically in soil so that sett is fully covered in soil, leaving 3-4cm of topped shoots above ground. Survival of transplanting is regularly inspected to fill in the gaps where necessary. The technique ensures saving of seed by 60 %, better tillering, more uniform stand, and 20-25 % higher yield over ridge and furrow system (Hunsigi, 1993). The technique can best be utilized for gap filling in usual planting practices as well as in patchy ratoons. Since growth is proportional to green leaf area, the transplanted seedlings often reduce the time required for the cane to close in (Humbert, 1968).

**Planting of Cane**

Cane planting is either manual or mechanical done by automatic cane planter. Manual planting is the conventional method usually adopted in most of the under developed and developing countries. Cane after harvesting is carried to the fields intended for planting. Trash is removed by hands or hand tools, and cut pieces of stalks are placed in furrows or
trenches in single or double rows of setts placed end to end. The cane setts may be placed overlapping each other. Setts are slightly covered with field earth lying around setts in the furrows or trenches. Soil cover is provided by hands or feet. In some countries whole cane stalks after de-trashing is planted in furrows or trenches. Seed setts are cut in situ with the help of an axe, or toka. Different hand tools are in use in different countries for harvesting cane and cutting cane stalks into seed setts. In the figure shown here under whole cane stalks are placed in canes rows and small seed pieces are manually cut by a sharp “toka” or knife. For manual planting the author found it very efficient and time saving operation.

**Mechanized Planting**

**Cane planters**

Planting is a very important operation and involve high costs. Good germination and emergence with no gaps are essential to provide a sound foundation of future crop stand both in plant and ratoon crops. A successful planting operation depends on the machinery used, the quality of planting material and the way the equipment is operated. Two types of planting machinery are in use 

A. **Billet Planter**  
B. **Whole Stalk Planter**

**A. Billet Planter:** Before planting operation, the cane stalks are cut into billets with billet harvesters and are than loaded into planter box. The billet planter has two boxes, one with the cut cane pieces, 'the billets', and the other one with fertilizer. A fungicide chamber is underneath it. The machine makes furrows, the cane setts pass through the fungicide chamber and a rotary mechanism feed out cane setts into furrow. Simultaneously fertilizer is applied in to the furrow around cane setts and the back tine covers the setts with soil. Some modification is however, needed in harvesters to avoid billet damage and regulate sett size to about 300 mm length.

**Whole Stalk Planter:** These planters have a cutting mechanism to cut the stalk into billets approx 300mm long. Whole cane stalks are loaded in the planter. As the machine operates, stalks are cut, passed through a chute and placed in furrow; setts are simultaneously covered with earth.
The farm machinery institute PARC, Islamabad, has designed a two rows tractor rear-mounted, automatic sugarcane planter (Farooque et al, 1986). It makes three trenches (75 cm apart) at a time; fifteen to twenty maund of seed cane is carried on side rakes of the machines. Two persons sit on the machine and feed the cane stalks manually to the sett cutting system behind the ridger. A chopper cuts the setts of about 45cm length, which are dropped through choutes and laid in lengthwise position in furrow bottoms. Two seed setts pieces go to each furrow. The tractor speed can control the placement of setts end to end, in 50% overlapping manner or double sett placement. There is arrangement of fertilizer application in bands on both sides of furrow. The covering tines and rollers then cover these setts with a thin soil layer. The machine has working efficiency of 3.25 hectares per day of 8 hours.

In using the automatic cane planter, care has to be exercised in selecting the erect cane stalks. Uniform feeding of stalks to cutting mechanism has to be regulated and choutes have to be frequently checked that these are not blocked with setts, machine is not choked and that setts are not missing in furrows or more than two drop in one place.

**Earth cover on seed setts**

Cane setts after planting are covered with a layer of soil. Care has to be taken to apply soil cover actually needed, and it depends on soil type, ambient temperature and moisture.

1. A thick soil cover on seed setts depress germination
2. The sets lying naked get dried, or buds sprouted would not survive long if set node is not in touch with soil for root development
3. The earth cover should not be more than 2 – 3 cm thick. Planting in hard clay soil need very light cover
4. The sett should have complete layer of soil around it without clods
5. The soil cover should be firm without air pockets

**Row spacing**

Cane is planted in furrows or trenches drawn at certain row space. Inter row space regulates plant density, competition among plants/ shoots for light, and nutrients from soil and for light interception above ground surface. These factors in turn affect tillering, shoot mortality, height, girth and weight of cane. Row width is regulated keeping into
consideration the soil type, climatic conditions and cane varieties.

The genus Saccharum belong to the family graminae, which under favourable conditions of light and space produces more of secondary and tertiary shoots. These shoots convert into mill-able cane availing of length of cane growing season. In climate regions with short growing season, quite a few shoots are transformed into mill-able stalks, but in long growing conditions they avail of longer period to produce more tillers that result in a large number of mill-able canes. Thus for a short season crop a narrow row width is considered optimum, but in case of long growing conditions of hot summer and mild winter wider row space is judiciously utilized to mature more number of stalks. The row spaces adopted in different countries, reviewed by Hunsigi, (1993) and Blackburn, (1984), is reproduced in Table-5.07

The data indicate that sub-tropical regions of India and Pakistan have adopted 0.75 - 0.90m row spaces, while the tropical regions grow cane with 1.2 - 1.8 m row distance. It is in fact the space adjustment for a crop producing more or lesser number of tillers/stalks according to prevailing conditions of climate and advancement in cane culture. In principle, row space should be such as to obtain a reasonable high percentage of ground cover by three months of crop age and one that will grow 4-6 mature stalks per foot of row at harvest (Humbert, 1968).

Table-5.07 Cane rows spaces adopted in different countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Row space (meter)</th>
<th>Country</th>
<th>Row space (meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>0.6 - 0.9, 1.2</td>
<td>Argentina</td>
<td>1.6</td>
</tr>
<tr>
<td>Puerto Rico</td>
<td>1.2 - 1.35</td>
<td>Cuba</td>
<td>1.65</td>
</tr>
<tr>
<td>Brazil</td>
<td>1.2 - 1.5</td>
<td>Taiwan</td>
<td>1.2</td>
</tr>
<tr>
<td>Australia</td>
<td>1.8 - 2.1</td>
<td>Philippine</td>
<td>1.25</td>
</tr>
<tr>
<td>Indonesia</td>
<td>1.2 - 1.5</td>
<td>Pakistan</td>
<td>0.75 - 1.2</td>
</tr>
<tr>
<td>Mauritius</td>
<td>1.5 -1.8</td>
<td>USA. Louisiana</td>
<td>1.8</td>
</tr>
<tr>
<td>S. Africa</td>
<td>1.5 - 1.8</td>
<td>Florida</td>
<td>1.5</td>
</tr>
</tbody>
</table>


In India - Pakistan sub-continent the indigenous planting system was to plant cane at 30 – 45 cm rows space. This space very well accommodated the thin slender stalked varieties with low biomass and yield. With change over of thin to medium thick cane varieties the row distance was increased to 60 cm. at Faisalabad. The 60 cm has been the usual recommended row space till the end of 1960, thereafter row space was gradually increased to 75 - 90 cm. But varieties and planting season do play a
considerable role in regulating the row spacing (Fasihi and Malik, 1989). Data indicate that in spring planting 1.5m row spacing produced more tillers per plant, but overall cane stalk population and cane yield exceeded in closer spacing of 1.0 m. On the other hand in autumn season crop, wider row spacing gave significantly higher yield than closer spacing (Table-5.08). The variety BL 4 showed better response to wider row spaces than erect growing variety BF 162. Due to long crop duration September planting had enhanced tillering and cane stalk population in wider spacing over closer spacing.

In case of closer spacing growth of excess tillers is suppressed due to shading effect. Wider spacing also improved cane quality due to better light interception, and its utilization for sugar assimilation. In Taiwan as well, traditionally, row spacing of 1.0 m for spring planting and 1.25 m for fall planting are being practiced.

Wider row planting showed better cane quality than closer row distance, due to better aeration and light interception to cane stools.

Table-5.08 Effect of row spacing on the yield and quality of sugarcane*

<table>
<thead>
<tr>
<th>Row spacing</th>
<th>Spring planting</th>
<th>Cane yield t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tillering</td>
<td></td>
</tr>
<tr>
<td></td>
<td>BL 4</td>
<td>BF 162</td>
</tr>
<tr>
<td>1.00</td>
<td>1.15</td>
<td>1.17</td>
</tr>
<tr>
<td>1.50</td>
<td>1.56</td>
<td>1.94</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Autumn planting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00</td>
<td>2.31</td>
<td>2.34</td>
</tr>
<tr>
<td>1.50</td>
<td>1.76</td>
<td>2.74</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>0.168</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cane Quality-CCS% Cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
</tr>
<tr>
<td>1.50</td>
</tr>
</tbody>
</table>

* Malik and Ali, 1990

Previous studies in India advocate for closer spacing of 0.75 m to 1.0 m between rows with setts placed end to end (Hunsigi, 2001). Since wider row spacing is essential for mechanized cultivation, Mahalingam (1999) considered 150 cm better than closer spacing. Wider spacing is likely to improve cane weight and girth, but plant density is considerably reduced. Plant density was made up by paired row planting at 60 – 120 - 60 cm with 80,000 three budded setts per hectare, that gave significantly higher yield than the conventional method of planting (Yadav, et al., 1997). The authors also observed 25% saving in water. However, land productivity is a key factor in determining row space; under low levels of soil fertility, closer spacing is considered better while under heavy soil fertility status wider spacing is beneficial (Parthasarathy, 1972; Singh et al, 1981). It was concluded that the profuse tillering variety performs
better at wider row spacing while low tillering variety gives better yield at narrow row spacing (Hunsigi, 2003).

Cane yield is taken as a function of stalk population, height and weight per cane, but the stalk population account for 70% variation in cane yield (Hunsigi, 1993). Studies in Louisiana also emphasize the role of cane stalk population in increasing cane yield. A review of experiments over 80 years showed that decreased spacing’s to 0.90 cm resulted in increased yield of cane over wider row spacing (Irivine et al, 1980). This yield increase was attributed to the increase in plant population. While deciding for row space in a given climate, there has to be a compromise on yield with the use of farm equipment and ease in operation. Yield should predominate as an economic factor, but advance in cane culture demand efficient use of farm machinery for efficient handling of various farm operations from planting to harvesting. Besides the fact that data favors closer spacing (61 to 91 cm) in Louisiana, poses field management problem in the use of farm machinery (Irivine et al, 1980). Therefore, wider row distance of 1.8 m has been adopted to accommodate machinery operation in the field from planting to harvesting.

In Australia single row spaced between 1.4 and 1.65 m apart has been the general practice. At row space of less than 1.4 m, there is every danger of stool damage during machinery operations, while at wider row distance crop yield is reported to suffer due to low plant density. The machinery is generally designed for a row track of 1.8 m. As such high density dual row spacing (50 cm) in 1.8 m space has been introduced and has given higher yield over single row spacing (Willcox et al, 2000).

In Mauritius as well, dual row planting in cane rows of 50 cm apart with 180 cm between their centers gave 11% higher yield over a single row control with 160 cm spacing. Dual row planting is considered more advantageous in terms of weed control due to high plant population, canopy closing approximately four weeks earlier and better working efficiency of chopper harvester (Seeruttun et al, 2003).

In Pakistan, equipment has been designed to accommodate dual row spacing at row distance of (60 – 120 – 60 cm). Since the system has higher plant density, works well both for autumn and spring sowing. Depending on soil productivity and planting season row spaces can be increased or decreased. For autumn planting (60 – 120 – 60 cm) space would work well and for spring season (50 – 100 - 50 cm) is better the wider inter-row space of 100/120 cm facilitates the movement of tractor for various inter-row operations. Importance of row space lies with the farm equipment and machinery in use and the size of farm. Closer row spacing (75 - 90 cm) would suit better to bullock cultivation and small holdings. Heavy farm machinery can’t operate in close space; their working
efficiency demands wider row spacing (120 – 180 cm). Cane varieties have also their preference to a certain space for effective utilization of light and nutrients. So the plant growth and farming system should coincide the row distance for the maximum yield. Nevertheless from future trends of mechanization minor yield deflection has to be over looked and farming efficiency has to be the main economic consideration.

Lodging

Lodging in a full grown crop occurs under conditions of irrigation and rain fall followed by wind. Standing crop is laid down partially, completely or may even be up rooted. Degree of lodging varies with soil type, varieties, stage of growth and wind velocity. A heavy yielding crop is more prone to lodging. Lodging has deleterious effect both on yield and quality of cane and causes tremendous economic losses both to growers and sugar factory.

1. Crop provides good shelter to rats and hibernation place to several pests. Rats cause severe damage by cutting and eating cane stalks.
2. Borer infestation in a lodged crop is considerably high.
3. Lodging induces buds to sprout and develop side shoots.
4. A lodged crop, if up rooted, dries soon.
5. Under water logged conditions or excessive rains, a lodged crop rots.
6. A lodged crop provides environment quite conducive to disease infection and spread of inoculums.
7. Lodged crop would give poor ratoon.

Overall effect of lodging is:
- A decline in cane weight and increase in fibre
- Fall in juice quality and rise in invert sugars
Yield and quality losses steadily increase with time after lodging

Once the crop is lodged the grower and industry has to bear the losses, nevertheless, the losses can be minimized if lodged crop is harvested for crushing at the earliest. But severely lodged and badly damaged crop if mixed with normal healthy stalks, would depress the juice quality. The juice of a lodged crop is heavily contaminated with non sugar forming bacteria that would deteriorate the juice during its clarification process.

In an experiment, the cane crop was artificially induced to lodging in the months of August, September and October. The lodging during this period showed a yield decline of 18.4, 14.1 and 3.8 % with C.C.S. loss of 21.1, 13.5 and 11.0 percent, respectively. The lodging reduced the sucrose contents from 16.34 to 8.82 % and increased glucose from 0.38 to 1.04 % (Fasihi and Malik, 1989). Losses in yield and quality depend on degree and time of lodging. In case of severe lodging, yield and quality losses may be as high as 50 to 75 %, and even more. Further that it is difficult to harvest, pick and load. In extreme cases crop, rot in excessive rains and floods.

**Measures to Control Lodging**

*Cane varieties*

Some varieties tolerate lodging while others are prone to lodging. Lodging tolerance is an inherent capability of varieties having hard rind, well-developed root system, tapering cane stalks with lightweight tops. Varieties having compact stool with erect growth habit are preferred than the varieties with loose scattered stalks and bent position.

*Soil fertility*

Very fertile soil produce vigorous crop and heavy crop has more tendency to lodging compared to a weak crop. Heavy soils need very judicious application of fertilizer at right time. Nitrogen application should be finalized by the end of May. Late application makes the crop more succulent, which is more prone to lodging.

*Irrigation*

In the early stages of crop development frequent irrigation keep the root system in upper surface. To promote roots growth to deeper layers, a slight moisture stress should be allowed in early plant growth stage. Negligence in proper irrigation application to a well-grown crop stage during July and later month is one of the main causes of lodging. A care has to be exercised while irrigating the crop. Heavy irrigation loosens the root mass and crop is more prone to lodging on higher wind speed. Light frequent irrigation is better than heavy irrigation. The soil must not remain wet; it should be intermittently kept wet and dry with better support to root system, and it is possible with judicious irrigation practices.

*Land preparation and planting methods*

Deep ploughing helps the roots to penetrate to deeper layers. Well-established deep root system gives better anchorage to cane plant, against lodging. Planting in trenches is helpful in establishing stout stools in soil. To avoid up-rooting on lodging, the primary and secondary shoots should not develop near to soil surface but from deeper layers, for which the soil should be loose and friable.
Row distance has special role in crop management against lodging. In narrow row spaces crop is tender and soft, but at wider row distance cane stalks are thick and stout due to aeration and light interception. The row distance should be suitable to facilitate earthing up of stools. The animal driven ridgers work well at 75m-90cm row distance, but tractors operation requires somewhat wider spacing.

**Earthing up**

The main objective of earthing up is to give anchorage and additional support to the stool as an aid in keeping cane stalks erect. Earthing up is also done to suppress late tillers, which are drains on mother shoots and early-formed tillers depress their growth. When to earth up is a matter of great concern to growers. Earthing up should be done as and when the tillering is complete. In the first phase, earthing up should be light, this practice promotes tillers formation. In the second phase, earthing should be heavy to suppress further tiller formation and to give strong anchorage.

In small holding earthing is done manually, but in large plantation, ridgers are used for the purpose. Inter-row disc cultivator does better function both for light and heavy earthing by angling and tilting the position of discs.

**Tying**

As a safeguard against lodging it has been usual practice in the past to tie up two stools of adjacent rows. Tying is done when the crop is fully-grown some times during August. Plants are tied with dried leaves of the same stools. Stools are brought close together, wrapped with dried leaves without breaking and are twisted, that they are not opened by heavy wind speed. Two rows are thus tied that wind passes through the rows without any barrier. Young green leaves should not be involved in tying; otherwise the photosynthetic action of plants is disturbed. The dried leaves just lower then the last green leaves are used for the purpose. These days’ nylon tapes are available, which are cheap and are efficient to handle the tying operation. Tying is possible only for 75-90cm row spaces. Wider rows can’t be tied in efficient manner. The same adjacent rows should be tied that tying is symmetric throughout the field length. Asymmetric tying in haphazard fashion would pose barrier and resistance in wind movement and would tend the crop to lodge.

Tying is possible in small holdings. The practice is not feasible in large plantations. Other agronomic practices should be adopted to save the crop from lodging. In tracts facing frequent winds some vegetative hedges safeguard the crop from the blow of winds.

**Ratoon Management**

After harvest of cane crop, there remain stubbles in the soil. Cane stubbles are underground portion of stalks and consist of closed spaced joints with buds and root mass of previous crop. These buds sprout to form shoots in ratoon crop thus a ratoon crop has its own shoots and root system.

**Shoot growth**

Stubbles have well established root system left from previous crop, therefore shoots start
emerging immediately in favorable environment of growth. These shoots grow fast when triggered with cultivation, fertilization and irrigation. As against this, plant crop takes more time in buds sprouting and initial growth is very slow. Thus ratoon has distinct advantage on plant crop for fast sprouting and rapid early growth. This phase must be triggered with good root development and nutrient supply, the imbalance in shoot and root development may cause cessation of growth.

**Root growth**

In the initial stages ratoon starts functioning on the stubble roots, but these are less efficient in absorbing moisture and nutrients. Meanwhile new roots develop from the root primordial on the new shoots. New roots become the source of nutrients and water uptake from the soil while the old roots get inactive and decay by time. Under favorable temperature new root formation may take 6-8 weeks after harvest of the crop (Hunsigi, 1993). A good ratoon crop is obtained by rapid development of shoots and roots, which is triggered by favorable climate, loose fertile soil and supply of nutrients and moisture.

Shoots of ratoon originate from stubbles buds, which are on higher level. Since roots develop from these shoots, remain shallow as compared to the roots of plant crop. Therefore, the ratoons have less anchorage and are subject to more chances of lodging and soil moisture stress.

**Tillering**

As the ratoon crop establish an initial stand of cane shoots, is followed by development of primary and secondary tillers. Plant density per unit area is very high in ratoon crop than preceding plant crop. The extent of tillering and shoot development depends on cane variety and environment for plant growth. However, their plant population is subject to high competition for light and food, followed by shoot mortality noticed in July - August. Due to high plant density, per cane weight of ratoon stalks is generally low.

**Maturity**

Early shoots formation and their fast growth increase the age of cane stalks relative to the age of plant cane. This feature is associated with lower water intake, low intake of N fertilizer but large consumption. It results in early ripening of cane leading to high sugar contents during early harvesting. Depending upon cane varieties, this difference minimizes as harvesting proceeds till the end of December.

Economic gains in cane production are achieved by management of good ratoon crop. The ratoon economizes the production cost of cane by way of saving in the land preparation, seed bed, cost of seed and planting expenses. This saving accounts for 30 to 35 %, of the total cost of cultivation and it is a substantial saving for a farmer. As for sugar recovery, ratoon matures 3-5 weeks earlier than plant cane thus the crop harvest gives higher sugar yield during this period compared to plant crop. Depending upon the variety, ratoon crop gives 0.7 to 1.0 degree higher sugar in the earlier season. The early harvesting, if not to be kept as next ratoon, provides the opportunity to vacate the field earlier for accommodating some other crop in the cycle. Though, ratoons generally yield lesser cane weight, but still economic advantages to growers are substantial over plant crop.
Ratooning potential of varieties

Cane varieties have inherent potential to yield a good or poor ratoon. Cane varieties possessing more number of viable buds in stubbles, are considered good ratooner (Sethiya and Dandsey, 1992).

In Punjab province of Pakistan, Co 1148, a late maturing low sugar variety, replaced most of the varieties in commercial cultivation due to its high ratoonability. It spread in short span of time covering 95-98 % area in central regions. A high sugar variety SPSG 26 could not make ground due to its poor ratoonability. The variety BL 4 has high yield and sugar potential as plant crop, but has not appreciable ratooning; thus growers could not recognize it for large-scale propagation in Punjab. However, in lower Sindh, the growers harvesting high yield prefers to keep BL 4 as a plant crop of this variety. In lower Sindh, Triton also covers vast area due to high ratoonability. CP 43-33 and L 116 have been established varieties due to their better ratooning capacity. For economic production of cane, growers always prefer to grow a variety with high ratoonability. Selection of a good ratooner depends on the gene pool available with cane breeder.

In Pakistan, one to two Ratoons are generally kept and account for about 50 % share in total cane acreage in the country. In some countries with 5-6 ratoons in a crop cycle, ratoon may share 70 – 80 % of total cane area.

Main causes of low ratoon yields

It has been established that with proper crop management practices the yield of ratoon are as good as yield of plant crop. However, productivity of ratoons is generally low ranging from 65 to 90 % (Verma, 2002). Low yields of ratoon are attributed to:

a) Reduced plant population due to gaps and poor sprouts.
b) Decline in nutritional status of soil.
c) Poor physical condition of soil leading to compactness, loss in porosity, poor root development and poor microbial activities in soil.
d) Incidence of pests and diseases.
e) Improper harvest time
f) Improper harvesting technique
g) Stubble damage during harvesting and haulage of farm equipment
h) Growing varieties with low ratoonability

Better Ratoon Management Technology

01. Harvesting technique and stubble shaving

For proper sprouting, shoots development and root formation in ratoon crop, the cane should be harvested just close to or 2-3cm below the soil surface. Stalk pieces left uncut above ground would develop shoots from buds above the surface. Since shoots are not in contact with soil, would later die off. Further that due to top dominance and development of aerial shoots, shoot development on lower segments is depressed. The sub-surface
cutting facilitates healthy sprouts of under ground buds with development of deep root system. Deep roots are beneficial in utilizing moisture and nutrients from lower soil horizon and also give proper anchorage to cane stalks against lodging.

To promote sprouting of shoots from sub-terranean buds, cane stubbles are shaved soon after cane harvesting. In case of manual operation it may be done with sharp axe or Toka, but the most efficient and effective device is the use of stubble shaver. It is tractor operated and shaves the stubbles at desired depth. Stubble shaving is, however, avoided in shallow rooted varieties and in very loose soil.

The practice helps in sprouting of only sub-terranean buds that produce healthy shoots.
As the stubbles are shaved the larvae of borers hibernated in underground parts of stubbles are either killed or exposed to several birds of prey. The device is thus very effective in mechanical/biological control of borers.

Stubble shaving is reported to increase millable cane by 16.6 % and yield by 14.42 % (Verma, 2002).

02. Gaps in crop stand
Gaps in rattoon crop arise due to a number of reasons:

a) Physical injury to stubble buds at the time of harvesting.

b) Severe infestation of pests and diseases depress shoot and root formation, and ultimately die off.

c) Some fungal diseases cause rotting of stubbles.

d) Soil inhabiting organisms like nematodes and grubs attack the roots of cane stubbles and check the growth of new shoots. Severe infestation of organisms results in death of whole stump.

e) Compact soil checks the root development and development of new shoots. Use of heavy farm machinery may induce compaction.

f) Carelessness in the use of farm machinery during farm operations may cause uprooting of stubbles.
g) Persistent cold spells either damage the buds or reduce the capacity of buds to sprout with onset of spring season.

Harvesting plant crop in winter months caused 18 to 26 %, gaps as against 11 to 13 %, observed in February harvested crop (Mathur, 1986). A gappy stand reduces the yield of ratoon crop. ‘Gaps’ causing a reduction of 10 % clumps population does not cause significant loss in cane yield, however, further increase in gaps causes corresponding reduction in yield. Gaps induced to the extent of 10, 20, 30, 40 and 50 %, reduced yield by 1.5, 9.9, 15.9, 23.0, and 33.0 % respectively (Prasad, 1981).

Presence of three viable stumps per meter length in a cane row is considered to be a normal stand for ratoon crop (Prasad, 1981). Depending upon the extent of gaps, gap filling is reported to bring a yield increase of 7.3 % to 40.1 % in sub-tropical and 2.2 % to 14.4 % in tropical belts of India (Verma, 2002).

The gaps can be filled by a number of ways:

a) **Raising of settling in nursery**: Planting single eye nodes in polyethylene bags or single buds on nursery beds, about 3 weeks before gap filling can help develop shoots to fill the gaps. The pre-germinated setts in polyethylene bags ensure quick establishment of plant compared to settling raised on nursery beds (Kanwar and Sharma, 1981).

b) **Uprooted stubbles**: The uprooted stubbles from a discarded cane field can help to fill in the gaps. These stubbles may be planted as such or cut into 2, 3 or 4 parts depending upon the volume of the stubble or the expected sprouting buds in the stubble.

c) **Planting cane setts in gaps**: Cane setts may be placed in gaps portion of cane rows and given the environment to germinate. This method is not much effective in filling gaps. Since rate of germination of cane setts is slow do not match the fast sprouting buds and rapid growth of sprouts established in the ratoon stubble. By the time seed setts germinate, sprouts from neighboring ratoon stubbles grow enough to suppress the sett shoots by shading. However, large gaps can be covered by cane setts.

Gap filling should be completed in early tillering phase. Transplanting in later period dose not keep pace with normal shoots and lack behind in growth.

**03 Soil compaction**

Sugarcane is a long duration crop, that remain in field for over one year and for about two and three years in case of ratoon. In the crop season, soil is subject to the use of machinery for various cultural operations, harvesting, haulage and transport of cane, and irrigation. These interceptions result in soil compaction. The compaction brings disorder in physical characters of soil, soil structure is disturbed, bulk density is increased and pore space is reduced. The impact is magnified with successive ratooning. Penetration capacity of plant root is reduced, and roots face inadequate soil aeration. It also reduce water intake into soil. It has been observed that progressive increase in bulk density is associated with corresponding decrease in dry weight of roots and shoots (Varma, 2002).
Growth and yield of sugarcane ratoon have shown negative response to increasing level of compaction (Srivastava, 1983). The extent of compaction depends on the nature and type of soil. Hard clay soil gets more compact, especially when ploughed wet, while sandy loose soils are not that affected. So while working the soil, its nature and moisture level must be kept in consideration. So as to mitigate the ill effect of compaction, the soil has to be loosened by suitable implements at suitable soil moisture.

**Inter-row cultivation:**

The previous crop is harvested in pockets as per requirements of sugar mills indents. Usually, one cane field is not harvested all at the same time. Since harvesting proceeds throughout the crushing season, growers do not manage a proper care to the crop.

After the harvest is over the inter-row spaces should be thoroughly cultivated. In conventional planting bullock drawn conventional implements including “Desi Hal” may be used followed by Tarphali. In case of tractor operation, inter-row cultivator and harrows have been designed with adjustments of tines or discs for inter row spaces. The implements should thoroughly pulverize the inter-row spaces. One run of cultivator close to stubbles should tear and break the old root mass.

In the initial stages of sprouting, shoots grow fast but stubble roots are quite less efficient, and this imbalance in shoot-root ratio is of disadvantage to ratoons. The growth of new roots is very slow, while stubble roots are inactive. Compact soil hampers the root development and uptake of nutrient moisture. The efforts have to be made to accelerate the development of new roots. Deep cultivation of soil is advocated to reduce bulk density and loose the soil to 30cm depth. Deep cultivation is especially needed in clayey soil to permit better aeration and water infiltration, besides decay of old roots. Cultivation also accelerates the activity of soil organisms.

Usually the inter-row cultivation is delayed till the buds sprout and grow. But it is a burden on old stumps and roots. By this new roots development is slow, thus new shoots get pale. The more feasible situation would be not to delay cultivation after stubble sprouting. Fertilization and irrigation should follow the cultivation. The cultivation operations should continue till tillering and close in of shoots. The objective is to keep the crop free of weeds to conserve moisture and to provide environment for enhanced activities of soil organisms.

**04. Poor crop and soil condition**

General health of preceding crop very well predicts the stand of the expected ratoon. Very weak crop with poor stand and stunted growth in malnourished field would not yield a good ratoon. It is better to abandon such ratoon and replenish the productivity of soil.

Generally growers take ratoon as a free crop and pay least attention to its management. Timely operations to its initial post harvest cultivation, hoeing, gap filling, fertilization and irrigation are altogether neglected.

**05. Nutritional status of soil and crop**

Ratoon is known to have shallow root system and is less efficient user of nitrogen and
irrigation. To harvest good yields ratoons have to be given more fertilizer than plant crop.

06. Weeds

Weeds are a big challenge to sustain yields of ratoon crop. The cane fields with rhizomatous weeds like nuts and sedges pose serious problems in the very start of the crop growth. To assure good cane stand such weeds have to be destroyed through interrow cultivation and manual hoeing within and around stubbles. Suitable herbicides may be used to suppress the weed growth till cane canopy covers the ground.

07. Cane diseases and pests

During the growth cycle of previous crop, pest and diseases are gradually built up in the cane field. If remain unchecked they flourish in the subsequent ratoon. Borers and sucking pests like pyrilla, bugs have ample opportunities to rest in stubbles, hide in trash and flourish on young shoots of ratoon. Some diseases might have shown minor infection on plant crop, but may amplify in ratoon to suppress growth and or destroy the crop. Diseases like RSD, smut, red rot and mosaic have more chances of spread in ratoon. The preceding crop infested with diseases should be critically examined. The red rot infected crop even if in sporadic form should in no case be kept ratoon. Isolated spots of smut may be rouged out to avoid spread, but a large infestation would further intensify the situation. Therefore the crop highly susceptible to a disease should not be kept as ratoon. Similarly care has to be exercised in red stripe and Pokka Boeing. The crop severely infested by pests may provide a ground for further build up of pest population. Crop should be critically watched for population of borers, scale insects, black bugs and pyrilla. Check on cane pest’s lies in adoption of integrated pest management practices.

08. Lodging

A badly lodged crop does not give healthy sprouts of its stubbles. In case the crop was lodged much earlier in the harvested season, it is not likely to give good ratoon. Cane pests including rats hibernate in lodged crop, which cause serious damage to stubbles. By lodging, stubbles are also uprooted. Persistent shade accelerates the decay of stubbles. It is therefore preferred to keep ratoon from an erect standing crop.

09. Time of keeping ratoon

In sub-tropical and temperate climate, time of harvest for keeping ratoon is of great economic significance. In these regions, harvesting period commences during October-November and continues till March or even April. Sprouting is fast in early harvesting, but low atmospheric temperature has adverse effect on sprouting of December and January harvested crop. The crop after harvesting is likely to be exposed to severe winter and frosty nights in some tracts. The buds near the surface are subject to cold/frost injury and results in very poor sprouting. In case the cold spell persists for longer period, stubbles decay and result in large gaps. Therefore, the ratoon kept from winter harvests does not produce good crop stand and yield low. The crop if harvested after winter and
has evaded severe frost damage would produce healthy shoots. For the purpose of ratooning, crop should be harvested in October, November or by the end of winter or early spring. Ratoon kept during this period sprout profusely and grows fast. During a bumper crop season, harvesting may proceed till the end of April. Late harvests give low tillers and total growth period of the crop is reduced which affect both yield and recovery. Autumn harvesting of plant cane resulted in 33.5 percent loss in the yield of subsequent ratoon as compared to spring harvesting of the corresponding crop (Singh, 1976).

In coastal belts and tropical areas crop does not experience extreme cold, and the stubble produce profuse tillers. Tillering is more than plant crop and need proper care to maintain reasonable number of cane shoots. If not properly looked after extra tillers die. In sub-tropical areas suitable time of harvesting is February to April month (Agarwal and Gupta, 1960). April- May harvest gives poor yield of ratoon (Mathur, 1986).

10. Low temperature effect

Under sub-tropical conditions, harvesting during winter is subject to very low temperature that depresses the sprouting of buds. Buds mostly remain dormant and sprout with the rise in temperature during spring. Longer exposures to low temperature affects bud viability and or are sometimes infected with rotting organism. Consequently buds sprouting are considerably reduced. This situation can be mitigated by use of some growth promoting hormones, mulching and intercropping practices.

11. Effect of growth regulators

Some growth regulating hormones are reported to increase sprouting of buds followed by increase in yield. Low temperature effect was reported to be minimized and sprouting of plant shoots and cane yield was increased by spreading of transparent polythene sheet, loosening of soil, spray of fungicides and growth regulators. The growth regulators, Cycocel @ 5 l ha\(^{-1}\) (Verma and Yadav, 1988; Chauhan et al, 1984), when sprayed on stubbles just after harvesting of preceding crop enhanced stubble bud sprouting and gave 7 to 21 %, increase in yield. Treatment of Etheral causes the release of ethylene in plant tissues (Warner and Leapold, 1969) which stimulates peroxidase activity leading to destruction of endogenous auxins responsible for the inhibition of buds (Verma, 2002).

The Management of Cane Trash

The harvesting of cane may be mechanical or manual. When green cane is harvested with combine harvesters, trash is uniformly spread on cane field as green cane trash blanket (GCTB). The GCTB is dealt as mulch and is later incorporated within cane rows as organic manure for ratoon crop.

In case of manual harvesting of a good yielding cane, heaps of trash is lying in the field. In conventional cropping this trash causes difficulty in inter-row cultivation, hoeing, irrigation and fertilization of crop. Trash if not removed suppress stubbles sprouting and tillering. The trash suppressed shoots of cane remain weak and pale. It is therefore imperative to properly handle the trash. There could be four options to handle the trash:

a) The usual procedure is to burn the trash and clean off the cane fields.

b) To use it as a mulch for moisture conservation.
c) To remove it aside from cane field.
d) To collect it from cane fields and to use it as fuel in cane factories.

Trash burning
In some of the field's trash is burnt before harvesting in standing cane crop for mechanized harvesting. In Indo-Pak sub-continent trash is mostly burnt after cane harvests. Thus the nutritional value of the trash is often ignored and is burnt in the field. Burning takes minutes to dispose off the trash without any cost. If cane crop has to be kept ratoon to initiate better growth it needs inter-row cultivations. Trash creates hindrance in cultivation operation. It is considered worthwhile to burn and clear the field. In fact losses are more than benefit if any.

Poor impact of trash burning
1 Burning of trash residue after harvest results in losses of 90-95 % of carbon, nitrogen and sulfur as gases to the atmosphere. 80-90 % phosphorus, potassium, calcium and magnesium can also be lost as air born ash.
2 Organic matter is burnt thus biological activities in soils are affected.
3 Smoke pollutes the environment with CO₂ gas.
4 Heat generated in the field destroys useful parasites and predators and thus upset the natural balance in pests and predators/parasites population.
5 Heat generated kills the earthworms that affect the macro bioactivities in soil degradation.
6 The stubble buds near surface are killed by heat, creating gaps in cane stalk population.

Benefits of trash residue
During manual harvesting tops are collected to use as fodder, while dry leaves, the trash remains in the field. It should be spread in the cane field to give even cover on the ground.
1 In sub-tropical and temperate conditions this ground cover raises the temperature and thus saves the stubbles from exposure to chilling cold.

2 Trash cover is very helpful in suppressing the weed growth during winter and spring season.

3 Trash blanket helps in the conservation of moisture under condition of water shortage, this practice economizes considerable amount of water.

4 Since burning is avoided, it saves the whole biological system in cane fields. Useful soil microbes and microbes remain active. All the parasite and predators are saved to keep up their breeding cycle, which otherwise is destroyed by burning. Thus it keeps the natural balance in pest and predator/parasite population for favorable biological pest control environment.

5 The environment below the trash blanket should be kept under close watch against spread of unwanted pests like centipedes, millipedes and other hibernating insects.

Complete trash cover on cane field not only suppresses the growth of weeds, checks the sprouting of stubbles. The sprouted shoots remain pale and week. So as to promote healthy sprouting, as the winter is over and stubbles starts sprouting, trash should be removed aside to expose the stubble rows to light. By the time cane sprouting is complete; disc ratooner should be operated in inter-row spaces. By this time the trash gets soft and can easily be churn and incorporated in soil to mix as organic matter.

In actual field practice advantages of using trash as mulch are far more pronounced than looking for an ease in trash disposal as burning.

**Trash as mulch**

Trash is a potential source of organic matter and when properly incorporated add considerable amount of nutrients in soil. Trash, the leaves portion of cane crop, amounts to 10-12 % of weight of mill-able cane. It is a big volume of surface residue to be used as mulch to conserve moisture and later to be converted to organic matter, when incorporated in soil. Its value as organic matter and nutrient supplier is of great worths (Shrivastava et al, 1992). Trash mulching @ 3 t ha$^{-1}$ and use of gamma BHC at 1 kg a.i. ha$^{-1}$ gave higher yield of ratoon crop over other methods of disposal of cane trash (Yadava, 1991).

Allowing the trash to remain in soil resulted in improvement in soil fertility with obvious increase in organic matter, a decrease in pH, and an increase in level of N and K in the soil. The recommended ‘K’ level could be reduced by 25-30 kgs ha$^{-1}$ when trash has been incorporated in soil and N inputs could be reduced by about 50-60 kgs ha$^{-1}$. As such trash blanket reduced the organic matter depletion and maintain the ‘N’ level in soil (Thorburn, et al, 2001).

Burning cane trash after harvest is the usual practice followed by cultural operations involving the use of heavy farm equipment including stubble shaving, off barring, ripping, inter-row cultivation and fertilization. The objective of intensive cultivation in ratoon is to obtain good soil physical environment for root development, supply of
nutrients for early ratoon growth and eradication of weeds. The practice of burning trash is now being replaced by the use of trash as mulch.

One way of trash mulch is the GCTB uniformly spread on surface of harvested field during harvesting operation by chopper harvester. The GCTB sets uniformly on surface of cane field.

Introduction of GCTB has altogether eliminated the cultivation operations in ratoon field and has benefited the crop with advantages of nutrient supply, control of weeds and biologically active environments for crop growth. Trash is a potential source of organic matter and when properly incorporated adds considerable amount of nutrients in soil.

Green manure crop in rotation and GCTB practice keep up the organic status of soil to the required level. Besides the supply of nutrients, cane trash on decomposition enriches the soil with organic matter, the main seat of biological activities in soil.

The dual row planting at 60 – 120 – 60 cm or the inter-row space of 120 – 150 cm is the ideal distance for working of disc ratooner. This row space can accommodate all the trash in the field, while 1 meter or lesser space can accommodate a little portion of the trash and the rest has to be stacked out.

Some agronomists prefer not to delay inter-row cultivation operations after harvesting. If such is the case trash blanket may be applied on every alternate row space, keeping one row free of trash. Trash free row may be given inter row hoeing /cultivation treatment.
Studies conducted in Fiji under conditions of manual harvesting indicate no mechanical compaction and hard pan in root zone. The effects of intensive cultivation were compared with trash blanketing and no cultivation. The intensive mechanized operations did not produce beneficial effect on cane yield compared to trash blanketing. Rather the trash blanketing was made cost effective and economical (Table-5.09).

**Table-5.09 Effect of ratoon management practice on yield of sugarcane in alluvium soils**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Cane yield t ha⁻¹</th>
<th>POC %</th>
<th>Sugar t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trash burnt, stubble shaving, off barring, inter row ripping, cultivation and hilling up</td>
<td>77.2</td>
<td>17.18</td>
<td>13.0</td>
</tr>
<tr>
<td>Trash burnt, stubble shaving, inter row ripping and cultivation</td>
<td>85.5</td>
<td>16.57</td>
<td>14.6</td>
</tr>
<tr>
<td>Trash burnt, inter row ripping and cultivation</td>
<td>81.7</td>
<td>17.07</td>
<td>13.9</td>
</tr>
<tr>
<td>Trash burnt, inter row cultivation</td>
<td>82.2</td>
<td>17.57</td>
<td>14.4</td>
</tr>
<tr>
<td>Trash raked in every other inter-row, inter-row ripping and cultivation in rows without trash</td>
<td>85.5</td>
<td>17.00</td>
<td>14.5</td>
</tr>
<tr>
<td>Trash conservation, no cultivation, fertilizer on top of cane rows</td>
<td>83.9</td>
<td>17.33</td>
<td>14.6</td>
</tr>
</tbody>
</table>


In Australia and South Africa substantial increase in cane yield has been reported in trash blanket field (Maberly and McIntyre, 1983; Wood, 1986). Yield increase is due to conservation of moisture through reduction in transpiration and run off and reduced weed infestation. Weed infestation is reported to be suppressed by 83 – 92 % (Lorenzi et al, 1989).

As the cane shoots initiate sprouting the GCTB on the cane rows is removed by specially prepared hoe, and later on as the tillering completes the GTCB is incorporated in soil by Disc type incorporator.
Besides the mechanized way of GCTB application on ratoon field, trash could be conserved by manual operation. However, the trash spread by manual harvesting is somewhat laborious to handle and involves proper management techniques. The proper method of trash management would be:

1. Trash to be uniformly spread in the harvested field, giving about 10 cm thick cover, like a mat.
2. In favorable season, when sprouting starts, trash from cane rows to be slightly removed aside to allow light penetration to accelerate sprouting of buds.
3. The cane fields should be normally irrigated during winter. It would help soften the trash. Urea spray @ 5% further accelerates rotting of trash. Rotting is also accelerated with spray of effective microbes (EM) solution, as well as spreading a light layer of filter press cake.
4. In sub-tropical and temperate conditions trash cover increases temperature by 2 – 3°C during winter and save the buds from exposure to severe cold shocks. Trash mulch reduces soil temperature by 3 - 4°C due to shading during summer. Low temperature reduces evaporation losses that helps evade crop from heat stress.
5. Trash helps in conservation of soil moisture, there is experimental evidence to show that soil under trash blanket kept moisture at field capacity for a longer period than the trash free field. Trash covered stumps produced more tillers and vigorous shoots than a trash free naked field (Malik et al, 2002).
6. Trash conserves parasites and predators, which later help in control of cane pests.
8. With advancement in technology, trash management has now become an integral part of cane production technology.

Since burning is avoided, it saves the whole biological system in cane fields. Useful soil microbes remain active and all the parasites and predators are saved to keep up their breeding cycle, which otherwise is destroyed by burning. Trash cover generally curtails pest activities in cane fields in a number of ways (Mukhdoum et al, 2000):

- Borer infestation in trash mulched field is late, while it is 20-25 days earlier in trash burnt fields.
- Many egg batches in trash thus larval survival is low.
- Error! Not a valid link. More incidences of natural enemies-ants, spiders, beetles that eat up eggs of pests.
- Parasitoids in larvae detected earlier in April as against June in burnt cane.
- Parasitoids remain healthier in trashed fields but found dead in burnt larvae of burnt cane.
Pest infestation much low in trash mulched field (1.96 to 6.66), but internodes damage much higher (3.15 to 13.40) in burnt cane. While keeping trash as mulch it should be closely watched of any incidence of pest attack. Sometimes caterpillars of army worm find place for hibernation and seriously damage foliar parts of cane leaves. Application of suitable pesticides becomes necessary in case trash covers such hidden pests.

In manually harvested fields cane trash on cane rows are to be removed aside, by manual labour using hand rakes. Meanwhile, crop receives 2–3 irrigations during winter-spring, trash in rows softens, and disc ratoooner cuts and churns the trash in one pass and incorporates in soil in the next pass. A rotavator has also been designed to shred the trash into fibrous form. The disc ratoooner can be used for its incorporation in inter-row spaces. Suitable row space has a key role in trash management. Success in use of trash as mulch is achieved in wider row spacing of 120 to 180 cm. Dual row planting in 180 cm also gives desired results. The author has successfully incorporated trash with disc ratoooner in 120 cm single row space as well as in 60 – 120 – 60 cm dual row space. The dual row space is especially helpful in applying trash within 120 cm row space and leaving inter-row space of 60 cm for initial cultivation and fertilizer application in ratooon.

In Mauritius, the author noticed that much before harvesting, the trash is removed from standing crop of cane and is laid in alternate inter-row spaces. At harvesting, cane stalks are topped, cane is supplied to sugar factory and trash is later incorporated in soil. In Mauritius 40 % of cane area is burnt prior to harvest (McIntyre et al, 1996). Where cane is harvested green, trash is lined up in alternate rows. In the case of harvesting by chopper harvester, trash settles on surface of ratooon field as GCTB. Comparative studies conducted on trash management indicate substantial yield increase from trash mulch over the trash burning (Table-5.10).

### Table-5.10 Effect of trash management on cane yield (t ha⁻¹) in Sub-humid regions

<table>
<thead>
<tr>
<th></th>
<th>1993</th>
<th>1994</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment-1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trash lined on alternate inter rows</td>
<td>88.7</td>
<td>65.2</td>
</tr>
<tr>
<td>Trash lined on every inter row</td>
<td>90.1</td>
<td>60.6</td>
</tr>
<tr>
<td>Trash blanket</td>
<td>95.1</td>
<td>57.1</td>
</tr>
<tr>
<td>Trash burning</td>
<td>83.9</td>
<td>60.8</td>
</tr>
<tr>
<td>LSD (P = 0.05)</td>
<td>10.1</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Experiment-2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trash blanket left in situ without herbicides</td>
<td>107.3</td>
<td>107.1</td>
</tr>
<tr>
<td>Trash blanket left situ + post emergence herbicides</td>
<td>108.2</td>
<td>105.4</td>
</tr>
<tr>
<td>Cane rows cleared + pre emergence herbicides</td>
<td>106.8</td>
<td>110.7</td>
</tr>
<tr>
<td>Cane rows cleared + post emergence herbicides</td>
<td>104.2</td>
<td>106.2</td>
</tr>
<tr>
<td>Trash burning + pre-emergence herbicides</td>
<td>99.0</td>
<td>91.7</td>
</tr>
<tr>
<td>LSD (P = 0.05)</td>
<td>NS</td>
<td>13.3</td>
</tr>
</tbody>
</table>


GCTB is reported to give agronomic advantage in that no further manual handling of residue is required; give weed control without herbicides, is environmentally friendly and
is economical (McIntyre et al, 1996). This technique is also reported to conserve moisture to the extent of 35%.

GCTB has multifarious impact on soil fertility and physical state of soil. In some studies in Australia soil organic carbon and N were 21% greater under trash blanketing than under burning (Robertson et al, 2007). Soil microbial activities also increased under GCTB. It was worked out that with standard fertilizer application the entire trash could be decomposed without compromising the supply of N to the crop. It was suggested that the fertilizer N application should not be reduced in the first 6 years after adoption of GCTB system. In GCTB soil organic carbon could increase by 8-15%, total soil N by 9-24% and organic soil N could increase by 37 kg ha⁻¹ year⁻¹.

**Fertilizer application**

**Nitrogen:** Ratoon crop is considered the less efficient user of fertilizer than a plant crop, especially the nitrogen and phosphorus. This is due to inefficient stubble roots, delayed root development and imbalance in the shoot root ratio at the initial stage of development. The fertilizer use efficiency was 1030 Kg cane per Kg N applied to plant crop, compared to 850 Kg and 902 Kg cane per Kg N applied to the ratoon crop (Yadav, 1986).

It has been found that ratoon crop; generally need 25 to 50%, higher level of ‘N’ than plant crop (Singh et al, 1977; Subramanian, 1982; Prasad et al, 1984 and Mathur, 1987). Higher dose of ‘N’ for ratoon than the corresponding plant crop may be due to:

1. Depletion of ‘N’ content in rhizopheric soil
2. Microbial tie up of soil available ‘N’

At the initial stage, sugarcane ratoon starts functioning on old stubble roots. After 3-6 weeks, old root system ceases to function and new root system is formed. Thus new root system of ratoon is surrounded by old decomposing roots of high C: N ratio. Microbial activity is likely to be high in root zone, as a result of the decomposing old root system, which immobilizes a part of applied ‘N’. Depleted level of ‘N’ may be partly responsible for increased level of ‘N’ requirements for succeeding ratoon. To meet the ‘N’ demand of microbes during decay of stubble roots, ‘N’ application is necessary immediately after plant cane harvesting. Additional ‘N’ (35-40 kg) is required to lower the C: N ratio to overcome the microbial tie up. To realize ratoon yields at par with plant crop, 224 Kg N ha⁻¹ had to be applied to first ratoon as compared to 112 Kg N ha⁻¹ to plant crop (Yadav, 1986).

In some studies cane production per kg ‘N’ ha⁻¹ was 1.03 tonnes in plant crop and 0.5 in ratoon crop (Lakshmikantham, 1973). At normal rates of ‘N’ application yield of ratoon crop is far less than plants crop yields. The reduction in mill-able canes, stalk weight and the yield of successive ratoon over its plant crop was reported to be considerably minimized with the application of enhanced dose of ‘N’ fertilizer (Gascho et al, 1986).

Ratoon yield can be substantially improved by incorporation of inter cropped legume residue, such as that from french beans, sunhemp, green gram or soybean along with application of 200 to 225 Kg N ha⁻¹ (Hunsigi, 1993). The extent of yield reduction in
successive ratoon can also be minimized with the addition of FYM @ 15 t ha\(^{-1}\) (Yadava, 1991).

**Phosphorus:** Ratoon crop requires double the amount of P compared with the plant crop (Clement, 1980). Phosphorus is essential to hasten the formation of shoot roots. Since P is largely fixed with soils, its uptake can be assured when applied along with farmyard manure (FYM) or Filter press cake (FPC). Application of 20 t ha\(^{-1}\) of FPC can increase cane yield of plant and ratoon crop by 60 and 30% respectively (Prasad, 1976). The P use efficiency in both the plant and ratoon crop is almost alike (Hunsigi, 1993). Addition of P tended to increase the Pol in juice and at an optimum level of P application, the purity of juice was enhanced (Hunsigi, 1993).

The optimum NPK level for a plant crop was considered to be 2:1:2, while the same for a ratoon crop may be generalized as 2:1.4:3.0 (Humbert, 1978)

**Number of ratoons in crop cycles**

Economics in cane cultivation advocate multiple ratooning in cane. Due to favourable condition for ratooning, 9-12 ratoons are reported in Venezuela, 7-8 in Taiwan, 5-6 in Louisiana, and 2-3 in Australia (Hunsigi, 1993). In India-Pakistan sub-continent only one to two ratoons are considered enough for economic return. Multiple ratooning can best be adopted in well drained, deep soil with high native fertility. Loose organic soils can yield better ratoons than hard, compact and saline sodic soils. Good ratoonability demands a cane variety with high ratooning capacity, good initial crop stand, heavy soil, lack of gaps, and adequate control of pests, diseases and weeds. Good inter-row cultivation promotes better root and shoot development under optimum inputs of fertilizer and irrigation. Data indicate that if initial stand and crop condition is satisfactory, and the post harvest operations assure a good crop yield, two or even three ratoons can be had without appreciable reduction in yield (Annon, 1959). On the other hand, if borers persist, crop is patchy, is badly infested with weeds, cane field has developed hard pan, required cultural operations are lacking, even the first ratoon may yield a poor cane crop. Thus the question as to how many ratoon should be kept can not be answered in simple words. To have more than one ratoon, the only option with the cane growers is to grow better ratooning variety under judicious combination of inputs with good post harvest operations. The approach to consider ratoon a free crop without appreciable inputs and cultural operations would not yield good sugar.

**Stubble protection**

- Spreading polyethylene sheets (250 gauge) over the stubble of winter harvested plant crop and/ or loosening of soil for improve sprouting, stalk population and yield of ratoon (Kanwar and Kaur, 1977).
- Covering stubble with three inches soil cover prior to the frost occurrence and removing the soil in the following spring with stubble shaver, significantly increased the yield of ratoon crop (Anon-Louisiana 1987, 1989).
- Trash mulches in trenches immediately after the January harvest was found effective for ensuring high ratoon yields (Panwar et al, 1989).
Irrigation

During the course of cane growth, irrigation application and use of machinery in cane fields, upper soil layer get compact. Root system in ratoon is largely confined in upper soil surface and does not penetrate to deeper layers. Therefore the ratoon is not efficient user of irrigation water. Data showing lesser water use efficiency of ratoon compared to plant crop is reproduced in Table-5.11.

Ratoon crop is reported to produce higher yield when irrigated at 75 % of available soil moisture (Yadava, 1993). Due to shallow root system and lesser water use efficiency ratoon are less tolerant to drought.

Table-5.11. Water requirements of plant and ratoon crops

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Plant crop</th>
<th>Ratoon crop</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water use efficiency: Kg cane wt mm⁻¹ ha⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a) Clay soil</td>
<td>130</td>
<td>161</td>
<td>Annon (1980-81), Taiwan</td>
</tr>
<tr>
<td>b) Loam soil</td>
<td>116</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td>c) Sandy soil</td>
<td>89</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Water required (Kg) for production of:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Kg cane</td>
<td>89</td>
<td>118</td>
<td>Shih and Gascho (1980), Taiwan</td>
</tr>
<tr>
<td>1 Kg sugar</td>
<td>884</td>
<td>1115</td>
<td></td>
</tr>
</tbody>
</table>

Source: Shrivastava et al, 1992

Area under ratoon crop

Ratoon crop avails of a considerable share of total cane area in the country. In sub-tropical conditions area under ratoon is more than in tropical and coastal regions. The survey carried out by Agricultural Prices Commission of Pakistan indicates more or less 50 % ratoon in Punjab and only 31 % in Sindh province. In Sindh as well, the area under ratoon in lower Sindh is much less than in upper Sindh area. Similar features have been noticed in India where Punjab, U-P, Karnataka, Orissa and Tamil Naudo are reported to grow ratoon to the extent of 55 %, 40 %, 38 %, and 34 %, of total cane area, respectively (Verma, 2002). In climatic regions raising 5 –7 ratoons in crop cycle area under ratoon crop are proportionately high.
Chapter-6

Crop Rotation

Crop rotation refers to the sequence of crops in a cropping intensity of a certain area. Sugarcane may be grown alone in the tract as a monoculture or in combination with other crops during certain period of crop cycle. In some of the countries cane is grown in the same field year after year and the crop may occupy the land for 5 – 7 years or more. They don’t have an alternate crop to grow and the new crop will follow the old ratoon after necessary land preparation. Such monoculture has created problems of soil compaction and soil degradation associated with gradual yield decline. This usually happens in large belts of cane plantation. And, there are countries which have multi-cropping system, where in sugarcane follow some other crop in rotation during a crop cycle. Selection of crops is influenced by a number of factors like, soil productivity, availability of irrigation water and the marketing forces for commodity needs. Combination of different crops in a proper sequence results in more efficient use of soil, irrigation water and labour force and crop production becomes more remunerative. Keeping in view the diverse types of soil and climate, different cropping patterns are observed in different cane growing regions of Pakistan (Khan, 2001).

Punjab

1  Wheat – Cotton – Sugarcane
2  Wheat – Maize – Sugarcane
3  Wheat – Maize + Senji /Barseem – Sugarcane – Cotton
4  Sugarcane – Sugarcane ( Ratoon ) – Maize ( Fodder )
5  Sugarcane – Sugarcane – ( Ratoon ) Fallow
6  Wheat – Cotton – Sugarcane – Sugarcane ( Ratoon )
7  Sugarcane / Guar – Mustard – Cotton – Wheat
8  Sugarcane – Sugarcane ( Ratoon ) Fallow – Wheat
9  Sugarcane – Sugarcane ( Ratoon ) – Mung – Mustard – groundnut
10 Sugarcane – Sugarcane ( Ratoon ) – Mung
11 Sugarcane + Potato – Sugarcane ( Ratoon ) – Fallow - Wheat

NWFP

1  Sugarcane – Maize – Tobacco – Maize
2  Sugarcane – Wheat – Maize – Berseem
3  Sugarcane + Sugar beet intercrop – Sugarcane Ratoon – Maize – Wheat / Tobacco / Berseem
5 Wheat – Maize – Sugar beet + Sugarcane – Sugarcane (Ratoon)
6 Berseem – Sugarcane – Sugarcane (Ratoon)
7 Maize – Sugarcane – Maize
5 Sugar beet – mung – sugar beet
6 Wheat – Mung – Sugar beet – Moong
7 Wheat – Sugar beet

**Sindh**

1 Sugarcane – Sugarcane (Ratoon) – Cotton – Wheat
2 Sugarcane – Sugarcane (Ratoon) – Fallow
3 Sugarcane – Sugarcane (Ratoon) – Wheat
4 Sugarcane + Vegetable intercrop, Chilies, Tomato
5 Sugarcane – Sugarcane (Ratoon) – Maize (Fodder)
6 Sugarcane – Wheat – Cotton
7 Rice – Sugarcane – Sugarcane (Ratoon)

The growers, having small holdings with ample supply of irrigation water and labor, usually observe intensive crop rotations. Increased use of organic and chemical fertilizers and varied marketing trends has bent upon the growers to adopt most remunerative cropping pattern. Cropping intensity in some cases of use of vegetables as intercrop has increased to 250 percent. But in areas of limited water supply rotation remain within 75 – 100 % of crop intensity. In larger belts sugarcane is being grown as a mono-crop. Depending upon the soil productivity and the cane variety growers take just one or at the most two ratoon. With poor ratooning varieties like BL4, SPSG 26, progressive growers prefer to have only one plant crop.

Various rotations are characterized by specific crop growing region. Multan, D.G Khan, Sukkher and Khairpur Divisions are specific for growing cotton crop; Gujranwala division and part of Lahore and Dadu area are famous for growing rice. Lower Sindh which is known best area for growing sugarcane also has huge acreage under rice due to non-perennial Canal Zone. Central Punjab has mixed cropping all over its districts. The NWFP has small holdings with intensive cropping. Thus the sugarcane is accommodated according to the specific crop condition and irrigation water availability. However, marketing forces, the prices of crop commodities influence the area under crop that affect the rotational trend. Market prices of competitive crop like cotton, rice, maize, sunflower, tobacco, do affect the rotation in specific areas. Supply of irrigation water has a leading role in curtailing area under cane.

In a long term strategy to sustain crop productivity with improved soil physics, green
manure crop must be included in rotation. Main field crops like Cotton, Maize, are considered exhaustive for soil nutrition. Legume crops increase organic status of soil with additional advantage of N proliferation in the soil. Legume crops may be grown both for grain in rotation or for incorporation of green manure or both. The crops like lentil, berseem, senji and metha are considered good for autumn cane and mung, cowpeas, sunhemp for spring cane. Green manuring in the plant cane also shows residual response in subsequent ratoon crop. Production potential of cane crop with legumes as intercrop has been established in several cane growing countries. Cowpeas (Vigna unguiculata) and sunhemp (Crotolaria juncea) have proved excellent in biomass production. Improved growth and vigour following legumes show a 15 to 30 % improvement in cane yield (Schumann, 2000).

In some overseas countries, where more than 5 / 6 ratoons are taken, sugarcane in monoculture faces severe problems of disease infection, pests’ infestation; build up of deleterious soil organisms and loss of cane productivity. Where monoculture is associated with mechanized farming, soil degradation proceeds with time, followed by soil compaction, surface crust ing, and decline in water and nutrients intake (Meyer and Antwerpen, 2001). Change in soil chemistry, reduction in microbial biomass and soil organic status is also the result of physical soil degradation in mono-culture (MC Garry and Bristow 2001). Crop rotations are therefore preferred over mono-cultures; various rotational trials have always shown significant yield increase over mono-culture (Garside and Bell, 1999). In Australia, it has now become mandatory to grow a green manure crop in fallow period after cane harvesting (Calcino, et al, 2000). Soybean and cowpeas are grown as fallow legume. Legumes are known to sustain the biological activities of soil and also improve physical structure of soil with enhanced bio-chemical reactions.

**Cropping Intensity**

Pakistan agriculture has diversified cropping system growing food, fiber, fodder, fruits and vegetables, all or a few grown in sequence rotation with one another. Wheat is the major crop planted in cane growing provinces. According to crop estimates for 2001-02, it covers 36.12% of the total cultivated area of the country, followed by cotton 13.99% and rice 09.49%. The sugarcane crop occupies 4.48% of the total acreage followed by maize (4.22%) and Jowar and Bajra (3.04%). Practically cotton and maize are the main competing crops with sugarcane in Kharif (summer) season. Rice may also compete in rice growing tracts. Compared to wheat, cotton and rice area, the sugarcane seems to be a minor crop, but occupies most important position due to its being a cash crop and huge industrial base. Leaving aside the average cropping intensity of the provinces, huge variation in crop acreage is observed with in regions of the provinces.

The choice of cropping pattern is a complex decision depending on climatic, soil, economics, social and conventional factors. The selection of crops is the sole choice of the grower for a number of objectives. Under climatic influence sugarcane crop has developed large belts in lower Sindh, cotton crop has by for been concentrated in some parts of upper Sindh, south western tracts of Punjab, while rice crop got adapted in high rainfall and high water table areas. The maize crop has attained specialized and social importance in some pockets of NWFP and central Punjab, according to market requirements. Economic forces influence the area under sugarcane and cotton under
which wide fluctuations are observed in different years. Growers and Millers relations have strong social binding to grow or abandon cane cultivation. As such cropping intensity varies from regions and districts to districts within regions. On Pakistan basis sugarcane occupies 4.46 percent area in cultivated tracts, while the average cropping intensity of Punjab, NWFP and Sindh accounts for 5.28 %, 4.11 % and 5.37 %, respectively.

Crop diversification in specific areas of Punjab province has developed very variable cropping intensities. In Faisalabad division, cane intensity varies from 10 to 21 percent, while rice and cotton crop intensity is low. In the case of individual farms, where enough irrigation resources are available, cane intensity may range between 30 and 40 percent.

Rice-wheat system is of special importance in specific soil condition of Sialkot, Gujranwala, Narowal, Hafizabad, Sheikhupura and Lahore districts, where rice planting has attained international importance due to its special aroma. The cropping intensity of cane is very low in this region, except in Mandi Bohaudin and Kasur districts where cane is grown to the intensity of 14-17 percent. In climatic condition suitable for cotton growing in Multan, Bahawalpur and D.G. Khan Divisions, cane intensity is low except in districts having sugar mills.
Chapter-7

Irrigation

Sugarcane is a tropical plant and thrives best under conditions of adequate supplies of irrigation water. Cane yields in the sugarcane world are the highest in the regions of ample water supplies through well distributed rainfall or irrigation met through out the growth cycle of the crop. Though of course sugarcane is hard enough to grow under drought stress or under water logged conditions but vigorous crop stand and optimum yields are obtained under well managed distribution of water to the crop as per requirements.

Water, in fact, is the lifeblood of cane that plays vital role in the build up of plant parts and the photochemical process in cane plant. In sugarcane main role of water is the manufacture of sugars through photosynthesis and its translocation to storage tissues. It is estimated that 5% of total water absorbed is utilized for the physio-chemical functions, of which less than 1% of water absorbed is utilized chemically in photosynthesis (Humbert, 1968; Mayer and Anderson, 1952). As for total water uptake by plant it is estimated that for each part of dry matter produced, cane plant absorbs some 250 parts of water (Van Dillewijn, 1952). While others conclude as much as 500 parts of water are required to produce one part of dry matter. And, the mature plant generally constitutes ¾ parts water and ¼ part dry matters (Richard, 2003). The dry matter consists of sugars, cellulose, mineral salts, nitrogen compounds and other substances. Production of these materials involves large quantities of water that must be available to the plant throughout its active growth period. The important role the water plays is the absorption of nutrients by roots and their translocation within the plant parts. On the whole water makes up 85 to 90% of the fresh weight of actively growing plant parts that control the physiological functions of plant for its growth and development (Humbert, 1968). Turgidity of cells and plant growth is affected by internal water balance, which in turn is controlled by relative rates of water absorption and water loss through transpiration. A balance in water uptake and its loss is important for growth of plant. Failure to replace the water loss by transpiration results in the loss of turgidity, cessation of growth and death of plant by de-hydration.

Water Uptake by Cane Plant

Water uptake by plants depends on water retention in soil, root growth and development and stage of plant growth with active leaves. The water filled in pore spaces has two categories; water available for plant growth and water not available to plant. The unavailable water is the gravitational water that drains away from root zone and can not be extracted by plants except a few amounts; or is the water held tightly around soil particles. Plant available water is the water that plants can extract from soil through its roots. Within plant available water, the water that plant can easily extract is called readily available water. And when all the plant available water is gone out of its root zone and plant is not able to extract, the soil is said to be at permanent wilting point.
Soil:

Soil is composed of sand, silt and clay in different proportion with pore spaces filled by air. Sandy soils have larger and fewer pores while clay soils have much smaller but larger number of pores spaces. Thus sandy soils do not hold water for long, however, a large proportion of the total water in sand is easily available for growth of plant but is lost soon. Water in clay is tightly held and has a large water holding capacity, however all the water is not made available to plant. A loam soil, which has roughly 20 % clay with 40 % each of silt and sand, holds good amount of water and is easily made available to plants.

All the irrigation scheduling to crop is done taking into consideration the readily available water in soil. Water availability to plant varies with the soil texture. As a general rule the available soil water for different textured soils is reported to be as under (Hunsigi, 1993):

- heavy textured soil = 20 cm per meter depth of soil
- medium textured soil = 14 cm per meter depth of soil
- coarse textured soil = 6 cm per meter depth of soil

Considering the water holding capacity of soils, irrigation interval should be narrower in coarse textured soils and should be increased in fine textured soil. Due to this reason sandy loam soils need frequent irrigations compared to clay or clay loam soils.

Roots:

Roots contribute the major share of water up take from soil and its supply to plant parts. Roots vary in depth and distribution depending upon water availability, soil texture, stage of plant growth and cane variety. The deep roots system plays important role in extracting water from the deeper layers during the period of drought. Rooting depth is considered one of the main differences between drought tolerant and drought susceptible varieties (Mongelard, 1967). In a roots system, root hairs form the active surface of water absorption. Roots system is optimally developed under loam and sandy loam condition of soil; poorly developed in hard clay soils and poor drainage. Similarly some varieties have deep root system than others. Moisture extraction through roots of Co 62175, grown in sandy loam soil under furrow irrigation system, was estimated to be 40 %, 30 %, 20 % and 10 % from surface layer of 20, 40, 60 and 80 cm depth, respectively. It indicates that 70 % of the total root mass is within 40-cm depth (Mangelard, 1968). In another case roots went as deep as 180 cm depth, nevertheless 60.4 % of the root mass remained in 0 – 30 cm depth, 83.0 % in 60 cm depth, the 91 % in 90 cm and the remaining 9 % in rest of the 90-180 cm depth (Paz. Vergara et al, 1980). However, there is a general consensus that most of the water and nutritional uptake occurs in the top 60 cm soil. While the best soils are the soils with preferable 90 cm rooting depth and 10 – 12 % pores in the soil filled with water after rain or irrigation. In deep well drained soils, the 'butt' roots of some sugarcane varieties may even extend to a depths of over 4 meters but these are not much effective in uptake of water. In irrigated clay loam soils of Queensland the most effective rooting depth is reported to vary from 90 to 120 cm and under rain fed condition may extend to 1.8 meters (Ham et al, 2000).

Distribution of roots in soil is affected by soil types and irrigation frequency. The soils
receiving frequent irrigation would develop shallow root system. With longer interval in irrigation and in stress conditions rooting depth would be considerably more (Table-7.01). Under drip irrigation roots are mostly spread on the surface of soil around emitters.

Roots systems if not properly developed, can limit the yield potential of sugarcane. Roots reach their peak absorption efficiency about two months after planting and decrease effectiveness if not adequately supplied with water. Severe water stress may damage the roots and does not support transpiration. Flood conditions may develop dense mass of small diameter roots growing vertically upward towards soil surface. Sodic soils have poor water holding capacity as such roots are restricted to top soils. The soil holding less amount of readily available water would need more frequent irrigation compared to the soil with better root system and good water holding capacity. Therefore, water holding capacities of soil and root zone play important role in water management of cane crop.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Rooting irrigation weekly</th>
<th>Irrigation 2 weeks interval</th>
<th>Irrigation 3 weeks interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>45 %</td>
<td>37 %</td>
<td>32 %</td>
</tr>
<tr>
<td>15</td>
<td>23 %</td>
<td>23 %</td>
<td>18 %</td>
</tr>
<tr>
<td>35</td>
<td>18 %</td>
<td>21 %</td>
<td>19 %</td>
</tr>
<tr>
<td>95</td>
<td>11 %</td>
<td>16 %</td>
<td>24 %</td>
</tr>
<tr>
<td>170</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>3 %</td>
<td>3 %</td>
<td>7 %</td>
</tr>
</tbody>
</table>


Leaves:

Role of leaves is the transpiration of water through leaf surface and maintains internal water balance by suction of water from soil through roots. Sugarcane leaves have also the capacity to absorb moisture from the atmosphere. Though may not have a significant
role, but dew deposits on the leaf surface and moisture from light showers is absorbed by leaf and trans-located to stem and roots. This type of absorption keep the plant alive for long under moisture stress condition and plant does not show withering sign at the earlier stage of wilting.

**Cane stalks:**

The cane stalk itself does not absorb water through rind; nevertheless nodes portion can absorb water to some degree. Cane stalk acts as reservoir of water storage in internodes in the form of sugar solutes. It keeps up the equilibrium of solute translocation from roots to leaves and vice versa.

Water relations play an important role in tiller elongation and resultant height of cane stalks. Moisture stress causes a significant reduction in stalk population and this is due to high mortality of tillers during cane formation stage (Gosnell, 1968). There is highly significant correlation between stalk elongation and amount of irrigation water. Most striking elongation of stalks is the maximum during the grand growth stage when the maximum amount of water is required (Chang et al, 1968).

**Water Requirement**

Adequate available moisture throughout growing period is important to obtain maximum yield. Water applied to cane fields through different sources including irrigation and rainfall is utilized, conserved or lost in different ways:

1. Transpired through cane leaves
2. Transpiration losses through weeds
3. Evaporated from soil surface
4. Water required for metabolic activities of plants
5. Irrigation losses through leaching, seepage and run off

The water transpired is the water which is taken up by root; part of it is consumed for the metabolic activities of the plant, some is conserved in plant tissues to maintain turgidity of cells with solutes and the rest is transpired through leaves. The water actually consumed for physiochemical functions of plant hardly accounts for 5 %, of total evapo-transpiration. A wide range of water needs have been worked out in different regions. Under adequate growing conditions this crop is capable of producing 10 tonnes per hectare of cane for each 1.0 to 1.2 ml (100 to 120 mm). Very efficient irrigation practices can use the same amount to produce 15 tonnes of cane per hectare (Ham et al, 2000). As such the water requirements of a 100-tonne crop per hectare would be about 1000 to 1200 mm. But in actual field practice almost double the amount of water is needed to mature a crop in a crop cycle. While some water is absorbed for use in photosynthesis and other physiological and metabolic processes of plant, and more or less 50 percent water is lost through surface evaporation, run off, leaching down beyond root zone and transpiration by weeds. It signifies that all the water applied as irrigation is not fully available to the plant, and the average efficiency of water is about 50% for surface irrigation.

Water requirement of sugarcane varies widely with climate and soil conditions and the
duration of the crop. Cane grown in sub-tropical region avails of 10-15 months crop duration while in tropical region cane has the crop growth cycle of 15-20 months. For cane crop in India water requirements of sub-tropic is stated to be 800 – 1200mm and for tropics 2000 mm (Gupta and Tripathi, 1998).

Some countries receive adequate rainfall (2000 mm), uniformly distributed throughout the crop duration. This rainfall pattern fully meets the water needs of the crop. There are countries that receive sufficient quantity of rainfall but are not well distributed during growing season. Water needs of such crop have to be compensated through intermittent irrigation as per crop requirements. Still other countries receive quite insufficient rains, thus irrigation is essentially needed to mature a crop. Irrigation application needs special management practices and account for additional cost to cane production.

Sugar cane though is a tropical plant, but two third of total world production is obtained in sub tropical regions under irrigated condition. In Pakistan cane is planted in semi arid regions having annual precipitation of less than 100 mm to a little above 400 mm. Most of the rainfall is received during monsoon with small down pour in the spring and autumn months. Cane is exposed to dry spell for a major part of its growing season. As such most of the water needs of the crop have to be met through irrigation. Irrigation is the main constraint of this region, as canal water meets hardly 50-60% of total irrigation needs of the crop. Only a few tracts have the privilege of sweet ground water, where tube well compensates the canal irrigation. However, most of the cane fields are usually subject to moisture stress.

Irrigation Scheduling

It is the frequency and amount of irrigation water applied to the crop during its growth stages. Cane growth is directly proportional to the water supplies according to its requirements. Excess application is of no use, rather has negative effect with respect to nutrient leaching, over growth, lodging and finally the loss in yield and juice quality. On the other hand reduced water supplies to crop depress growth and yield of cane and sugar. Poor irrigation management like short or longer intervals, over Irrigation or stress conditions, besides having deleterious effect on yield, often leads to soil problems of water logging or development of salinity. The economics of irrigated cane crop lies in irrigating the crop according to its actual water needs.

Irrigation scheduling pertains to the frequency at which water is applied to the crop, and it varies with soil type as different soils store different amounts of readily available water. The soils holding lesser capacity of readily available water would need more frequent irrigation. Similarly weather conditions including temperature, sun radiation, wind velocity and rainfall / humidity have profound effect on water loss from soil surface and transpiration by leaves. The scientific approach to irrigate cane crop is based on soil moisture analysis and evapo-transpiration from cane leaves and soil surface. The amount of readily available water between the point of field capacity and the point plant suffers from moisture stress determines the actual water needs and frequency of irrigation to cane crop. The important aspects are the measurement of soil water depletion and the evapo-transpiration. The amount depleted by the soil is to be refilled by irrigation to upkeep the growth rate. This is a water balance approach considering the available soil moisture holding capacity per centimeter depth of soil to a specified rooting depth. The
target of irrigation scheduling is to initiate irrigation when available soil moisture reached 50% depletion.

To assure optimum yields and recovery from a given soil it is imperative to assess and apply water actually needed by the crop at the particular growth stage. The crop utilizes full amount of water at field capacity and the soil water diminishes as it is taken up by the plant or evaporated from soil surface.

In the initial stages of research, studies were confined to the treatments of irrigation intervals or number of irrigations from planting till crop maturity. Later, the amount of effective irrigation including rainfall was estimated and its effect on yield of cane and its quality was determined. In this context several field employed, theoretical and empirical methods have been developed to work out actual periodic needs for irrigation over a crop cycle. The methods widely used to schedule irrigation are:

1. Evapo-transpiration losses through open pan
2. Determination of soil moisture depletion
3. Use of Tensiometers
4. Use of electronic probe
5. Tissue moisture contents

**Determination of evapo-transpiration**

The standard procedure for scheduling irrigation is the measuring evaporation rates by the use of 'class A' pan. The amount of water required by the crop and the evaporation rate is referred to as the crop factor that varies with crop growth and the ground cover by the crop canopy. Crop coefficient varies with stage of crop growth and environmental conditions with respect to temperature, humidity and wind velocity. The crop factors for various growth stages at Faisalabad are given in Table 7-02. The data pertain to extreme weather during summer and winter months at around 30° N Latitude.

**Table 7.02 Crop factors and water needs in various growth stages of sugarcane at Faisalabad**

<table>
<thead>
<tr>
<th>Crop development stage</th>
<th>Growth period</th>
<th>Crop duration (days)</th>
<th>Crop coefficient (kc)</th>
<th>Crop water needs ET) mm/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting to 25% canopy</td>
<td>Planting to 15 Apr.</td>
<td>30 - 60</td>
<td>0.30 - 0.60</td>
<td>1.8 - 4.5</td>
</tr>
<tr>
<td>25 - 50% canopy</td>
<td>15 Apr. - 10 May</td>
<td>60 - 85</td>
<td>0.60 - 0.85</td>
<td>4.5 - 4.9</td>
</tr>
<tr>
<td>50 - 75% canopy</td>
<td>10 May - 31 May</td>
<td>85 - 105</td>
<td>0.85 - 1.12</td>
<td>4.9 - 9.7</td>
</tr>
<tr>
<td>75 - full canopy</td>
<td>01 June - 30 June</td>
<td>105 - 135</td>
<td>1.12 - 1.12</td>
<td>9.7 - 8.5</td>
</tr>
<tr>
<td>Peak use</td>
<td>01 July - 31 Aug</td>
<td>135 - 195</td>
<td>1.12 - 1.23</td>
<td>8.5 - 6.7</td>
</tr>
<tr>
<td>Early senescence</td>
<td>01 Sept. - 31 Oct.</td>
<td>195 - 255</td>
<td>1.23 - 1.02</td>
<td>6.7 - 3.7</td>
</tr>
<tr>
<td>Ripening</td>
<td>01 Nov. - 30 Nov.</td>
<td>255 - 310</td>
<td>1.02 - 0.88</td>
<td>3.7 - 1.7</td>
</tr>
<tr>
<td>Maturity</td>
<td>01 Dec - harvesting</td>
<td>310 -</td>
<td>0.88 - 0.15</td>
<td>1.7 - 0.5</td>
</tr>
</tbody>
</table>

*Source: Anon (1982)*
For a crop planted in spring – early March water requirements of cane are low in the initial stages of plant development, and gradually increase with increase in growth. Irrigation water is applied to make up the moisture losses through evaporation from soil surface and transpiration through leaves during metabolic process of plant. Evaporation from the soil surface is of significance to the stage when cane is young in the initial stages. Once the soil is covered by the canopy of leaves, evaporation losses are reduced to a minimum. As the plant growth proceeds, surface area of leaves and root mass expand, rate of transpiration is increased, more so under climate with high temperature, low humidity and high wind velocity. As such water needs of plant is gradually increased till the boom stage of crop growth. As the cane approaches maturity, temperature get low, irrigation requirements are receded to dehydrate the cane for storage of sugar.

**Determination of soil moisture**

Different soils have different water holding capacity. Evapo-transpiration rate data may not give accurate forecast, for that purpose soil tensiometer or electronic probes are help full. Use of these instruments is a usual feature of Queensland Sugar Industry. The irrigation experts of BSES record the daily reading of tensiometer/electronic probe and work out the water needs. The daily reading indicates the water lost from root zone to one meter depth. When moisture deficiency occurs to the level of moisture holding capacity, which is usually 50 % of ASM, the field is irrigated. The studies conducted under three irrigation scheduling based on 40 % (1878 mm), 60 % (1190 mm) and 80 % (737 mm) moisture depletion of available soil moisture (ASM), indicated maximum sugar yield under 60 % depletion of ASM, closely followed by 40 % ASM (Rehman and Rehman, 1997).

The stage of cane growth, climate and soil type affects the interval in irrigation. For getting optimum yields irrigation has to be applied very judiciously at suitable intervals according to evapo-transpiration demands of the crop. Mismanagement of water, like improper scheduling, longer intervals, over irrigation, lack of proper drainage, besides having deleterious effect on yield, often leads to soil problems of water logging or development of salinity. For effective water utilization, during early growth and in the boom stage of growth, the crop should be irrigated as soon as 50% of available moisture has been depleted from soil (Humbert, 1968), Yadava (1991). As the cane approaches maturity, irrigation interval is extended to reduce the rate of vegetative growth and to force the accumulation of sucrose in cane stalks.

Several theoretical and empirical methods have been employed in different countries to work out periodic water needs of the crop for irrigation scheduling. Evapo-transpiration data from class 'A' pan and soil moisture tests have mostly been used to work out periodic needs of water for irrigation scheduling (Yadava, 1991; Ham et al, 2000). Stalk population, weight and length were adversely affected when irrigations were applied using a pan evaporation factor (Irrig Coefficient) of less than '1' (Thompson, 1976). Irrigation coefficient of 1.0 and 1.2 did not show significant differences in cane yield, indicating that irrigation water application equal to pan evaporation gives economic return (Ali et al, 1998). Excess amount of water results in luxuriant growth to produce high cane yield. In later stages crop may lodge to depress yield and recovery. Results have shown that supplying 85 % of crop water requirements can produce as much sugar as for meeting the total water needs of crop (Ham et al, 2000). For irrigation based on
Cane and Sugar Production

class 'A' pan an average pan ratio (PR) of 0.85 has been used to calculate ET (Chang et al, 1968; Ham et al, 2000).

Keeping into consideration the daily evaporation through open pan and irrigation water application at the rate of 100 mm to each turn, the crop would demand water at an interval on 13-18 days in April, 9-11 days in May and June and 12-14 days in July-August months. With termination of boom growth period and with advance in maturity, water requirements are gradually receded and the interval between irrigation is prolonged in subsequent months. During September-October, the irrigation interval may be extended to 15-22 days. In winter months temperature gets low, plant growth is checked and metabolic function of leaves and roots are reduced, as such requirements of water are minimized to extend irrigation interval to 25-58 days. The crop has a largest demand for water during March-June period, which are almost 50% of the total needs of 2000-mm per annum. While 25%, is needed during July to August and the remaining for rest of the period of September - February months. Besides the pan evaporation data, the Table-7.03 showing irrigation water needs, include one additional irrigation at the time of planting and two extra irrigations to save the crop from cold shocks during winter.

Irrigation efficiency also depends on proper amount of water per turn or distribution of water for drenching the soil to root zone. While comparing 5, 10 and 15 acres cm of water per round of irrigation, 10 acres cm gave higher yield of cane and sugar per unit area (Humbert, 1968). In Punjab (Pakistan) conditions 10 cm of water is considered the optimum amount applied to cane per turn (Fasihi et al, 1980, Malik, 1991 and Malik et al, 1992).

Table-7.03 Irrigation requirements and irrigation interval during different period of crop growth

<table>
<thead>
<tr>
<th>Period (month)</th>
<th>Irrigation interval (days)</th>
<th>Number of irrigations</th>
<th>Periodic pan evaporation (mm)</th>
<th>Cumulative pan evaporation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>25</td>
<td>2</td>
<td>103</td>
<td>200 (including 100 mm at planting).</td>
</tr>
<tr>
<td>April</td>
<td>13-18</td>
<td>2</td>
<td>199</td>
<td>402</td>
</tr>
<tr>
<td>May-Jun.</td>
<td>9-11</td>
<td>6</td>
<td>569</td>
<td>998</td>
</tr>
<tr>
<td>July-Aug.</td>
<td>12-14</td>
<td>4</td>
<td>394</td>
<td>1392</td>
</tr>
<tr>
<td>Sept.-Oct.</td>
<td>15-22</td>
<td>3</td>
<td>300</td>
<td>1692</td>
</tr>
<tr>
<td>Extra irrigation in frosty days</td>
<td>2</td>
<td>200</td>
<td>2191</td>
<td></td>
</tr>
</tbody>
</table>

Source: Malik et al, 1992

Consumptive use requirements of water

The consumptive use requirement is the amount of water actually needed by the plant during its growth period. This is the water transpired by leaves and evaporated from soil surface and is termed as evapo-transpiration (ET). It makes a substantial amount that can
be measured. Different methods have been used to work out the consumption use (ET) needs of crop, which include Blaney-Criddle (1945), Thornthwaite (1948) and modified Penman (1948). Of these Penman method is simple and easy to apply based on the standard U.S. Bureau class-A Pan evaporation data. The crop, evapo-transpiration (ET) values are estimated using data on pan evaporation (mm/day), pan coefficient and crop coefficient. Evaporation from an open pan integrates the effect of temperature, radiation, humidity and wind velocity.

To find the consumptive use requirements of water for sugarcane voluminous work has been done on global level. Depending upon the agro-climatic conditions and crop cycles (12-20 months) in different countries consumptive use requirements are reported to vary from 1193 to 2400 (Table-7.04).

The studies on consumptive use requirement of water, carried out on spring crop at Faisalabad and Bhakkar (Table -05), indicated crop water needs of 1410 mm and 1492 mm respectively for a 340 days crop (Anon, 1982). The data further indicated that at initial stage of germination water needs were more or less 3 mm per day, which increased to 7-8 mm per day at FSD and 8.5 – 9.5 mm per day at Bhakkar during hot months of May and June. At maturity the requirements were hardly 2-1 mm during November-December, reduced to 0.5 mm in winter month of January (Table -02). The data further indicate that the crop coefficient (Kc) varies with stage of crop growth. It increases with a minimum value of 0.3 - 0.5 at crop emergence to a maximum value of 1.25 - 1.88 at full canopy and decreases to 0.4 – 0.6 at maturity.

Table-7.04 Water requirement of cane (ET) grown in different cane growing countries

<table>
<thead>
<tr>
<th>Country</th>
<th>ET per year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natal (South Africa)</td>
<td>1267</td>
<td>Thompsom (1976)</td>
</tr>
<tr>
<td>Hawaii</td>
<td>2000 - 2400</td>
<td>Chang et al, (1965)</td>
</tr>
<tr>
<td>Australia</td>
<td>1522</td>
<td>Ham et al, (2000)</td>
</tr>
<tr>
<td>Cuba</td>
<td>1681-2133(Plant)</td>
<td>Fonseca &amp; Egana (1989)</td>
</tr>
<tr>
<td></td>
<td>1193-1679 (Ratoon)</td>
<td></td>
</tr>
<tr>
<td>Taiwan</td>
<td>1500 - 2200</td>
<td>Chang et al (1968)</td>
</tr>
<tr>
<td>Philippines</td>
<td>2451</td>
<td>Parthasarathy (1972)</td>
</tr>
<tr>
<td>India - sub-tropical tropical</td>
<td>1400 – 1800</td>
<td>Srivastava &amp; Johri (1979)</td>
</tr>
<tr>
<td></td>
<td>2000 – 2400</td>
<td></td>
</tr>
<tr>
<td>Pakistan (Punjab)</td>
<td>1357</td>
<td>Anon (1982)</td>
</tr>
</tbody>
</table>

Soil moisture levels affect the consumptive use requirements of the cane crop. There is a linear relationship between growth rate and available soil moisture. In general, optimum moisture regime is 75-50 % available water at formative stage and 50-30 % at other stages (Srivastava and Johri, 1979).

Irrigation use efficiency

Water applied to cane field through irrigation and rainfall is partly utilized by cane plant and the rest is either leached down beyond root zone, evaporated from soil surface or lost
### Table 7.05 Cane crop water needs under optimum management conditions at various locations in Punjab, Pakistan*

<table>
<thead>
<tr>
<th>Month</th>
<th>Days Since planting</th>
<th>Faisalabad</th>
<th>Bhakhar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Crop coeffi</td>
<td>ET water needs – mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ent</td>
<td>Cumulative Daily average</td>
</tr>
<tr>
<td>Mar.</td>
<td>10</td>
<td>0.50</td>
<td>25 2.5</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.58</td>
<td>60 3.5</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0.67</td>
<td>100 4.0</td>
</tr>
<tr>
<td>Apr.</td>
<td>40</td>
<td>0.77</td>
<td>140 4.0</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>0.88</td>
<td>190 5.0</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.97</td>
<td>240 5.0</td>
</tr>
<tr>
<td>May</td>
<td>70</td>
<td>1.08</td>
<td>300 6.0</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>1.55</td>
<td>360 7.0</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>1.73</td>
<td>430 7.0</td>
</tr>
<tr>
<td>Jun.</td>
<td>100</td>
<td>1.72</td>
<td>500 6.0</td>
</tr>
<tr>
<td></td>
<td>110</td>
<td>1.60</td>
<td>560 8.0</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>1.15</td>
<td>640 8.0</td>
</tr>
<tr>
<td>Jul.</td>
<td>130</td>
<td>1.07</td>
<td>695 5.5</td>
</tr>
<tr>
<td></td>
<td>140</td>
<td>1.05</td>
<td>760 6.5</td>
</tr>
<tr>
<td></td>
<td>150</td>
<td>1.09</td>
<td>825 6.5</td>
</tr>
<tr>
<td>Aug.</td>
<td>160</td>
<td>1.25</td>
<td>885 6.0</td>
</tr>
<tr>
<td></td>
<td>170</td>
<td>1.82</td>
<td>945 6.0</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>1.88</td>
<td>1015 6.5</td>
</tr>
<tr>
<td>Sep.</td>
<td>190</td>
<td>1.88</td>
<td>1068 5.7</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>1.83</td>
<td>1130 6.3</td>
</tr>
<tr>
<td></td>
<td>210</td>
<td>1.70</td>
<td>1183 5.2</td>
</tr>
<tr>
<td>Oct.</td>
<td>220</td>
<td>1.20</td>
<td>1235 5.3</td>
</tr>
<tr>
<td></td>
<td>230</td>
<td>1.00</td>
<td>1280 4.5</td>
</tr>
<tr>
<td></td>
<td>240</td>
<td>0.94</td>
<td>1310 3.0</td>
</tr>
<tr>
<td>Nov.</td>
<td>250</td>
<td>0.89</td>
<td>1330 2.0</td>
</tr>
<tr>
<td></td>
<td>260</td>
<td>0.85</td>
<td>1348 1.7</td>
</tr>
<tr>
<td></td>
<td>270</td>
<td>0.80</td>
<td>1365 1.8</td>
</tr>
<tr>
<td>Dec.</td>
<td>280</td>
<td>0.77</td>
<td>1375 1.0</td>
</tr>
<tr>
<td></td>
<td>290</td>
<td>0.72</td>
<td>1385 1.0</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>0.70</td>
<td>1395 0.5</td>
</tr>
<tr>
<td>Jan.</td>
<td>310</td>
<td>0.60</td>
<td>1399 0.5</td>
</tr>
<tr>
<td></td>
<td>320</td>
<td>0.50</td>
<td>1400 0.4</td>
</tr>
</tbody>
</table>

*Anon, 1982
as run off. The water that is taken up by cane plant is utilized for various metabolic functions of plant for producing total biomass of cane. Water lost as leaching, run off and surface evaporation is of least utility to cane crop. Water actually taken up by cane plant to produce cane yield is valued for working the water use efficiency.

Irrigation use efficiency is the ratio of cane yield to the total amount of irrigation water used during the crop cycle. The water use efficiency refers to the net water used to mature a crop and could be referred as tonnes cane per hectare per centimeter of water (tc. ha⁻¹ cm⁻¹). Water use efficiency (WUE) varies with climatic regions and soils and its ranges are shown in Table-7.06

<table>
<thead>
<tr>
<th>Country</th>
<th>Water use efficiency (tc ha⁻¹ cm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>0.73 to 1.08 (Hunsigi, 1993)</td>
</tr>
<tr>
<td>Australia (bench mark)</td>
<td>1.2 (Soopermanien, 1999)</td>
</tr>
<tr>
<td>Argentina</td>
<td>0.7 to 1.9 (Yates and Taylor, 1988)</td>
</tr>
<tr>
<td>Pakistan (Punjab)</td>
<td>0.51 to 0.88 (Annon, 1982)</td>
</tr>
</tbody>
</table>

Water use efficiency gives the economics of water use and varies with a number of crops, soil and weather variants:

i) Crop season: long or short duration crop
ii) Variation in soil properties: sandy loam or hard clay soils with high or poor Infiltration rates
iii) Cultural practices: well prepared or puddled soil, uneven or leveled field
iv) Planting method: furrow/trench planting or Conventional planting
v) Irrigation system: flood, furrow, sprinkler or drip irrigation
vi) Weather changes: hot windy days or calm and rainy season
vii) Plot size: large borders or small plots
vii) Cane varieties: thick stalk broad leaved or thin stalk narrow leaved
ix) Soil fertility/productivity: Giving high yield potential or low crop growth
x) Plant population: A patchy crop stand or dense mass of crop
xi) Weeds infestation: Clean, weed free field or heavy mass of weeds allowing high transpiration losses

Any factor that is detrimental to cane growth and yield would reduce the water use efficiency. High water use efficiency is achieved with good water management in relation to crop and land management practices. Water is getting a costly resource for sugarcane crop and should be applied with proper irrigation scheduling considering all the features
of evapo-transpiration and soil moisture availability. Emphasis should be laid to judicial
use of water to cane during three main phases of crop development i.e. tillering, elongation and ripening phases.

Irrigation application efficiency

It is the quantity of irrigation water applied to the soil that is available for crop use. In
actual field practice it is the proportion of the total irrigation water applied which is
stored in the soil as readily available water (Ham et al, 2000). The highest irrigation
efficiency can be achieved by reducing the losses of applied irrigation water. The main
causes of irrigation losses are:

1. Poor storage and transmission of water to the field
2. Surface evaporation
3. Transpiration by weeds
4. Leaching down beyond root zone
5. Side percolation and run off

Critical Growth Stages for Water Requirement

Sugarcane is a long duration crop having a crop cycle of 10-15 months in subtropical
conditions of Pakistan. Growth period starts after germination i.e 25-45 days of planting.
June to August is the boom period of growth, September – October is a transitory phase
for termination of growth and start of sugar accumulation, while November onward is the
maturity period of the crop. Soil moisture deficiency, soon after planting, has detrimental
effect on germination and initial stand of the crop. With respect to plant growth and tiller
formation, early growth stage i.e April to June is the most critical period of growth for
spring planting and March to May for autumn planting.

In irrigated agriculture cane yield depends on availability of water with respect to its
quantity and frequency at desired time. Plant needs of water show great variation
according to physiological stage of crop development. These stages may be divided into
five phases (Table-7.07). The crop duration phases indicate that autumn crop avail of
long period during tillering and grand growth phase than the spring crop. Optimum yields
are obtained with proper scheduling of water in various growth stages. Irrigation
scheduling is greatly influenced by consumptive use requirements of the crop, moisture
intake and retention properties of soil as well as the soil moisture status.

<table>
<thead>
<tr>
<th>Table-7.07 Period under different growth phases of cane crop in sub-tropical region - in an ideal crop cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growth phases</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Grand growth period-elongation phases</td>
</tr>
</tbody>
</table>
The cane plant shows good response to liberal irrigation. But in case of limited supply of irrigation at one or the other stages of growth special consideration has to be given to critical stage of plant growth

**Germination stage**

For achieving good germination proper soil moisture is of paramount importance. Both extremes of water stagnation or poor drainage, low soils moisture or delays in irrigation affect the germination adversely. The crop should be irrigated soon after planting and the irrigation level should be such as to drench the soil to deep horizon. Germination is accelerated if the soil is kept at field capacity. By delay in irrigation moisture in cane setts is gradually depleted hence bud emergence is badly affected. During germination phase, besides soil moisture, sett moisture is also of critical importance (Srivastava and Joshi, 1979). Proper soil moisture while mobilize the nutrients for uptake by roots also help conserve the sett moisture as an aid in buds sprouting and initial root development to absorb nutrients. Delay in first irrigation by 0, 2, 4, 6, 8 and days after planting brought a significant reduction in germination and finally the yield of cane crop (Table-7.09).

<table>
<thead>
<tr>
<th>Delay in irrigation (days)</th>
<th>Germination %</th>
<th>Cane yield t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>61.48</td>
<td>183.51</td>
</tr>
<tr>
<td>2</td>
<td>57.37</td>
<td>171.48</td>
</tr>
<tr>
<td>3</td>
<td>54.68</td>
<td>159.66</td>
</tr>
<tr>
<td>4</td>
<td>52.51</td>
<td>147.79</td>
</tr>
<tr>
<td>5</td>
<td>45.66</td>
<td>134.58</td>
</tr>
<tr>
<td>6</td>
<td>39.49</td>
<td>115.48</td>
</tr>
</tbody>
</table>

* Minhas et al (1992)

**Irrigation use efficiency**

Water applied to cane field through irrigation and rainfall is partly utilized by cane plant and the rest is either leached down beyond root zone, evaporated from soil surface or lost as run off. The water that is taken up by cane plant is utilized for various metabolic functions of plant for producing total biomass of cane. Water lost as leaching, run off and surface evaporation is of least utility to cane crop. Water actually taken up by cane plant to produce cane yield is valued for working the water use efficiency.

Considering the type of soil, time of planting, irrigation quantity and method of planting, the crop may need one or more irrigation till the completion of germination. Excess irrigation may cause anaerobic condition to rot the buds and hamper germination, while too less moisture in soil may dry out the buds either. Due to less developed leaves and lesser evaporation surface at this stage, consumptive use of water is low, with crop coefficient of less then 0.5, However irrigation water has to be applied to maintain turgidity in roots, and for mobility of soil solutes for plant growth.
Tillering stage

The stage is important establishing initial stand for stooling in cane and for developing a good leaf canopy development. Though consumptive use is low (crop coefficient 0.7-1.0) due to low leaf area index, but adequate water is needed to promote tiller formation. Excess watering is deleterious for tillering. Moisture stress may induce more tillers but shoots are very weak and die soon after sprouting. The irrigation frequency should be judicious to induce tillering as well as growth of cane shoots. At second order of tillering, the irrigation may be delayed for 4-6- days; it would induce more tillers and would also promote root development to lower horizons in search of water. On the other hand too frequent irrigation at this stage may keep the root system shallow, which in later stage may apt the crop to lodging.

In case of spring crop effective tillering phase completes by 90-100 days of planting. i.e by early or mid June and by the month of March-April in case of autumn planting. This pre-monsoon stage of growth is very critical in respect of irrigation frequency and quantity to promote both the tillering and growth of cane. Any delay in irrigation at this stage can not be compensated by later supplies of additional irrigation water.

Grand growth period

During this stage the crop is on the peak stage of growth, leaf canopy is fully developed and is exposed for maximum water transpiration. At this stage the crop water needs are the largest as the pan evaporation measurements indicate the ET/ EP (Crop coefficient) ratio of greater than one. During this period adequate water availability should be assured to make up the water loss through evapo-transpiration.

The daily consumptive water needs of the crop are almost 10 mm in June and about 9 mm in May-June and June-July. Relatively low water needs during July- August is due to rainy season, other wise the plant produces maximum bio-mass with the largest uptake of water and nutrients. This is elongating phase of cane stalks and the crop must not suffer from shortage of water. In low rainfall regions or in the absence of rains longer interval in irrigation may have adverse effect on cane growth. Occurrence of sever moisture stress at this stage drastically reduce the size of inter nodes. During rainy season frequency of irrigation depends on pattern of rainfall and the prevailing weather condition.

Post monsoon period

By termination of grand growth period main vegetative growth is almost over and plant tends towards maturity. In the absence of rains, application of irrigation is the dire need of the crop. Due to increased humidity irrigation interval is some what increased. However, heavy irrigation should be avoided to save the crop from lodging.

Maturity phase

The stage initiates by the end of October - early November. Irrigation plays vital role in growth and sugar accumulation during harvesting phase of the crop. With the drop in temperature, water needs of the crop are reduced to 2-3 mm daily. Frequent irrigations delay maturity and reduce purity and Pol in cane juice, while restriction in irrigation hasten maturity and improve juice quality and sugar yield per unit area. However, a too longer interval in irrigation increase fibre in cane stalks, leaves get dry and cane weight is reduced.
In studies at Faisalabad, withholding irrigation for 30 days prior to harvesting enhanced sugar recovery by 1.37% in Nov., 0.94% in Jan and 5.53% in March (Table- 7.09).

<table>
<thead>
<tr>
<th>Time of harvesting</th>
<th>Sugar recovery %</th>
<th>% increase in recovery over 5 days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Irrigation before harvesting</td>
<td>5 days</td>
</tr>
<tr>
<td>15 Nov.</td>
<td>10.95</td>
<td>11.1</td>
</tr>
<tr>
<td>15 Jan.</td>
<td>11.75</td>
<td>11.86</td>
</tr>
<tr>
<td>15 Mar.</td>
<td>12.47</td>
<td>13.16</td>
</tr>
<tr>
<td></td>
<td>11.57</td>
<td>12.03</td>
</tr>
</tbody>
</table>


Cane water needs are to its minimum during winter; however, irrigation has to be applied during frosty nights. Irrigation water increases the soil temperature to some degree; hence the deleterious effects of frost damage to the plant and recovery are considerably minimized.

In subtropical regions the maturity phase coincides with the drop in temperature and receding soil moisture leading to accumulation of sugars in stalk. In tropical region, however, maturity is not properly achieved due to moderate winter temperature. In this context maturity is induced by controlling irrigation for which sheath moisture is the main criteria for irrigation application in a number of sugar producing countries.

Sheath moisture control

In some of the countries cane maturity is controlled through sheath moisture index. With a view to maximize cane yield and quality at harvest the sheath moisture is kept under desired level and the crop is irrigated at a stage of specific sheath moisture. In some ripening studies, the moisture index was brought down from 78.57 % in the first week of March to 74.35 % at maturity phase in the end of September (Srivastava and Johari, 1979). It was observed that the ripening treatment received 10 irrigations from March to September against 14 irrigation applied to a normal plot. The sheath moisture ripening plot yielded 131.19 tonnes cane with 8.75 % CCS against 124 tonne cane and 8.58 % CCS in the normal case. For batter yield and recovery the sheath moisture in early growth phase should be maintained at 85 % and the level be gradually brought down to 73 % in the maturity phase over a period of 4-5 months (Parthasarathy, 1975). The sheath moisture (3-6 leaf) in the first four months and at harvest may be taken as a reliable guide for production of optimum sugar yield (Perumal, 1978). Leaves are considered the best indicator of plant water needs than the soil. The sheath moisture index of 3-6 leaves is 83-85 % during the active growth period and reduced to 72-74 % at maturity (Turner, 1990).

Soil and crop management in relation to irrigation

Cane crop is grown over a wide range of rainfall conditions from areas of 4000 – 5000
mm per year to extremely moisture stress conditions. Under low natural precipitations, crop may receive optimum supplies of irrigation water or may face severe drought due to short water supplies. Hence crop management demand care and technique to obtain good cane yields under varying rainfalls/irrigation supplies conditions. It has been established that record yields of over 200 TCH have been obtained under well management irrigation systems. Water management aims at the conservation practices for efficient use of irrigation water to get economic yields. Water requirements depend upon soil texture, water-holding capacity of soil, land preparation, planting method, stage of cane development and depth of rooting.

**Soil type**

Irrigation requirements and intervals vary with soil type, slope and water intake characteristics of soil surface and its water holding capacity. Sandy loam soils have higher infiltration rate than clayey soils, while the former hold limited quantity of water and need frequent irrigation. Heavy clay loam soils would absorb and retain moisture better than sandy loam, and do not show stress readily, while light soils loose moisture readily and show moisture stress. Water can be conserved better in loam soils than in clay and sand. Clay soils are very difficult to manage with respect to water conservation.

**Water table**

Water table has direct bearing on drainage of water, irrigation water needs, and cane yield. High water table leads to poor drainage and significant losses in yield of cane. Water table at about one meter depth contributed 65.13 %, towards total ET of sugarcane and had no deleterious effect on growth, yield and quality of cane. The water table at less then 60 cm causes adverse effect on growth and yield of cane (Hunsigi and Srivastava, 1977).

In some studies, cane was grown at different water table levels of 25 to 125cm (Gosnell, 1971). The shallow water table depth of 25 cm inhibited germination and caused large reduction in stalk diameter, height, roots and plant growth. The 50 cm water table gave intermediate results and no differences were observed between 75 and 125 cm water table. It was suggested that to obtain optimum cane growth, the water table should be kept below 1 meter. Besides the depth of water table, the length of time for which the crop has been subject to shallow water table is also of great importance.

In some hydrometer studies the optimum range of water table depth for sugar cane was found to be 3.66 meters (Ali, 1994). Rise in water table from a depth of 3.66 to 0.9 m reduced the crop needs of surface irrigation from a level of 68.54 cm to 22.86 cm and frequency of irrigation from 9 to 4 watering, but at the same time yield of cane was decreased by 34.68 % *(Table-7.10)*. Optimum range of water table depth was found to be 2.7 m.that yielded 129.2 tons cane per hectare. Further rise in water table brought about corresponding decline in the rate of cane production.

The chemical composition of leaves showed lesser uptake of N, P, K, Ca and Mg at lower water table (Escolar et al, 1971). It indicates that under high water table, though water needs of crop are significantly reduced but poor drainage is a barrier in good aeration, movement of salts, and uptake of nutrients, crop growth and good yield. The area having shallow water table, i.e. less than one meter, is under constant threat of developing water logging and salinity.
Table 7.10 Results of Lysemeter studies on sugarcane at different water table depths.

<table>
<thead>
<tr>
<th>Water table (cm)</th>
<th>0.90</th>
<th>1.83</th>
<th>2.74</th>
<th>3.66</th>
<th>4.57</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total evapotranspiration (cm)</td>
<td>157.27</td>
<td>143.71</td>
<td>137.55</td>
<td>142.24</td>
<td>143.1</td>
</tr>
<tr>
<td>Total surface irrigation (cm)</td>
<td>22.86</td>
<td>45.72</td>
<td>60.96</td>
<td>68.54</td>
<td>68.5</td>
</tr>
<tr>
<td>Frequency of irrigation (No.)</td>
<td>4</td>
<td>6</td>
<td>9</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Rainfall (cm)</td>
<td>115.32</td>
<td>115.32</td>
<td>115.32</td>
<td>115.32</td>
<td>115.32</td>
</tr>
<tr>
<td>Drainage surface (cm)</td>
<td>63.1</td>
<td>50.31</td>
<td>45.09</td>
<td>43.02</td>
<td>41.09</td>
</tr>
<tr>
<td>Ground water contribution (%)</td>
<td>51</td>
<td>22</td>
<td>5</td>
<td>0.15</td>
<td>0</td>
</tr>
<tr>
<td>Cane yield (ha(^{0.5}))</td>
<td>87.2</td>
<td>87.2</td>
<td>129.2</td>
<td>133.5</td>
<td>133.5</td>
</tr>
<tr>
<td>Water use efficiency</td>
<td>555</td>
<td>555</td>
<td>941</td>
<td>919</td>
<td>933</td>
</tr>
</tbody>
</table>

Ali (1994)

### Organic status of soil

Besides providing nutrients to plants and improving microbial activities in soil, the organic matter has the enormous capacity of absorbing water and retaining it for a long period. Thus the soils rich in organic matter have a good moisture holding capacity and crop is able to sustain growth with longer irrigation intervals. As such cane planted in organic soils successfully evade the moisture stress for a long time. On the other hand soils deficient in organic matter gets dry soon and crop suffers severely if irrigation is delayed. Organic matter also improves soil structure for better root development. For good organic soils, if not more, the organic matter should in no case be less than one percent. General analysis of cane fields in Pakistan indicates soil organic matter in a range of 0.4 – 0.6 %. A small fraction of our cane fields contain little above 0.6 percent. The organic status of soils can be improved by growing green manure crop, incorporating farmyard manure, crop residues and the filter press cake (FPC).

### Land preparation

Deep soils retain more water than shallow soils; therefore the act of land preparation should include deep sloughing. Deep tillage help penetrate roots to deeper horizons for moisture extraction. Deep root system in soils finds more area for extracting water during times of scarcity. Though the effective root depth is more than one meter, for effective water use the soil should be worked to not less than the depth of 60 cm (Yadava, 1991). In cane culture the use of sub-soiler in clayey soils and chisel in heavy soils should be mandatory for deep root development and better water intake and retention. Use of mould board or disc plough is also necessary in some conditions of hard soil. Longer irrigation intervals with larger quantity of retained water can be managed with deep rooted crops, while shallow rooted cane will require more frequent irrigation. In times of irrigation scarcity cane planted in deep soil can sustain longer irrigation intervals, while the crop grown in shallow soils suffer more from short supply of water.
Leveling

For efficient use of irrigation water the cane field should be well leveled. In unleveled field some pockets are kept dry, while others are submerged in water, hence would affect germination adversely and would not promote tillering. Unleveled field also disturbs uniform flow of water and affect efficiency in irrigation. Un-even field may take 20 to 25 % more time for irrigation in ploughed land and the planted field also creates a considerable difference.

Planting methods

Generally two planting methods are in vogue: Trench/Furrow planting; “Wattar” planting. Trench or furrow planting is helpful where water can be made available at desired time and frequency. Under conditions of water shortage, “wattar” planting is helpful in conserving moisture for 40-60 days during initial stage of germination. First heavy irrigation in loam soils can help conserve moisture even for 60-70 days.

Inter-rows spaces

Suitable inter-row space has important role in mulching and hoeing of cane. Tractor operations are efficient in wider row spaces than the narrow row spaces.

Wider row spacing is recommended for fast growing varieties, as leaf canopy of such varieties close in fast than the slow growing varieties. For example the variety HS 2 close-in-fast than CP 43-33, similarly varieties BL 4 and BF 129 close-in-fast than Th 10.

Rapid close in of inter-row space reduce surface evaporation, thus conserve soil moisture.

The inter-row spaces that help close in within 80-90 days of planting is ideal for that particular variety and environment.

If facilities do not exist for mechanized operations then it is better to reduce inter-row space to even 60cm. This is to ensure fast close in to avoid surface evaporation. The recently modified row space of 60 – 120 – 60 cm is ideal for mechanization, both for fast or slow close-in varieties.

Mulching the field surface

Any practice or material that reduces surface evaporation and conserves moisture in soil is called mulch. The mulch conditions help in minimizing the evaporation losses in cane fields. Various forms of mulches used are soil mulch, bagasse, trash and plastic sheet.

**Soil mulch:** The hoeing and inter-row cultivation is the usual practice recommended in cane culture. Hoeing and cultivation in inter-row space of cane loosens the soil surface, breaks the capillary action in surface evaporation and conserves moisture in root zone of cane. It helps to prolong irrigation interval without appreciable loss in cane yield.

**Plastic sheet cover:** The practice of plastic sheet cover is getting common in row planting of vegetables. For cane crop as well the author observed in china that cane trenches, after planting in November, are covered with plastic sheets. The sheets remain in cane fields during winter season. Holes are made on the point of germinating sprouts to allow free emergence of plants. Sheets are removed when germination is completed by the end of March. The practice helps conserve moisture and also increase soil temperature to save
Irrigation

the crop from frost hazards.

**Trash mulch / blanket:** In case of ratoon crop trash can be conveniently used as mulch. It is a common practice in China, Mauritius and Australia. During harvesting trash is uniformly spread on cane fields. The practice conserves moisture in soil and raises soil temperature to promote germination. Through moisture conservation trash is reported to save water to the extent of 36% (Yadav, 1991). Trash also saves stubble from frost hazards. Trash mulch keeps the soil temperature favourable for microbiological activities, which result in the mineralization of nutrients into the soil.

As the winter is over, trash on cane rows should be slightly moved aside to expose the stubbles to light for better sprouting.

With advance in spring and with start of profuse sprouting, trash should be incorporated in soil with disc incorporator.

In an experiment at farmer’s field, in lower Sindh, trash blanket kept the soil moisture at field capacity for about 28 days after irrigation against the trash free field that got dried with only 15% soil moisture (Malik, 2002). The cane field covered with trash recorded 7 tillers per plant compared to 4 in an un-trashed field *(Table-7.11).*

**Table-7.11 Effect of trash blanket on soil moisture conservation in cane field (CV BL 4)**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Soil moisture %</th>
<th>Tillers per stubble shoot</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trash blanket</td>
<td>28</td>
<td>7</td>
<td>Vigorous &amp; shining</td>
</tr>
<tr>
<td>No trash</td>
<td>15</td>
<td>4</td>
<td>Weak &amp; dull</td>
</tr>
<tr>
<td>Crop harvested :</td>
<td>27 February, 2001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation :</td>
<td>10 March , 2001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture observed</td>
<td>: 07 April, 2001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Malik, 2002

**Hoeing/ inter row cultivation**

Under conditions of water shortage hoeing/inter-row cultivation is the main tool with cane growers to conserve soil moisture. As the germination is completed, one dry hoeing not only eradicates weeds, creates mulch to conserve moisture. The practice tends the young cane plants to extend their roots to deeper horizons.

The soil moisture can be conserved well when the crop is given inter-row cultivation on each turn of irrigation. Inter-row cultivation should continue till crop grows beyond the tractor’s clearance or complete close in of the leaf canopy. The crop left without hoeing dries up soon and suffers from moisture stress.

**Weed control**

Weeds are great competitor of water and more so in early stage of cane growth. Weeds have high transpiration rate through its leaves. Mechanical hoeing and chemical control of weeds is reported to conserve water and give significant increase in yield of cane
compared to weeded field (Malik, 1990). Elimination of weeds from cane fields ensured conservation of moisture in the soil profile and increased the pre-monsoon water use efficiency (Chaudhary and Mani, 1974). The data in Table-7.12 indicate that weed control treatment had the highest water use efficiency of 22.5-mm water per ton of sugar produced compared to 40.75-mm water per ton of sugar in un-weeded plots. Pre-monsoon water use in weeded plots was recorded to be 4.85-mm compared to 6.2-mm water used per day in un-weeded check. Therefore cane fields and water channels should be kept free of weeds.

Table-7.12 Effect of weed control on water use efficiency of sugarcane during pre-monsoon period*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Water use efficiency (mm ton⁻¹ sugar)</th>
<th>Water use efficiency % increase in cane &amp; sugar yield in weed control treatments over uncontrolled check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrazine</td>
<td>4.60</td>
<td>19.76</td>
</tr>
<tr>
<td>Simazine</td>
<td>4.85</td>
<td>21.85</td>
</tr>
<tr>
<td>Simazine + 2,4-D</td>
<td>4.75</td>
<td>20.70</td>
</tr>
<tr>
<td>Herbicide + one weeding</td>
<td>4.80</td>
<td>22.25</td>
</tr>
<tr>
<td>Weeded check</td>
<td>5.35</td>
<td>26.25</td>
</tr>
<tr>
<td>Mean</td>
<td>4.85</td>
<td>22.15</td>
</tr>
<tr>
<td>Unweeded check t ha⁻¹</td>
<td>6.20</td>
<td>40.75</td>
</tr>
</tbody>
</table>

* Chaudhry and Mani (1974)

Drought

It is the condition when precipitation and irrigation conditions fail to meet the potential water requirements of the crop. In this context evaporation exceeds soil intake of water and the soil and atmospheric moisture fail to sustain plant growth. This condition is reflected as the soil drought or the atmospheric drought. In case of soil drought the soil moisture is not adequate to keep pace with moisture absorption and transpiration of leaves. While in atmospheric drought the transpiration of moisture through leaves is in excess of moisture absorption due mainly to high temperature, low humidity, hot winds and bright sunshine. The atmospheric drought may even occur under conditions of higher soil moisture and is termed as the physiological drought.

Drought conditions are challenge to cane and sugar production potential in a region. It may occur in any season, but it’s occurrence in critical period of crop growth surmounts to severe yield losses. It may have serious effect during formation phase, elongation phase or even the maturity phase. The atmospheric drought due to the absence of rainfall, besides the frequent irrigation during grand growth period, has detrimental effect on yield. Therefore, cane crop has always suffered yield losses during years of dry monsoon season.

The effect of drought may be modified by soil conditions. The effect is aggravated in the light textured, sandy soils which have a little capacity to with-hold water than loam soils. The deep soils and those containing more of organic matter can conserve more water than shallow or barren soils. The soils with high water table can withstand the effect of
Irrigation
drought stress for a longer period. Saline soils due to high salt concentration have high osmotic pressure of the soil solution, thus plants are not able to absorb moisture. These soils exhibit more moisture stress than salt free soils.

**Effects of drought**

Drought exerts some visible symptoms on cane, like change in colour of leaves, drooping or curling of leaves and loss in turgidity and vigour of plant. If drought persists, leaves wither, dark green colour changes to yellow, then desiccate and ultimately get dry. These symptoms are associated with disruption of metabolic processes of plant and suppression of cane growth. The economic effect of drought is noticed on the following plant characters. The extent of the effect varies with the intensity and duration of drought stress and the cane variety.

**Poor growth and yield**

Growth of yield contributing characters i.e leaves, stalks and roots is adversely affected. Moisture stress reduces leaf area, number of tillers, mill-able canes, length and girth of internodes. It results into tiller mortality, stunted growth and finally to reduced yield.

**Photosynthesis**

Moisture stress has adverse effect on photo-synthetic process of leaves. Photo-synthesis is active in adequate moisture in plant, higher moisture status in leaves and active stomata. Water is essential component of photo-synthesis and makes the leaves turgid for stomata activities. Moisture stress closes the stomata, whereby gas exchange and photosynthesis is restricted disturbing the CO2 and oxygen balance in plant tissues. It has been observed that the plant that is adequately supplied with water produces more sugar than the plants exposed to moisture stress (Burr, 1957). Photosynthesis may be reduced to 90 percent when leaves are wilted (Humbert, 1968).

**Sucrose assimilation**

Moisture affects assimilation and storage of sucrose through its action on vital functions of plant especially growth. A plentiful supply of water is essential for the formation of sucrose in the leaf blades, its transport and storage in the stem and for expression of sugar in the juice. It has been observed that leaf blades of plants provided with adequate water made ten times more sucrose than those of moisture stressed plants (Dillewijn, 1952). Water starved plants might contain more sucrose on dry weight basis but less sucrose is recovered in juice. Therefore the extraction of sugar is adversely affected in cane grown in moisture stress condition (Evens, 1939; Gill and Singh, 1959). Difficulties experienced in clarification of cane juice of drought affected plants and extraction of sugar are due to increased amino acid contents of juice (Wiggins, 1953).

**Mechanism of drought tolerance in sugarcane**

Drought resistance is a complex phenomenon which is governed by the water balance of the plant. Loss of water through transpiration and the regulatory mechanism involved in it is one of the factors determining the degree of drought resistance. Thus the ability of the plant to cut down transpiration during the period of stress help reduce consumptive water use. Transpiration occurs in leaves and cane stalks, of which 90 % is from both surfaces of leaves. Stalk transpiration is from nodal region, which is devoid of wax. The varieties
that have high transpiration rates in the early morning hours of favourable water conditions followed by decreased transpiration with temperature rise and stomata closure have been associated with high yields in sugarcane areas of deficient soil water (Van Dillevign, 1952). The varieties withholding water in them keep up the turgidity and avoid drought injury, while the excessive transpiration results in loss of turgidity and eventually death from dehydration. Some physiological, morphological and anatomical characters are associated with drought tolerance in cane.

**Cellular structure:** Drought stress causes mechanical injury to the cells and induces structural changes in protoplasm. Due to severe loss of water cells collapse, vacuole is shrunk and protoplasm is pulled inward. Cellular water depletion may result in irreversible reduction in enzymes’ activities and sugar and protein synthesizing capacity of plant. Smaller cells undergo much smaller reduction in volume than do large cells, and therefore do not suffer severe drought injury (Humbert, 1968). Drought tolerant varieties have usually smaller cells; evade moisture stress better than do susceptible varieties. Drought susceptible plants have larger cells and on desiccation cells collapse and reduction in rate of growth are so drastic as to cause mortality of cane stalks (Levitt, 1956).

Plants with thicker cuticle transpire less water. Drought resistant clones are known to have thicker cuticle on the epidermis of leaf (Evens, 1939; Rao, 1951; Malik and Yousif, 1973).

A large number of veins give rigidity to the plant and are accompanied by a large number of conducting strands. These strands enable the plant to draw more water from root zone to keep the turgidity of the plant, preventing wilting and avoid tissue desiccation. Drought tolerant varieties CoL 61 and Co 205 were found to have densely venated leaves (Malik and Yousif, 1973).

**Leaf characters:** Leaf characters have pivotal role in drought tolerance of any variety. The potential rate of transpiration of water loss is associated with leaf size number and structural modification in the stomata, bulliform cells and cuticle, (Chang and Shih, 1948; Lal and Mehrotra, 1949; Rao, 1951; Gill ans Singh, 1959).

Low water requirements have been associated with high cell sap concentration and high level of hydrophylic colloids (Anon, 1959; Malik and Yusuf, 1972).

**Stomata:** Stomata control the process of carbon assimilation for photosynthesis and transpiration of moisture. At the available soil moisture level the stomata are open to transpire water and to exchange CO2 for photosynthesis action. Under stress condition stomata get closed and check the CO2 infiltration and transpiration that avert the photosynthesis activities. The stomata characters such as low frequency, small size and rate of stomata action have been associated with drought resistance (Dillewijn, 1952; Naidu and Bhagyalakshmi, 1967 and Malik and Yusuf, 1973). In addition, stomata of resistant varieties are often sunk in the leaf and may also be characterized by the presence of hair protecting the air chamber (Dillewijn, 1952).

**Leaf curling:** Some varieties show in-volute curling of upper leaves during period of moisture stress. Passive curling reduces the radiation receipt by leaves and reduces water use compared to uncurled leaves. A 10-20% reduction in rate of transpiration is reported by leaf curling (Enens, 1939).
The mechanism of in-volute curling is closely tied up with bulliform cells in the upper epidermis of the leaf. These cells are thin walled and due to un-protective outer walls, they lose moisture during drought, rapidly, resulting in loss of turgidity and shrinkage and ultimately curl. A large number and narrow width of bulliform cell zone avoid moisture loss by rolling their leaves under moisture stress conditions. The drought resistant clones have efficient mechanism of leaf curling, as they possess more of bulliform cells per unit area than susceptible varieties (Dillewijn, 1952;
Levitt, 1956; Chen and Bor, 1966; Malik and Yusuf, 1973). Cane varieties vary in extent of curling; some varieties do not curl or wilt even under severe drought.

**Leaf area:** The leaf area, orientation of leaves and the leaf thickness determine the total transpiring surface. The number and size of leaves are more or less reduced in drought resistant varieties, which results in reduction of total leaf area per plant. Reduced leaf area reduces the total transpiring surface resulting into reduction in moisture loss through leaf surface (Evans, 1939; Dillewijn, 1952; Malik and Yusuf, 1972). Varieties with broadleaves in general have proved drought susceptible (Rao, 1951). Erect position of leaves is also associated with lower transpiration rate than the drooping position (Dillewijn, 1952; Malik and Yusuf, 1972). Drought tolerant varieties Co 205, CoL 61, L116 and CP 43-33, had narrow leaf area with erect position compared to broad drooping leaves of susceptible varieties BL 4 and BF 166 (Malik and Yousuf, 1972; Fasihi and Malik, 1980 and Malik et al, 1992).

**Roots:** A better development of buttress roots and rope-system than lateral roots characterizes drought resistant varieties. Vertically developed roots enable the plants to draw moisture from the deeper layers of soil during period of drought when surface layer of soil lose most of its moisture (Evans, 1935; Anon, 1959). Increased ratio of roots to shoots is also important to maintain suitable moisture balance in plants. Thin and spreading root system is associated with greater efficiency in shallow soils. It is the effective absorbing surface of the root which is important for water uptake and the transpiring surface which regulates water loss (Annon, 1959). At soil temperature of 15° C, roots are not much active to take up water; as such its transpiration is curtailed at this temperature (Mongelard and Nickell, 1971).

**Tillering:** Higher tillering capacity of cane varieties avoids drought or postpones dehydration (Dillewijn, 1952). On the other hand varieties with large number of superfluous tillers cause wastage of water (Kramer, 1949; Anon, 1959). Drought tolerant variety L 116 and CP 43-33 produce more tillers than the susceptible variety BL 4 (Fasihi and Malik 1980, Malik et al, 1992). Yield of sugarcane is influenced by the number of tillers which survive to form mill-able canes, and only those tillers are important which develop into mature stalks.

**Osmotic pressure:** Osmotic pressure is considered important physiological aspect of drought tolerant varieties: develops considerable suction tension to draw moisture from soil more rapidly (Dillewijn, 1952). The osmotic pressure of cell sap was higher in drought tolerant varieties than the susceptible ones (Malik and Yousuf, 1973).

**Approaches to Withstand Drought**

**Drought tolerant varieties**

The yield of any variety is a function of its response to environmental stress and its genetic potential. Cane varieties show different behaviour of growth and plant survival during moisture stress. Drought tolerant varieties remain near optimum growth for longer period of time and show lesser yield reduction under moisture stress condition. Such varieties keep a fair degree of balance in intake and loss of water because of morphological and anatomical modifications of plant parts and tissue and physiological traits to survive tissue desiccation.
In one of the studies at Faisalabad it was observed that the variety CP43-33 showed the lowest yield reduction of 5.1% & 20.6% under irrigation coefficient of 0.8 & 0.6, respectively. The variety BF162 also showed better performance under stress conditions, while BL4 suffered heavy yield losses of 16.2% and 31.3% at the same level of moisture stress (Table-7.13). L 116 and SPSG 394 are also known for drought tolerance.

Table-7.13 Yield performance of different cane varieties under various levels of Irrigation *

<table>
<thead>
<tr>
<th>Varieties</th>
<th>Cane yield t ha⁻¹</th>
<th>Percent yield reduction over 16 irrigations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Irrigation No. Coefficient</td>
<td>(1.0)</td>
<td>(0.8)</td>
</tr>
<tr>
<td>BL4</td>
<td>71.4</td>
<td>59.8</td>
</tr>
<tr>
<td>BF 162</td>
<td>87.4</td>
<td>79.3</td>
</tr>
<tr>
<td>BF 166</td>
<td>78.7</td>
<td>66.5</td>
</tr>
<tr>
<td>Co 1148</td>
<td>85.3</td>
<td>73.7</td>
</tr>
<tr>
<td>CP 43-33</td>
<td>69.2</td>
<td>65.7</td>
</tr>
<tr>
<td>CPF 147</td>
<td>53.5</td>
<td>45.2</td>
</tr>
<tr>
<td>Mean</td>
<td>74.3</td>
<td>65.0</td>
</tr>
</tbody>
</table>

Table 7.13 Yield performance of different cane varieties under various levels of Irrigation

* Malik, 1996; Irrig. Coeff: ( ) = Irrigation equivalent to pan-evaporation

Trench Planting

This planting technique helps to place the seed at deeper layer, thus the roots can easily find the way to penetrate in lower horizons. Thus the roots are well placed to draw more volume of water from deeper soil strata and thus help plants to sustain growth for a pretty long time on exposure to moisture stress.

Organic status of soil

Soils with higher organic matter have a large capacity to absorb water and retain and develop a granular structure to conserve moisture for a longer period of time. Cane crop grown in organic soils withstands moisture stress for a longer period.

Crop hardening

This is to enable the cane plants to withstand moisture stress through enhanced root development. Frequent irrigation help spread roots superficially and laterally on upper soil layers. If irrigation is withheld, for a little longer time in early stage of cane growth, roots develop vertically down in deeper horizons, in search of water. Deep root penetration help absorb more water during stress period. Thus plants on completion of germinations should be exposed to longer irrigation interval, on alternate turns of watering. This induced stress, during March-April or early May, is beneficial to promote deep root growth. This hardening is a preparation to face the expected drought spell during water scarcity period of May-June months.

Early planting

A well established crop with good tillering and deep root development can withstand the
drought stress better than a very young crop with weak stand. Therefore, the crop should be planted well in time to help establish a good stand by the time it is subject to moisture stress. Month of February is the ideal period of planting a spring crop. In non-perennial canals areas crop is planted in autumn. Under such condition, September planting is the ideal time to have an accelerated growth for better canopy cover to combat the ill effect of drought that reduces surface evaporation.

**Rows spaces**

Closer row spacing is considered best to combat the ill effect of drought. It is advocated that increased planting rate per unit area provides thick canopy cover on soil surface which restricts surface moisture evaporation losses. Thick populations also suppress weed growths. Therefore, a row spacing of 75-90 cm should be adopted under moisture stress condition. Dual row planting at 60 – 120 – 60 cm row distance is a better technique in obtaining dense stand under wider row planting system. For spring planting inter row distance can still be reduced to 50 – 100 – 50 cm in dual row planting system.

The usual drought stress period is March to June in non-perennial canal command areas. In case the planting is done in wider rows (120 cm), all out efforts should be made to accelerate growth that cane canopy covers the ground during April. After every irrigation, the inter-row spaces should be cultivated / harrowed to conserve moisture in soil. The cultivated field would withstand moisture stress better than an uncultivated crop. If such mechanical operations are not within the provision of a grower, one may resort to closer spacing for better results.

**Mulching**

Trash is considered to be the best mulch for conserving soil moisture. Trash covering provide a barrier to wind current and reduce vapour flow from soil surface to atmosphere. Use of trash mulch in moisture conservation of ratoon crop has been an established practice. Trash mulch can also be provided to plant crop. The practice is reported to conserve moisture during drought and help increase cane yield from 10 to 25 %, (Verma, 2002). During June-July, the dry leaves on cane plants can be safely de-trashed/removed and spread on inter-row spaces to reduce surface evaporation.
Spray of potassium

Potassium plays an important role in metabolic processes of plants, especially respiration, transpiration, transformation of carbohydrates, and enzymatic action. During stress periods, uptake of potassium from soil is checked, affecting metabolic processes of plants. Foliar application of potassium is reported to be absorbed by leaves and activate the process to increase vigour and yield of cane. Foliar spray of potassium at 2.5% concentration made 60, 90, and 120 days after planting, was reported to increase yield by 5-9% and 30.8%, in loam and sandy loam soil, respectively (Naidu et al., 1983).

Use of moisture absorbents

Some polymers are known to absorb soil moisture applied through irrigation and conserve it for later use during severe stress periods. The data available, yet show divergent information and are not conclusive for application on a commercial scale. A polymer compound, potassium acrylamide, is granular in shape and is marketed by the name of Qemisol. Upon getting contact with water, it hydrates into a transparent gel. One gram of Qemisol can retain an average of 300-400 ml of water, and acts as a reservoir for plants (Farooq, 2001). The chemical is applied in furrows before the cane sett placement at 20 kg/ha. Whenever the crop is irrigated, it absorbs water and retains it for 10-15 days. Roots first meet their need from soil available water, and after the soil moisture is reduced, roots apply pressure on the hydrated chemical and squeeze out the retained water. The chemical once applied keeps its water retention character for 3 years (Farooq, 2001).

Water Quality

Quality of water is of great importance with respect to soil management, cane yield, and juice quality. Good quality water assures good yields while salts are of great concern to water and need special irrigation management practices. Saline alkali soils can easily be managed and reclaimed if irrigation water is sweet. On the other hand, good quality soils need special crop management practices if water quality is not good. The quality of water is affected by the presence of soluble salts. Rainfall water is considered to be pure water, but still, some atmosphere gases (CO2, O2, and NH3) are dissolved in it. It may also be adulterated with salts if winds carry ocean spray to the cloud layers.

Water quality problems lie with subsoil water. This water is charged with chemicals dissolved to a greater or lesser degree while water percolates through the soil layers of different rocks. Thus, the constituents of salts in the soil affect the quality of subsoil water. The water quality is generally affected by salinity, sodicity, and toxic ions. Salinity refers to the total quantity of dissolved salts (TDS), while sodicity is concentration of sodium expressed as SAR.

The parameters to determine the quality of water are:

- **pH**: It is the unit that indicates the acidic or alkaline nature of water. The water having pH 7 is considered neutral, less than 7 has an acidic reaction, and above 7 has an alkaline reaction. It is measured by pH meter.

- **EC**: (Electrical conductivity) - The EC unit is decisiemens per meter (dS/m)
and is measured by conductivity meter, commonly read as millisiemens per centimeter (mS/cm)

\[ \text{TDS} = \text{(Total dissolved salts)} = \text{EC (dS/m)} \times 640; \text{commonly expressed as milligram per liter (mg/L)} \]

\[ \text{SAR: (Sodium absorption ratio). It is the relative proportion of sodium, to calcium and magnesium.} \]

\[ \text{SAR} = \frac{Na}{\sqrt{(Ca + Mg)/2}} \]

\[ \text{RSC: (residual sodium carbonate) Excess of carbonates and bicarbonates over calcium and magnesium in water.} \]

\[ \text{RSC} = (CO_3 + HCO_3) - (Ca + Mg) \]

\[ \text{RA: (Residual alkali): It is the exchangeable sodium percentage (ESP) of water / soil and represents amount of sodium carbonate in water; is expressed as milli-equivalent per litter (meq/l)} \]

\[ = (Na+ K) \times 100 / (Ca + Mg + Na + K) \]

The major constituents of irrigation water are sodium, calcium and magnesium as cation and sulphate, chlorides, carbonates and bi-carbonates as anions. Excess of sodium salts always create problems in salinity. In general, river-canal water has TDS around 300 and is always good for irrigation purposes. The problem lies with the ground water pumped out from soil through tube wells or the water lifted from open drains. The factors affecting the quality of ground water resources could be grouped as:

1. Water of arid and semi arid regions
2. Water quality influenced by high water table in irrigated areas and river basins
3. Water quality in areas of coastal regions influenced by sea water.

Of all the factors aridity is the most important single factor responsible for saline soils. The basic soil forming rocks determine the quality of water stored in under ground layers. There are regions of sweet water zones within zones of brackish quality water. The soil survey department and WAPDA have already earmarked the zones of quality water in Pakistan.

The poor quality irrigation water affects both the chemical and physical properties of soil. The chemical effect could be salinity and sodium hazards and the physical effect could be on the texture of the soil. The quality specification and acceptable limits of salts in irrigation water are given in Table-7.14.

In well drained soil water with TDS 1500 ppm is used in unavoidable cases. The saline water should be mixed with canal water in 1:1 ratio when TDS of saline water ranges between 1000 – 2000. However when TDS of the saline water ranges between 2000-3000, the ratio of canal to ground water should be 5:2. Generally, when TDS exceeds 3000 ppm the saline water is not recommended.
Table-7.14 Criteria for measuring water quality

<table>
<thead>
<tr>
<th>Factor</th>
<th>Fit water</th>
<th>Marginal fit</th>
<th>Unfit</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC (m mhos)</td>
<td>0 – 01</td>
<td>1 – 1.2</td>
<td>Above 1.25</td>
</tr>
<tr>
<td>RSC (m. eq/lit)</td>
<td>0 – 1.25</td>
<td>1.25 – 2.5</td>
<td>Above 2.5</td>
</tr>
<tr>
<td>SAR</td>
<td>0 – 10</td>
<td>10 – 15</td>
<td>Above 15</td>
</tr>
<tr>
<td>TSS</td>
<td>&lt; 700</td>
<td>700 – 1200</td>
<td>Above 1200</td>
</tr>
<tr>
<td>pH</td>
<td>7.0 – 7.8</td>
<td>7.8 – 8.2</td>
<td>8.4 &amp; above</td>
</tr>
</tbody>
</table>

Source: Richards, 1954

The high SAR and RSC level creates impermeability in soil of high clay contents. These conditions reduce aeration due to poor drainage. Root development is retarded, and nutrient uptake is restricted affecting the growth adversely. Repeated irrigation with such water causes accumulation of salts and soil under such conditions is dispersed and loses its normal structures.

The tube well water and the water from open drains should be tested infrequently. With continuous lifting of water, water table is receded that may adversely affect the quality. The water may be sweet during floods, rainy season and during regular canal irrigation flows. In non-perennial areas quality of water does not remain at fitness level. Continuous use of unfit water may deplete the soil productivity and damage the soil texture.

Problems associated with quality of water

The irrigation water having too low EC or too high a level of SAR have poor penetration rate in soil. Soils receiving such quality of water grow cane with poor growth and poor stooling. Cane may germinate, but poor water penetration in soil limit water storage, check root growth and plant show moisture stress. Plant moisture stress symptoms appear even one or two days following irrigation. The soil is wet but plant can not take up sufficient water. The moisture stress symptoms in such soils include poor growth, yellowish crop with brown leaf tips and margins.

Sugarcane is regarded as having only moderate sensitivity to the impact of soil salinity on yield (Kingston and Anink, 2003). Ratoon crop is more sensitive to salinity than plant crop. However, cane varieties vary greatly in their yield response to different salinity levels. Electrical conductivity of juice increases with increasing salinity as a reflection of increasing ash levels in juice.

The ideal soil for good cane yields has the EC level of less than 1 mmhos/cm. To obtain good sugarcane production in saline and saline sodic soils, the salinity in 0 – 60 cm layer must not be higher than 2 mmhos/cm (Yaldivia, 1980). At soil conductivity below 2 mmhos/cm cane growth was not affected, between 2 to 4 growth was reduced, while at conductivity above 4 mmhos/cm cane yield was adversely affected (Mehrad, 1968). Soil conductivity of 4 mmhos/cm was the threshold, above which the growth of sugarcane was drastically reduced (Shoji and Sund, 1965; Robinson et al, 1965).
Improving Water Penetration in Saline Soil

Irrigation techniques

Slope: The land should be quite even with minimum slope

Trash blanket: trash blanket improves water penetration. Water infiltration rate is slow and efficient with minimum evaporation and run off losses. Additional soil moisture can be conserved up to 40 mm by trash blanket (Ham et al, 2000).

Soil ameliorants

Application of gypsum can help improve water penetration in soil. The quantity needed for reclamation should be worked out on the basis of soil analysis. Sugarcane filter press cake when incorporated into soil can also improve water penetration.

Management of Saline Water

Irrigation water applied to soil adds considerable amount of salts into soil. As for instance 800 mm of water with an EC of 1.0 dS/m will add 5 tonnes of salts per hectare. Without adequate leaching this salt will accumulate in soil profile (Ham et al, 2000). Any additional application of water leaches down the salts. Additional water has therefore to be applied in excess of crop needs. This excess is known as the leaching requirements of the soil. And, this requirement varies with the EC value; higher the EC of water, the greater the leaching requirements. The leaching requirements for different irrigation and drainage water qualities are reproduced in Table-7.15. Excess application of water can cause ground water to rise. If the ground water rises to within 2 m of the soil surface, cane growth will be adversely affected. Sub-surface drainage and disposal of drainage water are then necessary.

Table-7.15 Irrigation leaching requirements

<table>
<thead>
<tr>
<th>Quality of irrigation water (dS/m)</th>
<th>Tonnes salt ha⁻¹ meter⁻¹ of water applied</th>
<th>Leaching requirements* as % of irrigation to produce drainage water quality of:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 dS/m</td>
</tr>
<tr>
<td>0.1</td>
<td>0.6</td>
<td>2</td>
</tr>
<tr>
<td>0.2</td>
<td>1.2</td>
<td>4</td>
</tr>
<tr>
<td>0.4</td>
<td>2.5</td>
<td>8</td>
</tr>
<tr>
<td>0.8</td>
<td>5.0</td>
<td>16</td>
</tr>
<tr>
<td>1.6</td>
<td>10.0</td>
<td>32</td>
</tr>
<tr>
<td>3.2</td>
<td>20.0</td>
<td>64</td>
</tr>
</tbody>
</table>

Source: Ham et al, 2000,  *Rainfall effects are ignored.

Cane varieties have inherent ability to tolerate different salt ranges. Choice of salt tolerant varieties only reduces the impact of salinity. Main emphasis should be given to reclaim the soils.
**Salinity effect on cane plant**

Salinity affects cane plant in a number of ways

- Soil moisture becomes less available to plant roots.
- Due to higher salt concentration and difference in osmotic pressure, plant roots can’t absorb moisture; rather reverse action in plants may deplete the moisture.
- Plants show moisture stress in the form of wilting, scorching of leaves, restriction of growth and in severe cases death of plant.
- Since plants absorb more minerals especially potassium, cane juice has high ash contents that affects sugar recovery in clarification process.
- Cane varieties show different levels of tolerance to salts.

**Sodicity**

Studies in Australia indicate a 20 % yield loss at ESP of 12.25, yield was halved by ESP 31 and cane growth had failed completely by ESP of 61 (Ham et al, 2000). Deleterious effect of sodium is due to deterioration of soil structure, as high levels of ESP coupled with low EC, cause clay particle to disperse when the soil is wet. This dispersion results in sealing and crusting of surface soil and resists water and root penetration in subsoil. Like salinity conditions, roots can’t extract water held strongly around soil particles.

**Fertilizer in relation to irrigation**

The water use efficiency is enhanced by adequate provision of nutrients through fertilizers. Higher rate of fertilizer demand more frequent irrigations to produce optimum yield (Srivastava and Johari, 1979). However, some balance in irrigation and fertilizer has to be established that cane growth is not hampered due to lack of nutrients or crop is not lodged by excessive application of nitrogen. Judicious use of both irrigation and fertilizer give added advantage in enhancing cane yields. In one of the studies it was noted that compared to low fertilizer (78 Kg N/ha) and low irrigation (15 days interval), optimum fertilizer (156 Kg N) with liberal irrigation (10 days internal) increased yield to the extent of 33.3%, but yield was not increased by low irrigation (15 days interval), with higher dose of fertilizer (156 kg N/ha) (Table-7.16).

**Table-7.16** Cane yields affected by different levels of fertilizer and irrigation interval

<table>
<thead>
<tr>
<th>Nitrogen Kg ha⁻¹</th>
<th>Irrigation interval days</th>
<th>Cane yield t ha⁻¹</th>
<th>Increase in yield t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>78</td>
<td>15</td>
<td>78.00</td>
<td>0</td>
</tr>
<tr>
<td>78</td>
<td>10</td>
<td>88.00</td>
<td>12.82</td>
</tr>
<tr>
<td>156</td>
<td>15</td>
<td>92.56</td>
<td>18.66</td>
</tr>
<tr>
<td>156</td>
<td>10</td>
<td>104.00</td>
<td>33.33</td>
</tr>
</tbody>
</table>

In studies on various nitrogen levels (0, 56, 112, 168, 224, Kg N/ha), there was little effect of additional water at “0” N level, yield increased with increasing water at high N level (Table 7.16). However, yield increment at very high N levels resulted to additional cost of N. On the whole, 112 Kg N with irrigation supplies equivalent to pan evaporation seem to be fairly a good combination (Fasihi et al, 1980). It has also been observed that under high soil moisture stress (6.0% and 8.4%), the higher fertilizer application was not as effective as under low moisture stress (13.1 %), (Bhatti et al, 1986).

The data given in Table-7.17 confer the fertilizer use efficiency with the application of appropriate amount of irrigation water. At low irrigation levels nutrients are not fully taken up by plant roots and fertilizer applied is not optimally utilized, and with excessive application of water there is tendency of nutrient leaching. Crop also lodges with excessive irrigation and high rate of fertilizer.

**Table-7.17 Effect of different levels of irrigation and fertilizer on the yield of sugarcane – variety BL 4**

<table>
<thead>
<tr>
<th>Fertilizer Kg. N ha⁻¹</th>
<th>Irrigation coefficient</th>
<th>Cane yield tons per hectare</th>
<th>Mean for fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.6</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>0</td>
<td>39.29</td>
<td>-</td>
<td>42.22</td>
</tr>
<tr>
<td>56</td>
<td>-</td>
<td>58.31</td>
<td>-</td>
</tr>
<tr>
<td>112</td>
<td>60.88</td>
<td>-</td>
<td>77.95</td>
</tr>
<tr>
<td>168</td>
<td>-</td>
<td>62.08</td>
<td>-</td>
</tr>
<tr>
<td>224</td>
<td>63.97</td>
<td>-</td>
<td>72.40</td>
</tr>
<tr>
<td>Mean for irrigation</td>
<td>54.71</td>
<td>64.19</td>
<td>65.10</td>
</tr>
</tbody>
</table>

Fasihi et al, (1980)

**Irrigation Systems**

There are different irrigation systems under which cane crop meets its water needs from planting to harvesting. In regions receiving sufficient rains crop is grown entirely under rain fed conditions and does not involve much of water management cost. However, some rain fed areas are compensated with irrigation water during period of drought. Main bulk of the cane crop is irrigated under different systems and water is applied by any of the following three means.

1. Surface irrigation
2. Over Head or Sprinkling
3. Drip or trickle irrigation

Surface irrigation is a widely used system in sugar world. Other systems are invariably successfully adopted in countries with advance technical know-how and requisite facilities. While in developing countries farmers are confronted with decision to shift from surface to sprinklers or drip systems, considering the initial cost of the equipment, operating cost and the cost involved per tonne of cane produced. While installing any of
the systems for economic production of cane, growers should have basic knowledge of
the following parameters.

1. Water availability and timings
2. Quantity and frequency of irrigation applications
3. Salinity and sodicity problems of the area
4. Adaptation of the system to soil conditions
5. Water intake capacity of soil and wetting pattern under the drip
6. Energy-power required, availability and operating cost

**Surface Irrigation**

The water is applied directly to soil surface. In spite of its poor water application and
water use efficiency the system is practiced over large areas around the world. It is the
most suitable method for heavy soils and where water supply is abundant, labour is cheap
and cost of energy is very high. This is the most common method of applying irrigation
water to cane in Pakistan. Water is brought to the field by open lined or unlined channels
and is delivered either to entire field, border strips, furrows, or trenches. The system does
not require much technology, but still some technique is needed to avoid water
application losses and poor water use efficiency.

The water losses usually met in the system are conveyance losses and the application
losses. Conveyance losses are experienced in poorly aligned watercourses, weak
embankment allowing frequent water leakage and breakage, shrubs and weeds reducing
the flow as well as stimulating seepage and transpiration losses. Widened beds of
channels reduce velocity of water flow thereby cause the increase in seepage. Water
wastage is also common through holes of rodents and trespasses.

The method is often misused, as excessive amount of water is applied using large borders
without considering the soil types. It not only lowers the water use efficiency, the system
gradually raises the water levels of soils causing water logging. To achieve high
efficiency there should be proper water distribution system to provide adequate control of
water to the field. Land should be well leveled and prepared to permit uniform
distribution over the field. Water may be distributed to the crop through border strips,
check basins or furrows.

**Border Irrigation**

The land is divided into a number of long parallel strips called “border” separated by low
ridges or bunds. Each strip is irrigated independently. The width of a border usually
varies from 5 to 15 m depending on size of irrigation stream available and degree of land
leveling. The length of border varies from 60-120 m in sandy loam soil 100-180 m loam
and 150-300 m in clay loam soils

The border strip has a little 0.2 % or no slope to the direction of irrigation. The essential
feature of border irrigation is to provide an even surface over which the water can flow
down the slope, nearly with uniform depth. Uniform distribution and high water
application efficiencies are possible if the system is properly designed.

**Check Basin Irrigation**

This is the most common and cheapest method of irrigation. The field is divided into suitable sized units having leveled surface. Water is conveyed to the field in separate units/plots by a main water channel and lateral field channels; size of check basin varies depending upon level of field and topography. Small plots give efficient use of water than larger ones. Under soil conditions which require leaching of salts, this method is preferred. However, the method usually results in high water application and poor distribution efficiencies.

The method has the limitation with respect to interference of ridges with the movement of farm implements for intercultural operations. Considerable land is wasted by ridges and irrigation channels. Labour cost in irrigation management is also high.

**Furrow Irrigation**

In this method water is applied by running small streams in furrows made in inter-row spaces of cane. The size and shape of furrow depends on the equipment used and the space between cane rows. The furrow could be shallow (12-15 cm) or deep (20-30 cm) called trench. The method however, requires proper land grading so that water can travel the entire length of the furrow without pounding. Length of furrow depends on the slope and nature of soil permeability. Longer length on uniform surface gives efficient control of water. A furrow length of 150-200 m is considered enough for effective and efficient irrigation. However, in uniform gradient of slope it may be extended to 250-300 m length depending upon the supply of water and suitable water intake.

Cane is planted in trenches or furrows and water is applied as per requirement of the field. After cane planting, irrigation is carried out in these furrows till germination is complete and plants have produced tillers/shoots. The trench/furrow is then filled with
Irrigation

earth during hoeing operation and new trenches/ furrows are made in inter row spaces of cane. In this process cane shoots are earthed up and furrows remain till the harvest of the crop. The irrigation water is then applied through these furrows. The furrows if clogged by rodents have to be kept clean for free flow of water.

During severe water shortage, the irrigation may be applied in alternate furrows, skipping one furrow. In next turn of irrigation, the previously irrigated furrow may be skipped. The skip furrow irrigation is reported to save 30-40 % of water without much reduction in cane yield (Verma, 2004). However skip furrow irrigation is suitable in loam soils with good infiltration rate; the method may not give good results in hard impermeable soils.

The irrigation efficiency can be regulated by:

- Inflow rate of water should be more than the infiltration rate of soil.
- Furrow should not be broad; V shaped furrow reduce infiltration rate and increase flow of water.
- Furrow slope of 0.2 – 0.3 % give appropriate flow rate of water.
- Duration in irrigation application should be just enough to drench the soil to cane root zone.
- The furrow length should be in accordance with soil infiltration rate; much longer furrows give more chance to water wastages.
- Furrow irrigation has several advantages over other surface irrigation techniques.
- It can regulate uniform flow of water as per requirements of the crop and can avoid excessive irrigation to save the crop from lodging.
- The furrow shows some economy of water in this system. Only 0.2 to 0.5 as much area is wetted as compared with flooding.
- Water is diverted into furrows by just opening the bank of the water supply channel or placing a small peace of pipe at the head of the furrow. Water can best be regulated when applied through siphons or plastic pipes.
- The furrows serve as drainage channel during rainy season.
- In case of very short supply of water, water can further be economized by irrigating the field in alternate furrows.

Trench-planting works effectively at 120 cm or wider row spaces. Mechanization is not practically possible in narrow row spacing. With narrow furrows chances of erosion are more and with advance in growth the field tends to flood irrigation. However, Yadava (1991) has reported his studies in favour of 90 cm row spaces. He has also reported the water use efficiency of skip furrow irrigation method, which gave 36.5 % saving of water.

**Over head/Sprinkler Irrigation**

In this method water is carried to cane fields through pipes and sprinkled on cane canopy through nozzles like rain. Different systems have been introduced.

1. Drag line sprinkler
2. Long boom sprinkler
3 Mobile gun sprinkler
4 The centre pivot sprinkler

Water is sprinkled over cane fields through medium or low-pressure sprinklers. Main pipelines are installed permanently, from reservoirs to main fields, while light portable lines are fitted for sprinkling water on crop. Portable lines are moved from field to field and water is sprinkled through pressure pumps. The rate of application can be adjusted by selecting nozzles for specific discharge at desired rate.

The drag lines are the medium and low pressure sprinklers and depend on the cost of energy and labour. Lack of labour and high cost of energy restricts its use to a few areas. The system causes inconvenience in dragging and fixing pipes during boom stage of crop growth and especially when crop lodges.

Long boom sprinklers may be of some use during early crop growth stage just for compensating the rain water during drought.

The advent of plastic pressure pipes and polyethylene pipes have contributed to static or mobile gun sprinklers. These are simple to operate, however need fixed pipe lines or water supply channels as a continuous source of water supply.

The Centre-Pivot system is the latest breakthrough that in spite of high initial investment and energy cost is labour saving with high water use efficiency. However, use of such system is not recommended for soils having very low infiltration rates. This system has gained more popularity than other systems, rain gun sprinklers rank next in order of effectiveness for sugarcane.

The main criteria for selection of the Over head irrigation system are:
1 Rate of precipitation
2 Infiltration rate and water holding capacity of soil
3 Uniformity of water application – water flow speed and pressure of the pumps
4 Drop size distribution – function of nozzle diameter and pressure
5 Area to be covered per unit time

Climatic conditions: evaporative losses to be given importance. Under humid climate this may be of less importance, but in hot dry climate these losses can be considerably high.

The system is used where water supply is inadequate and water is considered to be very precious for economic use. The method is particularly suited to unleveled, undulating fields or large sloppy areas that involve high cost in leveling.

Soluble fertilizer, herbicides and fungicides give most efficient use when applied through sprinklers.

Sprinkler irrigation is more effective than surface irrigation in the initial stage of germination and young seedlings when irrigation requirements are the lowest. For irrigation during boom stage of crop growth the system is poorly adapted. For later irrigation, surface irrigation should be relied upon.
Use of sprinkler is most suitable in sandy loam soils of good infiltration rates; the system is not that effective for clay soils having low infiltration.

It has also to be seen that water should be free of debris. Silting may also cause excessive wear of pump impellers, bearings and nozzles.

While adopting the system climate and temperature conditions and stage of crop growth have also to be given due consideration. At high temperature and wind velocity evaporation losses are considerably high. It is not economical to meet the water requirements of cane by sprinklers throughout the crop season. It may just compensate the water requirements partly with canal or tube well irrigation or intermittent period of rainfall.

Rotary sprinkler guns, however, can quench the thirst of crop, with limited supply of water, under extreme water scarcity condition. The system is to supplement the furrow irrigation so as to save the crop from severe drought effect. In Cuba over 50 % of the cane area is irrigated through sprinkler system (Soopramanien, 1999).

The system is very beneficial in saving conveyance losses and deep percolation losses in channels and fields. It can help in meeting the exact water needs of the crop. The system is reported to give water saving of 45.5 %, and water use efficiency of 2.367 t/ha-cm with cane yield of 94.7 t/ha. As against this, furrow irrigation gave water saving of 20.5 % and water use efficiency of 1.768 t/ha-cm with cane yield of 94.8 t/ha (Shrivastava et al, 1993). In this experiment irrigation of 50 mm depth was applied by sprinkler when CPE reached 167.11 mm, while furrow irrigation plots received 50 mm depth of water when CPE reached 100 mm. The studies conducted at VSI, Pune, indicate that the system gave a yield increase of 15-20 % with 30-40 % saving of water (Hapse et al, 1990).

Sufficient area is saved which otherwise would come under water channels. The system has not yet been commercially introduced in cane fields of Pakistan, nevertheless, this irrigation system has been widely adopted in regions/countries where water is scarce and electric/diesel power is cheap.
Limitations

Besides all the benefits from the sprinklers, the system has some limitations:

1. Needs electric/diesel power and skill to operate.
2. The main limitation is the cost involved in:
   - High initial investment in purchase of pumps, main connecting pipes and sprinkler guns.
   - Cost of electric and diesel power.
   - Labour cost in haulage of pipes, their frequent connections and disconnections.
3. Water distribution not uniform during windy days.
4. Moisture evaporation losses during hot summer months may be as high as 10-15%.
5. Shallow root system with tendency to lodging.
6. Salinity affected soils demand frequent flood or furrow irrigation to leach down salts beyond root zone. The water through sprinklers may not be discharged in the amount to meet the leaching requirements of salts.

Drip/Trickle Irrigation

Irrigation water is applied to the plants drop by drop through drip tape placed as a surface or sub-surface drip system.

**Surface drip system.** It is provided with low density polyethylene lateral pipe lines furnished with emitter or micro-tubes placed on the soil surface, in between two cane rows.

**Sub-surface drip system.** In this case low density polyethylene lateral pipe lines are buried at about 15-25 cm depths. Water is thus applied in the sub-soil.

The water is emitted through drippers/emitters placed at intervals of 30cm (faced upward). Main pipes are fixed up-till borders of cane fields to water source and drip laterals are spread throughout the length of cane rows, 135-150 meters being suitable length for uniform application of water (90%). Drip laterals are laid with different specification and spacing depending upon the type of soil and topography. Normally laterals are laid at 1.5, 1.8 and 2 m spacing with 0.3, 0.4 and 0.5 m dripper spacing and 2 or 1.3 liters per hour discharge under single or paired rows of cane. A pressure pump is needed to supply the required amount of water under a given pressure. Water is conveyed to the main feeder pipe through a gate valve which controls the flow of water by a water meter and a pressure head at which the water is being flown. Water is applied according to actual need of the crop through a set pressure for uniform gradient. A complete set of these systems includes:

1. Pumping station, filtration and fertilization station.
2. A net work of underground PVC distribution pipes.
Irrigation

Tape Drip System Layout

Sub-surface drip

Lateral drip tubes fitted with the main distributing pipes

Surface drip at Layyah sugar mill farm
Sub-surface irrigation
3 Control accessories, pressure regulating valves, solenoid valves, timers etc.

In this system lateral drip tubes have to be replaced for each fresh plantation after 3-6 years crop cycle, while other fixture lost through out the useful life of irrigation system. The system may show some economics in condition of 6 – 8 crops cycle ratoon. It may not be economical to layout the lateral each year afresh each crop cycle.

- The method is very useful for areas with water scarcity.
- It minimizes the conventional losses such as deep percolation, leaching, run off and surface evaporation. Still problems are faced in hard soils of poor porosity and low infiltration, where emitters are choked and efficiency is much reduced.
- Water is applied slowly to keep the soil moisture within field capacity. The slow release of water to root zone, helps the plant to absorb the same as per requirements.
- Plant nutrients use efficiency can also be increased if applied through drip irrigation.
- The system keeps the soil in aerobic condition, without disturbing soil structure. It does not allow soil crustation and compaction, thus the crop sustain its growth in very favorable soil and moisture environments.
- The irrigation scheduling, quantity, frequency and fertilizer application can be effectively tackled by this system.

Amongst various irrigation systems, it has been established that water use efficiency of drip irrigation is the highest. The sub-surface drip irrigation technique optimizes the use of water, covering large area with the unit supply of water. The water use efficiency of the system is around 95% compared with 50 % of furrow and 66 % of sprinkler system (Leiva and Barrantes, 1998). They worked out the water requirements for replacements of an evapo-transpiration of layer of 5 mm per day or 0.5-liter/sec/ha for drip irrigation, 0.8 liter for sprinklers and 1.0 liter for furrow irrigation.

Compared with furrow irrigation, the drip irrigation showed water saving from 30 to 50 %, with 20 to 50 %, increase in yield of cane (Hapse et al, 1991; Parikh et al, 1992). The ‘N’ fertilizer applied through drip gave a saving of 25 % ‘N’ compared with conventional method. The system has commercially been adopted in countries having loose organic soils and with cheap energy source. Nevertheless, the system has its limitations earmarked as under:

**Limitations**

The main limitation is heavy initial investment and high energy cost for irrigation at each turn.

After layout of the requisite pipes, the system requires a permanent source of water supply because water is to be applied daily or on alternate day.

It needs extra energy for pumping water which further adds to the operational cost.
The problems are faced in hard soils of poor porosity and low infiltration where there is a danger of choking of the emitters/drippers due to cracks or clogging. The extent of choking depends on soil type and the mechanical operation in the field. The system works more effectively in sandy loam and loam soil than in hard clay or clay loam soils.

The system is cost effective only in regions raising more than 5 ratoons; as the cost involved in one or two seasons crop is very high. The removing or re-laying of pipes for their re-utilization involves lot of damage and high cost for repair and replacement. Uprooting of drip tube laterals is cumbersome and may cause soil pollution to long span of time.

In drip irrigation since wetting area is limited, the root system is confined to upper layers. Due to shallow root system the cane crop is more prone to lodging. The system dose not work in soils having large leaching requirements.

**Special care needed**

- Provision of water filtration, chlorination and flushing of salts
- High initial investment on installation of infrastructure
- Energy consumption
- Whole time availability of water

**Water Logging**

Water logging appears as a result of rise in water table due to excessive irrigation, seepage from canals and ponds or frequent floods. The situation is mostly dealt with in tracts with poor drainage. The areas around the bank of main canals are water logged through seepage, if not provided with well-designed drains. Irrigated areas also get water logged when drains are choked. In such areas poor drainage is a common feature during rainy season and such areas are mostly submerged in water. High river floods may cover vast areas and land may be submerged in water for several weeks.

Sugarcane crop has a large demand for water applied through irrigation or rains, but excess irrigation or persistently heavy rains without proper drainage may lead to water logging. Both the situations hamper crop growth and have deleterious effect on yield and quality of cane. Sugarcane has the capacity to withstand water logging to some extent, though productivity is somewhat low, but still assures some return to growers. But, if crop roots remain submerged in water for a longer period, the growth, yield and quality are adversely affected.

**Effects of Water Logging**

In prolonged exposure to water logging the soil is subject to some structural disorders associated with some morphological changes and physiological disorders in cane crop. Water logging affects the soil, plant and environment in different forms.

**Depletion of oxygen**

Oxygen in the air, available in pore spaces of soil, plays vital role in respiration of roots
and soil micro-organism. Pore spaces when filled with water restrict the diffusion of oxygen into the soil. Thus the lack of oxygen disturbs the respiration of plant root. Water logging also inhibits the exchange of gases, resulting into CO₂ accumulation in soil that leads to plant damage.

**Loss of nitrogen**

Water logging cause de-nitrification resulting into loss of 'N' and its leaching.

**Poor microbial activity**

Due to lack of oxygen microbial activity in soil is slowed down.

**Morphological changes in plant**

The effect on crop varies with the stage of plant growth. Lack of air depresses the development of roots and root hairs.

At the stage of germination, root growth and bud sprouting is altogether checked leading to a complete death of plant.

At tillering phase sprouting is reduced with less number of shoots per unit area.

At grand growth period, growth is checked, cane formed shoots may die and plant population per unit area is markedly less.

Standing cane gets thin and slender and may develop aerial roots, mostly on lower nodes.

Nutrient absorption from soil is affected and leaves get pale yellow.

In case the roots are submerged in water, transpiration is at its lowest, photosynthetic activities are checked; plant growth is receded and leaves show curling. Crop gets weak and is vulnerable to lodging and uprooting following high wind velocity.

**Can yield and recovery**

Degree of crop damage depends on cane varieties, extent of water logging, soil temperature and weather. The yield loss depends on the stage of crop growth. Swampy condition in earlier phase may damage the plants completely. Water logging in boom stage of growth is reported to bring 23 % loss in per cane weight and 25 % loss in yield of cane (Yadava, 1993).

Cane plant is richer in invert sugar and gums and ripens earlier but with poor contents of sucrose. Moisture loss in cane increases fiber contents

**Physiological changes**

Lack of oxygen has drastic effect on respiration, transpiration and photosynthesis. The absorption of water and nutrients is receded even if the soil is rich in nutrients. Thus plant show nutrient deficiency symptoms. Chlorophyll, nitrogen, potassium and sheath moisture is decreased.

Water logging is a great menace in irrigated regions. In non perennial areas of lower Sindh, sugarcane severely suffers from drought in early stages of growth while land get inundated with high water table during and after monsoon period especially in rice
Irrigation

Growing tracts. Such areas are subject to two-fold problems.

1. Salinity hazards due to aridity in early stages and
2. Water logging in rest of the period of the year.

These situations call for the management of field and crop. On the whole, if soil structure is good for drainage this type of soil can be reclaimed by providing adequate drainage in the area.

Main emphasis should be given to the control of irrigation water. Free flow of water should be checked and water should be applied only when necessary.

**Care in growing cane under waterlogged conditions**

Cane varieties should be grown which can withstand waterlogging and are resistant to red rot.

Early planting should be practiced that the crop is fully established by the time the crop is waterlogged. September planting is the best but late spring is to be avoided.

Planting should be done on raised beds and seed to be placed on sides of the ridges for better germination and also to avoid the effect of salinity if any.

To avoid the ill effect of water logging earthing up can protect the basal portion of cane stool from complete submergence in water. The practice allows somewhat aeration to stubbles and also keeps the crop standing erect.

Wider row planting is better than narrow row planting; wider rows may help drain out the excess water.

**Flooding/ Floods**

Flooding is the term used in applying excessive water to cane fields. The flooding, that leads to water stagnation create the problem of water logging, is not at all useful for cane growth. Some tracts which are on the route of occasional river flood terrains, high floods pass through standing cane crop and period of flood may be one or several weeks. Moving floodwater with plant crown above the water level is not much harmful if it passes away after some days. Due to moving water plant is not starved with oxygen and the crown portions are active for photosynthesis and carbon assimilation. If water recedes after a few days, the crop is not much affected except the aerial root development at the level of the water or silt deposits on leaves and cane stalks, which have some deleterious effect on juice quality. The standing crop resumes its growth as flood water recedes.

After floods are receded, the crop may lodge badly, resulting into rotting of cane stalks and or bud sprouting if crop is saved from rotting. Lodging and sprouting of buds would create problems in harvesting, loading and haulage of cane to the factory and poor quality juice may result. In case of complete submergence of the top, lack of photo synthesis and silt deposit on growing point may cause mortality. In case the floods persist for a longer period cause swampy condition and poor drainage depressing yield and quality.

**Disease infection**

Flood water is one of the important carriers of secondary infection of red rot. Disease infection is accelerated at submergence or inundation levels. These conditions are often
witnessed during heavy rains in monsoon season, floods and or water logging condition due to poor drainage. Susceptible varieties in some years depict complete disaster. Spores of the disease move from field to field and infect the susceptible varieties. The possible measure to combat the disease is to provide effective drainage in the area and also avoid excessive irrigation.

**Pest infestation**

White fly and scale insects find favorable environment for spread of their population.

**Water Requirements of Plant and Ratoon Crops**

Plant crop, due to its well established root system, better water uptake and good dry matter production, compared to ratoon, are considered the efficient users of irrigation water. Shrivastava (1992) has reviewed the water requirements of plant and ratoon crops with respect to evapo-transpiration, water use efficiency and total water requirements for production of cane and sugar. Data is reproduced in **Table-7.18**

**Table-7.18 Water requirements of plant and ratoon crop of sugarcane**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Plant crop</th>
<th>Ratoon crop</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evapotranspiration- mm/day</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germination to close in</td>
<td>3.37</td>
<td>4.08</td>
<td>Fonseca and Egna(1989), Cuba</td>
</tr>
<tr>
<td>Grand growth period</td>
<td>4.03</td>
<td>4.08</td>
<td></td>
</tr>
<tr>
<td>Ripening</td>
<td>2.37</td>
<td>2.33</td>
<td></td>
</tr>
<tr>
<td>Water use efficiency----Clay soil</td>
<td>130</td>
<td>161</td>
<td>Annon(1980-88), Taiwan</td>
</tr>
<tr>
<td>Kg cane weight/mm/Ha -Clay soil</td>
<td>116</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td>- Sandy soil</td>
<td>89</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Water required</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For production of 1 Kg cane</td>
<td>89</td>
<td>118</td>
<td>Shih and Gascho (1980), Taiwan</td>
</tr>
<tr>
<td>1 Kg sugar</td>
<td>884</td>
<td>1115</td>
<td></td>
</tr>
<tr>
<td>Evapo-transpiration- Annual( mm)</td>
<td>1681-2213</td>
<td>1220-1679</td>
<td>Fonseca and Egna (1989), Cuba</td>
</tr>
</tbody>
</table>

**Water Requirements of Sugarcane Compared with Other Crops**

Different field and garden crops have different requirements for water and the variation is due to the bio-mass of the crops their root system, physiology and morphology of the crop plant and crop growth cycle and the season of the year. Water requirements of sugarcane and rice are the highest among all the field crops (**Table-7.19**). Compared to all other crops sugarcane is the long duration crop with growth span of 12-15 months.

Comparative consumptive use water requirements of some crops during growth period are given in **Table-7.20**.

The water use efficiency for each crop may be worked out considering the crop produce per unit area per month. It may further be checked with cash return per unit area and time.
Table 7.19 Consumptive use Requirements of Irrigation Water for different Crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Irrigation Period</th>
<th>Irrigation requirements of crops during growth period</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Begin</td>
<td>End</td>
<td>Jan</td>
</tr>
<tr>
<td>Rice</td>
<td>1-Jan</td>
<td>7-Nov</td>
<td>-</td>
</tr>
<tr>
<td>Cotton</td>
<td>1-May</td>
<td>31-Oct</td>
<td>-</td>
</tr>
<tr>
<td>Maize</td>
<td>1-Jul</td>
<td>31-Oct</td>
<td>-</td>
</tr>
<tr>
<td>Fodder</td>
<td>1-Mar</td>
<td>15-Sep</td>
<td>-</td>
</tr>
<tr>
<td>Wheat</td>
<td>1-Nov</td>
<td>7-Apr</td>
<td>86</td>
</tr>
<tr>
<td>Pubes</td>
<td>1-Oct</td>
<td>14-Feb</td>
<td>86</td>
</tr>
<tr>
<td>Oil Seed</td>
<td>8-Oct</td>
<td>21-Feb</td>
<td>91</td>
</tr>
<tr>
<td>Fodder</td>
<td>8-Oct</td>
<td>30-Apr</td>
<td>91</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>1-Mar</td>
<td>14-Feb</td>
<td>60</td>
</tr>
<tr>
<td>Fruit</td>
<td>1-Jan</td>
<td>31-Dec</td>
<td>39</td>
</tr>
</tbody>
</table>

Anon (1968): Water requirements computation: Adopted from T & K report on Scarp IV
Table-7.20 Water requirements (mm) of sugarcane crop compared with some field and garden crops during spring and autumn season

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugarcane</td>
<td>1200 - 1500</td>
<td>350 - 560</td>
</tr>
<tr>
<td>Rice</td>
<td>1200 - 1500</td>
<td>150 - 300</td>
</tr>
<tr>
<td>Cotton</td>
<td>600 - 800</td>
<td>300 - 400</td>
</tr>
<tr>
<td>Maize</td>
<td>430 - 715</td>
<td>300 - 400</td>
</tr>
<tr>
<td>Mung bean</td>
<td>250 - 350</td>
<td>330 - 450</td>
</tr>
<tr>
<td>Pegeon peas</td>
<td>250 - 400</td>
<td>800 - 1600</td>
</tr>
<tr>
<td>Soyabean</td>
<td>400 – 700</td>
<td>800 - 1120</td>
</tr>
<tr>
<td>Potato</td>
<td>700 – 800</td>
<td>450 - 600</td>
</tr>
<tr>
<td>Sorgum</td>
<td>450 – 600</td>
<td>350 - 550</td>
</tr>
<tr>
<td>Pearl millets</td>
<td>450 – 600</td>
<td>320 - 460</td>
</tr>
<tr>
<td>Sasamum</td>
<td>250 – 300</td>
<td>550 - 750</td>
</tr>
</tbody>
</table>

Nazir, M.S. (1994)
Fertilizer

Growth and development of sugarcane plant takes place under quite favorable environments of climate, irrigation, nutritional status, soil texture and depth of soil for water retention, drainage and root development. Deficiency of any of these requirements limits the growth of plant. As for the nutritional status, plant needs seventeen essential elements to grow and form different compounds during growth process. These nutrients are supplied from air, water and soil and are grouped as under.

**Essential Plant Nutrients Required for Cane Growth**

**The nutrients forming carbohydrates - 3**

- Carbon (C): Derived from air (CO₂) and water (H₂O)
- Hydrogen (H)
- Oxygen (O)

**Primary elements - 3**

- Nitrogen (N): Plants show large requirements for these elements. Plant requirements are met from soil and or through organic or inorganic fertilizers
- Phosphorus (P)
- Potassium (K)

**Secondary elements- 3**

- Calcium (Ca): Plants have the 2nd largest requirements for these elements.
- Magnesium (Mg)
- Sulfur (S)

**Micro or trace elements – 8:**

- Copper (Cu): They are required only in small fraction but are essential for plant growth activities. In case of limited soil availability, may be compensated by soil or spray application
- Zinc (Zn)
- Boron (Bo)
- Silicon (Si)
- Manganese (Mn)
- Iron (Fe)
- Chlorine (Cl)
- Molybdenum (Mo)

The cane plant absorbs carbon dioxide gas from the atmosphere through the leaves. The water that is composed of hydrogen and oxygen is taken up from soil by roots. The chemical reaction (photosynthesis) takes place in chlorophyll of leaves in the presence of light to synthesise carbohydrates.

\[
\text{Hydrogen} + \text{Oxygen} + \text{Carbon dioxide} = \text{Carbohydrates} + \text{Oxygen}
\]


Carbohydrates make up almost 95 percent of dry weight of plant and include sugars, starches and cellulose. The cane plant obtains rest of its nutrients mostly from soil, dissolved in water. The water uptake is through roots to leaves due to suction pressure created by transpiration in leaves. An average fresh weight of full grown plant contains 76 % water, 10 % sugar, 12 % fibre and the remaining 2 % are mineral constituents. The mineral elements, although constitute a small fraction, control complete metabolic activities of plants; they have to perform essential functions in plant growth and development.

**Relationship of soil pH with nutrients availability**

The pH is the most important indicator of soil health. It is the degree to which the soil is acidic, alkaline or neutral in chemical reaction. The neutral soil has pH 7, while pH below 7 indicates acidic reaction and soils with pH above 7 are alkaline. The pH of normal productive soils ranges between 6 and 8. Most of the productive soils in Pakistan have pH 7.0 to 8.2. The soil pH is a guide towards good nutrient management. As the pH influences the fixation and release of nutrients for plant availability and the activities of micro-organism, some nutrients are in available form at low pH, while others are made available at relatively high pH.

![pH ranges](image)

Figure 1 shows the relationship of soil pH and the availability of plant nutrients: wider the band greater the availability. Under extremely acidic conditions, the primary nutrients are locked up in soil and are un-available to plant. The figure indicates that the availability of P and some micro-nutrient like Fe, Mn, Zn, Cu and B is impeded by high pH under soil conditions in Pakistan.
Nutrient uptake by crop

All mineral nutrients are present in all agricultural soils; however soils vary in their capacity to supply plant nutrients due to difference in composition of the parent material and climate. With continuous removal of soil nutrients by continuous cropping, erosion, leaching etc, soil gradually becomes deficient in one or more nutrients. A deficient soil can not supply nutrients in adequate amount out of its reserves to meet the crop requirements. With intensive cropping, and or due to higher yields the crop demand for nutrients increases, thus nutrients become more and more deficient with time and age. The external supply of any plant nutrients to crop is governed by the economic response of the crop to these nutrients. The kind and amount of nutrients needed to be applied vary with the fertility status of the soil and the cane yield targets.

Sugarcane produces a large biomass; as such cane plant compared to other field and garden crops, takes up large quantities of plant food elements from the soil. The quantity taken up by cane crop varies with cane varieties, climate and soil conditions. The nutrient removal from soils of India (Yadav et al, 2000) and Australia (Calcino et al, 2000) are reproduced in Table-8.01

<table>
<thead>
<tr>
<th>Nutrients removed as kg ha⁻¹</th>
<th>Australia</th>
<th>India</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>154</td>
<td>208</td>
</tr>
<tr>
<td>P</td>
<td>37</td>
<td>53</td>
</tr>
<tr>
<td>K</td>
<td>276</td>
<td>280</td>
</tr>
<tr>
<td>Ca</td>
<td>55</td>
<td>-</td>
</tr>
<tr>
<td>Mg</td>
<td>57</td>
<td>-</td>
</tr>
<tr>
<td>S</td>
<td>47</td>
<td>38</td>
</tr>
<tr>
<td>Cu</td>
<td>0.11</td>
<td>0.20</td>
</tr>
<tr>
<td>Zn</td>
<td>0.59</td>
<td>0.60</td>
</tr>
<tr>
<td>Fe</td>
<td>5.65</td>
<td>3.40</td>
</tr>
<tr>
<td>Mn</td>
<td>1.90</td>
<td>1.20</td>
</tr>
<tr>
<td>Cane yield (t ha⁻¹)</td>
<td>119</td>
<td>100</td>
</tr>
</tbody>
</table>

The N.P.K nutrient requirements per ton of cane quoted by different researchers are reproduced in Table-8.02.

The N, P and K requirements of cane crop are met through fertilizer application, which varies with soil type and climatic conditions. The rough guide representing average N.P.K. application to cane crop in different countries, as quoted by Hunsigi (1993), is given in (Table-8.03).
Table 8.02. The N, P and K requirement of cane

<table>
<thead>
<tr>
<th>Kg nutrients required per ton of cane</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.83</td>
<td>0.7</td>
<td>2.12</td>
<td>(Naidu et al, 1999)</td>
</tr>
<tr>
<td></td>
<td>2.50</td>
<td>0.50</td>
<td>2.75</td>
<td>(Hunsigi, 1993)</td>
</tr>
<tr>
<td></td>
<td>1.54</td>
<td>0.37</td>
<td>2.76</td>
<td>(Calcino et al, 2000)</td>
</tr>
<tr>
<td></td>
<td>1.20</td>
<td>0.46</td>
<td>1.49</td>
<td>(Anon, 2003)</td>
</tr>
</tbody>
</table>

Table 8.03 NPK fertilizer doses generally used for sugarcane in different countries

<table>
<thead>
<tr>
<th>Country</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>kg per hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>60-120</td>
<td>40-60</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>112</td>
<td>67-90</td>
<td>78-168</td>
<td></td>
</tr>
<tr>
<td>Barbados</td>
<td>75-100</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>60-120</td>
<td>75</td>
<td>60-80</td>
<td></td>
</tr>
<tr>
<td>Cuba</td>
<td>67-134</td>
<td>50-65</td>
<td>70-85</td>
<td></td>
</tr>
<tr>
<td>Egypt</td>
<td>119-262</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hawaii</td>
<td>224-336</td>
<td>225</td>
<td>224-450</td>
<td></td>
</tr>
<tr>
<td>India sub-tropical</td>
<td>160-200</td>
<td>80-100</td>
<td>0-60</td>
<td></td>
</tr>
<tr>
<td>-tropical</td>
<td>250-300</td>
<td>100-120</td>
<td>60-120</td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>80-120</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Java</td>
<td>130-150</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Mauritius</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>120-240</td>
<td>60-120</td>
<td>75-85</td>
<td></td>
</tr>
<tr>
<td>Pakistan</td>
<td>135-202</td>
<td>90-135</td>
<td>78-112</td>
<td></td>
</tr>
<tr>
<td>Philippines</td>
<td>90-200</td>
<td>80-200</td>
<td>80-160</td>
<td></td>
</tr>
<tr>
<td>Puerto Rico</td>
<td>135-200</td>
<td>50-80</td>
<td>112-120</td>
<td></td>
</tr>
<tr>
<td>S. Africa</td>
<td>112-224</td>
<td>70</td>
<td>40-45</td>
<td></td>
</tr>
<tr>
<td>Taiwan</td>
<td>160-225</td>
<td>75</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Venezuela</td>
<td>150-200</td>
<td>80-150</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

Source: Hunsigi, 1993
Nitrogen plays an essential role in growth and development of plants. Nitrogen is an integral component of protein. It is present in chlorophyll molecules and combines with carbohydrates to form protein nitrogen, essential for all enzymatic processes in living plants. It promotes growth and metabolic processes in plants. Nitrogen accelerates growth, gives vigor to plants and promotes dark green color in leaves due to better chlorophyll synthesis. Due to rapid mobility of nitrogen its effect is quite visible in the form of rapid growths due to its presence and rapid retardation in growth and yellowing of the crop due to its deficiency.

**Deficiency symptoms**

- Leaf blades are uniformly light green to pale yellow due to low chlorophyll and photosynthesis.
- Leaf sheath is pale green to yellow and is separated from cane stalks before maturity.
- Leaf tips and margins may become necrotic.
- In severe N deficiency abscisic acid is also synthesized leading to premature dropping of leaves and leaf sheaths.
- Vegetative growth is retarded and stalks become short and slender.
- The main roots may be extended but lateral root formation is retarded which affects the nutrient and moisture absorption surface area.
- Leaf area is reduced.

**Nitrogen sources**

Nature has provided abundant quantity of nitrogen in air and soil. Air constitutes 78% of nitrogen but plants can’t use this form of N until it is converted into ionic forms of ammonium (NH₄⁺) or Nitrate (NO₃⁻). Industrial factories have been installed where the natural source the nitrogen gas is converted to various forms of nitrogenous fertilizer e.g. ammonium sulphate, ammonium nitrate, urea and anhydrous ammonia.

**Forms of Nitrogen**

A mineral soil contains nitrogen in three forms:

1. Organic nitrogen associated with the soil humus
2. Ammonium nitrogen fixed by certain clay minerals
3. Soluble inorganic ammonium and nitrate compound

Most of the nitrogen associated with organic matter is protected from rapid microbial release. About half of the organic nitrogen in the form of amino compounds may be available after mineralization. Clay fixed form of ammonium nitrogen is slowly available to plants and microorganisms. Soluble inorganic ammonium and nitrate nitrogen is readily available to plants, however it is seldom more than 1-2% of the total present,
except where large application of inorganic nitrogen fertilizer have been made. Nitrogen is added or made available in soil in any of the following forms:

a. Atmospheric: natural enrichment from rainfall and lightening.

b. Industrial sources that include inorganic fertilizers.

c. Natural organic N sources that include farmyard manure, sugar mill press mud, plant residue, compost and municipal sludge’s.

d. Symbiotic and non symbiotic nitrogen fixation of soil nitrogen by soil organism including a number of fungi and bacteria.

For the availability of N to sugarcane plants, the N in any of the above mentioned forms has to be converted into ionic forms of NO₃ and NH₄. This conversion involves following mineralization process completed in phases.

Ammonification:

The organic nitrogen compounds are attacked by heterogeneous soil organism and as a result of enzymatic digestion, the more complex proteins and allied compounds are simplified to simple amino compounds which are hydrolyzed to produce ammonia and finally to ammonium ions. The NH₄ nitrogen is fixed by clay minerals and is slowly available to plants directly or through nitrification in the form of nitrate ions as per plant requirement.

Nitrification:

It is the process of enzymatic oxidation of ammonium (NH₄) to nitrate (NO₃) ions brought about by certain micro-organisms in the soil. It takes place in two steps. The first step is the production of nitrite (NO₂) ions followed immediately by their oxidation to nitrate (NO₃) form.

\[
\text{nitromonas} \rightarrow \text{nitrobacter} \rightarrow \text{nitrate}
\]

Under most conditions two steps take place simultaneously one after the other to prevent any great accumulation of the nitrite. In some alkaline soils, where large amount of ammonia fertilization (e.g. urea) have been made, second step may be delayed. It may result in accumulation of sufficient amount of nitrite ions to have adverse effect on plant growth particularly young plants or to encourage gaseous losses of nitrogen. The nitrate anions are not held on soil and are very mobile. The plant may take it up or it may be lost through leaching in high rainfall area or excessive irrigation.

Management of applied nitrogen is necessary to retain it in root zone. The nitrification is quite active in soils having adequate soil moisture, proper aeration and suitable soil temperatures (27°C - 32°C). The nitrification process is low / restricted at low temperatures of 10°C to 18°C and higher temperature of 40°C to 50°C. It is also low where a large amount of compost or plant residue is incorporated in soil, because nitrification consumes oxygen.

Losses of nitrogen from the soil

The sugarcane crop takes only 30-40% of the applied nitrogen from the soil, some of it is
Fertilizer

adsorbed by soil and some may be lost through de-nitrification, volatilization and leaching (Hunsigi, 2000).

De-nitrification:

It is microbial reduction of nitrate nitrogen to gaseous compounds of nitric oxide (NO), nitrous oxide and free nitrogen ($N_2$), which escapes to the atmosphere. The process is active with heavy application of urea or ammonium fertilizers under condition of low oxygen i.e. restricted drainage; water logging and submerged irrigation condition. De-nitrification losses are also high when N fertilizer is buried in inter-row spaces followed by heavy persistent rainfall leading to water logging. The high organic matter or presence of trash in soil may also deplete $O_2$ and produce $CO_2$ to trigger the process. In soils where drainage is restricted and heavy application of urea is made, 20-40 % of nitrogen losses of applied nitrogen are expected. The losses may be as high as 60 – 70 % in conditions favoring the process (Anderson, 1997). De-nitrification is responsible for the loss of 41 % urea in Australia (Chapman, 1994).

Ammonia volatilization:

It is the process through which ammonium containing fertilizer (e.g. urea and ammonium sulphate) hydrolyzes to form ammonia gas which is lost in the air. Such losses are quite significant in sandy soils and or high pH calcareous soils. Ammonia losses are also increased when fertilizer applied on surface without mixing it in subsoil. Volatilization losses are higher when light rainfall (< 15mm) or heavy over night dew is sufficient to cause the urea to dissolve and form ammonia gas, but insufficient to wash the urea from surface layer into soil (Calcino et al, 2000). This loss can be reduced if the fertilizer is placed below the soil surface.

Leaching:

The nitrates in the soil are leached down below the root zone by heavy rains or excessive irrigation. In light texture sandy or sandy loam soils considerable amount of N may be lost in heavy rainfall areas or un-management excessive irrigation. Leaching losses in sandy soils are reported to be 30-40 % (Hunsigi, 2000).

Nitrogen yield response

It is difficult to determine exact N requirements of sugarcane crop. The N requirements vary with climate, crop growth, cane yield pattern, irrigation frequency and distribution, land preparation, soil types and soil behavior. The N requirements have been generalized under different climatic and soil conditions. Depending upon different environmental conditions, a cane crop of 100 t/ha may remove from soil 75 to 335 kg N, 24 to 43 kg P and 125-235 kg K and that the nutrient demand for N may increase with increasing yield, more than that needed for phosphorus and potash (Anderson, 1997).

It has been established that the nitrogen is absorbed in much greater quantities than actually used for plant development (Humbert, 1968). After having utilized the requisite amount of N applied to the crop, the excess N is partly stored in the basal joint as ammonia, amides, amino acids and peptides. These metabolites are available to plant whenever and wherever needed (Humbert, 1968). Only about one third of the N applied as fertilizer to cane crop is used for the crop, while the rest of the N goes into plant and
soil reserves or is lost by volatilization or leaching (Calcino et al, 2000). In some other studies it was observed that sugarcane crop recovered only 40 percent of applied nitrogen (Kanwar, 1989, Hunsigi, 2000). As such crop needs for N are much higher than are actually removed by the crop.

On an average net requirement vary from 1 kg N per ton of mill-able cane for plant crop and 1 ½ kg N per ton for ratoon crop. Studies on different N levels (0 to 225 kg ha⁻¹) indicated that N recovery from soil declined with increasing doses of N and that the application of N in excess of 150 kg kg ha⁻¹ was wasteful under agro-climatic condition of Indian Punjab (Yadav, 1993). Therefore the best approach of applying nitrogen fertilizer is to first consider the productivity level of the cane field and the expected cane yield pattern of the soil. Though the recommended NPK level for Taiwan cane fields is 200: 40: 80 kg ha⁻¹ but in actual practice the N rate is based on cane productivity potential (Li, 1993). Therefore, the fertilizer doses should be determined with relation to soil productivity and economic yield and fertilizer efficiency per ton of cane should be given prime importance. In Australia nitrogen requirement of the crop is assessed considering the land productivity and expected cane yield from the field. The fertilizer dose is generally worked out using the formula (Calcino et al, 2000):

N requirement from all sources = 1.4 kg N per ton of expected cane yield to 100 ton ha⁻¹; 
then + 1.0 kg N per ton of expected yield, thereafter.

Under Pakistan conditions as well the fertilizer recommendation have been put forth according to the fertilizer status of the soil. The doses generalized for cane growing provinces on national level are given in Table-8.04.

Table-8.04. Recommended level of N, P and K for cane growing Provinces of Pakistan

<table>
<thead>
<tr>
<th>Province</th>
<th>Fertilizer kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Punjab</td>
<td>170-270</td>
</tr>
<tr>
<td>Sindh</td>
<td>200-300</td>
</tr>
<tr>
<td>NWFP</td>
<td>120-175</td>
</tr>
</tbody>
</table>

Source: Ahmed and Rashid, 2003

Effect of nitrogen on sugar recoveries

Sugarcane varieties have different potential to yield sugar; however sugar contents in cane are greatly affected by the 'N' level in cane plant, with relevance to the tissue moisture level and the maturity period of the variety. The 'N' application triggers the metabolic function of plant thus creates new demand for water. Increased 'N' level increases the succulence in plants and is indicative of vegetative growth, which has inverse relationship with sucrose contents. The increased level of 'N' results in higher percentage of reducing sugars and is detrimental to sugar recoveries. So long as the invert sugars are not converted to sucrose good sugar yields can not be harvested. On the other hand an in-adequate supply of 'N' reduces the moisture level of plant irrespective of the moisture status of soil (Clements and Kubota 1943). With the adjustment in fertilizer
Fertilizer

The nitrogen application should be considered with the overall increment of sugar yields. While an adequate quantity of 'N' is applied to obtain higher cane yield, the juice quality is reduced with excess doses. Delayed application of nitrogen may have detrimental effect on sugar recoveries. In fact, with approach in maturity time the 'N' contents in plants should gradually exhaust to retard growth. For a twelve-month crop, a definite curve can be drawn showing fertilizer doses to achieve an optimum level of peak recoveries, beyond which sugar contents decline. However, pattern of fertilizer-sugar curve would vary with climatic and soil factor that affects the fertilizer use efficiency. A considerable drop in juice quality was observed where cane was fertilized at the excess doses of 200:150:150 and 250:200:200 NPK kg ha⁻¹ (Ali et al, 1997). The standard NPK dose of 168: 112: 112 Kg ha⁻¹ gave the optimum yield and juice quality. Losses in sugar recovery with higher dose were due to excessive vegetative growth and lodging of treated plots. During studies on response of sugarcane to five nitrogen levels (0, 50, 100, 150 and 200 kg ha⁻¹), it was observed that sugar yield significantly increased with each additional dose of N up to 150 kg ha⁻¹, thereafter yields started to diminish (Rehman and Rehman, 1997).

Factors affecting “N” use efficiency in sugarcane

A number of factors including soil type, climate and biotic factors, and irrigation and fertilizer input greatly affect the 'N' use efficiency and N uptake pattern by cane plant.

Soil type

The soil type with respect to soil pH, texture and soil moisture are extremely important for microbial action for N uptake by cane plant as well as N losses due to leaching, volatilization and de-nitrification. When fertilizer is applied it undergoes series of changes before being taken-up by the plant. Several biotic factors and physical condition of soil affect the absorption of nutrients by the crop. Fertile soils have low N requirements than medium and low fertility soils. Heavy soils have better mineralization in the presence of organic matter and soils organism can hold nutrients in a better way. Loose textured sandy or sandy loam soils can not retain N for a reasonable time and are more apt to leaching losses.

In slightly acidic to slightly alkaline soils around 6.5 - 7.5 pH, nitrate form of N predominates in the soil and is best taken-up by the plant. While in alkaline soil N uptake is considerably low due to low bacterial action and restricted mineralization.

At soil temperature lower than 18°C, roots are not active (Humbert, 1968) and nitrification process is low or restricted for uptake of nutrients (Anderson, 1997). Therefore N fertilization to cane crop during winter months is of no use and is liable to leaching losses.

Soil moisture has important role in bringing the N in soluble form for availability to plants. But the moisture should be high enough to keep the soil in field capacity within root zone. Excessive water application may tend to leaching or de-nitrification, and moisture stress may lead to volatilization losses in soil.
Climate and crop duration

Long duration crop in tropical countries shows higher requirements for nitrogen. This is due to vigorous growth and higher bio-mass attained during longer period of growth. As the growth of plant is increased the N is greatly utilized to meet the growing need of the plant.

In India application of nitrogen to irrigated sugarcane ranges from 120 to 150 kg ha⁻¹ in subtropical and 250 to 400 Kg ha⁻¹ in tropical region (Yadav and Singh, 1995). In Pakistan as well recommended N level in lower Sindh availing longer crop duration, is higher than short growing season of Punjab and NWFP (Table-8.05).

Table-8.05 Fertilizers recommended for various cane growing provinces of Pakistan

<table>
<thead>
<tr>
<th>Kg nutrients per hectare</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sindh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Sindh</td>
<td>200</td>
<td>80</td>
<td>125</td>
</tr>
<tr>
<td>Centeral Sindh</td>
<td>225</td>
<td>95</td>
<td>150</td>
</tr>
<tr>
<td>Lower Sindh</td>
<td>275</td>
<td>112</td>
<td>175</td>
</tr>
<tr>
<td>Punjab</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor Fertility</td>
<td>230</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>Medium Fertility</td>
<td>170</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>Fertile Soils</td>
<td>115</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>NWFP</td>
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<td></td>
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</tr>
<tr>
<td>Poor Fertility</td>
<td>200</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>Medium Fertility</td>
<td>175</td>
<td>115</td>
<td>115</td>
</tr>
<tr>
<td>Fertile Soil</td>
<td>115</td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

Source: Annon (1988)

Nature of crop- Plant Vs Ratoon

Plant crop is considered to be an efficient user of N fertilizer than a ratoon crop. Therefore ratoon crop for optimum yields require considerably more amount of N than a preceding plant crop. In Brazil the recommended level of N is 60 kg ha⁻¹ for plant crop and 80-120 kg ha⁻¹ for ratoon (Uruiga et al, 1992). The N application to plant crop in USA is reported to be 56 kg ha⁻¹, while for first and second ratoon the fertilizer dose is increased to 100-157 kg ha⁻¹ and 134-190 kg ha⁻¹, respectively (Wiedenfeld, 1998). The differential response of plant and ratoon crop is due to multifarious reasons. The vigorous root system of plant crop has high degree of efficiency, while deteriorating soil structure and poor aeration limit the effectiveness of root system of ratoon crop (Humbert, 1959).

Compactness in soil restricts root development, and also reduces oxidation of organic matter and mineralization of nutrients. Ratoons produce professed tillering soon after the harvesting of preceding crop but root development is yet slow and restricted. Bacterial decomposition of stubble roots immobilize the soil N, thus nutrients supply to new shoots
is restricted. If N requirement is not met soon plant shows nitrogen hunger. A high rate of nitrogen and its earlier application has been found to increase the yield of ratoon crop. The ratoon crop needs 90 Kg nitrogen per acre, as against 60 Kg for the plant crop (Kanwar, 1991). In NWFP the general recommended nitrogen dose for plant crop is 100 to 150 Kg ha\(^{-1}\), while additional dose of 25 percent is recommended for ratoon crop (Sarwar and Amin 1990). As for the nitrogen out put results from plant and ratoon one Kg N produced 1.03 ton of plant cane as against 0.85 ton of ratoon cane (Yadav, 1986).

**Cane varieties**

Some varieties are able to utilize higher levels of nitrogen than others. The varieties having greater partitioning of leaf N to chlorophyll have better in use efficiency (Ranjit and Meinza, 1997). The author has noticed that variety with dark green leaves respond better to N fertilizer and it has also been observed that such varieties can survive better under low input conditions then the varieties having dull greenish – pale leaves. A number of workers have given experimental evidence to indicate that sugarcane genotypes responded differently to various N fertilizer levels for cane and sugar yields (Kanwar et al, 1989; Rehman et al, 1995). The data in Table-8.06 reveal the response of cane varieties Co 1148, Triton, BF 162 and BL 4 to 125, 250 and 350 kg N ha\(^{-1}\). The variety BL 4 shows better N use efficiency (153 kg cane per kg N) at the highest N level (375 kg) than at the lower doses. The other varieties showed relatively higher N use efficiency at lower levels of N application. BL 4 is a broad leaved thick cane variety having high yield potential.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cane variety</th>
<th>Cane yield t ha(^{-1})</th>
<th>Increased response due to N t ha(^{-1})</th>
<th>kg cane per kg N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 150 150</td>
<td>Co 1148</td>
<td>58.60</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Triton</td>
<td>46.06</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>BF 162</td>
<td>52.63</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>BL 4</td>
<td><strong>66.45</strong></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>125 150 150</td>
<td>Co 1148</td>
<td>76.00</td>
<td>17.40</td>
<td>139.20</td>
</tr>
<tr>
<td></td>
<td>Triton</td>
<td>58.68</td>
<td>12.62</td>
<td>100.96</td>
</tr>
<tr>
<td></td>
<td>BF 162</td>
<td>73.40</td>
<td>20.77</td>
<td>166.16</td>
</tr>
<tr>
<td></td>
<td>BL 4</td>
<td><strong>83.73</strong></td>
<td><strong>17.28</strong></td>
<td><strong>138.24</strong></td>
</tr>
<tr>
<td>250 150 150</td>
<td>Co 1148</td>
<td>92.44</td>
<td>33.84</td>
<td>135.36</td>
</tr>
<tr>
<td></td>
<td>Triton</td>
<td>71.31</td>
<td>25.25</td>
<td>101.00</td>
</tr>
<tr>
<td></td>
<td>BF 162</td>
<td>85.35</td>
<td>32.72</td>
<td>130.88</td>
</tr>
<tr>
<td></td>
<td>BL 4</td>
<td><strong>97.46</strong></td>
<td><strong>31.01</strong></td>
<td><strong>124.08</strong></td>
</tr>
<tr>
<td>375 150 150</td>
<td>Co 1148</td>
<td>105.83</td>
<td>47.23</td>
<td>125.94</td>
</tr>
<tr>
<td></td>
<td>Triton</td>
<td>83.72</td>
<td>37.66</td>
<td>100.96</td>
</tr>
<tr>
<td></td>
<td>BF 162</td>
<td>94.07</td>
<td>41.44</td>
<td>110.50</td>
</tr>
<tr>
<td></td>
<td>BL 4</td>
<td><strong>124.04</strong></td>
<td><strong>57.59</strong></td>
<td><strong>153.57</strong></td>
</tr>
</tbody>
</table>

*Source: Ali et al, 1999*
Irrigation

Irrigation has an important role in uptake or loss of nutrients. Successful N management depends on good water management as water serves as a vehicle for nitrogen transport from soil to plant. Large doses of N benefit the crop only accompanied by an adequate supply of irrigation water in favorable growth period (Clement, 1951). In the case of short supply of irrigation water, crop is not able to use high application rate of fertilizer. In these conditions, increasing rate of N does not help increase the crop yields. Higher rate of N are justified where irrigation water is available at desired quantity and frequency.

Studies carried out at Faisalabad show that fertilizer use efficiency is increased under optimums irrigation supplies to sugarcane (Fasihi and Malik, 1989). Comparing the response of 0, 78 and 156 kg N ha$^{-1}$ to irrigation intervals of 10 and 15 days, it was observed that 156 kg N dose gave the maximum cane yield efficiency of 140.25 kg cane per kg N with irrigation interval of 10 days. Under restricted irrigation (15 days interval), 156 kg N dose produced only 94.55 kg cane per kg N; at this irrigation level. The 78 kg N was more economical dose which produced 119-kg cane per kg of N applied (Table-8.07).

Table-8.07  Response of different N levels to liberal and restricted irrigation conditions

<table>
<thead>
<tr>
<th>Irrigation interval</th>
<th>Nitrogen level kg/ha</th>
<th>Cane yield t/ha</th>
<th>Yield increase over control</th>
<th>Kg cane per kg N</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Days</td>
<td>0</td>
<td>69.12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>78</td>
<td>73.36</td>
<td>4.24</td>
<td>54.35</td>
</tr>
<tr>
<td></td>
<td>156</td>
<td>91.00</td>
<td>21.88</td>
<td>140.25</td>
</tr>
<tr>
<td>15 Days</td>
<td>0</td>
<td>56.70</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>78</td>
<td>66.04</td>
<td>9.34</td>
<td>119.74</td>
</tr>
<tr>
<td></td>
<td>156</td>
<td>71.45</td>
<td>14.75</td>
<td>94.55</td>
</tr>
</tbody>
</table>

Source: Fasihi and Malik (1989)

In India as well, it has been reported that increased yield with high doses of N was noticed only when associated with larger quantities of water (Anon, 1959). The response of 0, 100 and 300 Kg N to irrigation intervals of 6 and 18 days was observed in India (Lakshmikantham et al, 1964). 100 kg N with short interval gave the highest yield index. Higher fertilizer doses under liberal irrigation showed higher plant moisture, larger leaf surface area, and higher yield than the crop grown under longer irrigation intervals.

While the optimum irrigation application are beneficial for optimum utilization of N, the excess irrigation or rainfall leading to flooding or water logging has detrimental effect on N utilization due to:

a) Leaching of nitrate ‘N’ in well drained soils

b) Soil oxygen is depleted due to creation of anaerobic condition that checks the process of mineralization.

c) Anaerobic condition may also be enhanced by excess amount of compost or soil organic matter especially in hard soil or hard pans

Under these conditions the applied N fertilizer or stored N is transformed and results in
losses of gaseous $N_2$ and increase of soil $NH_4$. Some $NH_4$ in the anaerobic layer may diffuse upward in aerobic zone causing $NH_3$ volatilization. Due to this very reason, N deficiency symptoms of yellowing of cane leaves can clearly be observed after excessive flooding or irrigation in spite of adequate or excessive fertilization (Anderson, 1997).

**Sugarcane diseases and pests**

Some pathogens may depress the uptake of nitrogen by plants. Mosaic infected crop is not efficient user of N fertilizer as is mosaic free crop (Ahmed et al, 1990). It is due to visibly more chlorophyll and better rate of photosynthesis to assimilate the nitrogen in disease free crop. The crop kept free of mosaic pathogen with hot water treatment gave higher cane yield by 27.28 % over disease infected crop with the normal N level of 168 kg ha$^{-1}$. The mosaic free crop gave equivalent yield of cane at half the level of N (84 kg ha$^{-1}$) compared to the recommended level (168 kg N ha$^{-1}$). Thus a mosaic free crop can save considerable amount of fertilizer (Table-8.08).

**Table-8.08. Response of mosaic free and mosaic infected crop of sugarcane to fertilizers**

<table>
<thead>
<tr>
<th>Fertilizer levels kg ha$^{-1}$</th>
<th>Mosaic free crop t ha$^{-1}$</th>
<th>Mosaic infected crop t ha$^{-1}$</th>
<th>% increase over mosaic infected</th>
</tr>
</thead>
<tbody>
<tr>
<td>168</td>
<td>84</td>
<td>84</td>
<td>60.21</td>
</tr>
<tr>
<td>84</td>
<td>84</td>
<td>84</td>
<td>65.01</td>
</tr>
<tr>
<td>84</td>
<td>42</td>
<td>42</td>
<td>58.67</td>
</tr>
<tr>
<td>Mean</td>
<td>61.29</td>
<td>51.06</td>
<td>20.03</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>2.69</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Ahmed et al, (1990)

It has been established that healthy, disease and pest free conditions are necessary to harvest a good crop. Soil application of gamma BHC and Endosulfan at 2.0 and 1.25 liters per acre greatly improve the N use efficiency. It was emphasized that the recommended rate of 150 kg N ha$^{-1}$ can be reduced to 100 kg N ha$^{-1}$ if the fore-said pesticides are applied over the setts in the furrows at the time of planting along with the nitrogen (Kanwar, 1991). It was also observed that malnourished crop of cane was heavily infested with borers than the cane receiving ample quantities of N fertilizer (Naqvi et al, 1984). The studies indicated that regulating the time of fertilizer application could be instrumental for minimizing the borer infestation.

**Forms of ’N’ fertilizers**

Different forms of nitrogen fertilizers are available in the market; the products commonly available are listed in the Table-8.09. Sugarcane at the same rate of nutrients applications is not sensitive to any form of nitrogen fertilizer except under specific soil conditions(Hunsigi, 1993; Kapoor et al, 1993). However, economic factors and soil reaction must be considered while selecting the forms of fertilizers (Tandon, 1992). The response of N fertilizer to soil properties and soil pH is quite varied. Ammonium sulphate has the tendency to slightly increase acidity or lower the soil pH, due to presence of
sulphur. Its application is therefore preferred in high pH- saline and saline sodic soils. Further that soils can hold Ammonium N better against leaching, but can not hold the amide N of urea. Thus under heavy irrigation and light textured soils ammonium sulphate may be preferred over urea.

<table>
<thead>
<tr>
<th>Common names</th>
<th>Available grade%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Ammonium sulphate</td>
<td>21</td>
</tr>
<tr>
<td>Calcium ammonium nitrate (CAN)</td>
<td>26</td>
</tr>
<tr>
<td>Urea</td>
<td>46</td>
</tr>
<tr>
<td>Diammonium phosphate (DAP)</td>
<td>18</td>
</tr>
<tr>
<td>Mino-ammonium phosphate (MAP)</td>
<td>11</td>
</tr>
<tr>
<td>Nitrophas (NP)</td>
<td>23</td>
</tr>
<tr>
<td>Complete fertilizer-N P K</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>13</td>
</tr>
</tbody>
</table>

In light sandy soils, nitrate N losses are higher than from ammonical N. Similarly, ammonical source of N placed on the surface of alkaline soil has more tendencies of volatilization losses. Ammonium cation may depress cane growth by inducing Ca or Mg deficiency. Therefore, in soils with low CEC (pH < 5 or >7-5), NH₄ nutrition should be avoided. Sugarcane absorbs both forms of N i.e. NH₄ and NO₃; however, under adequate water supplies NO₃ is absorbed more than NH₄, it is because the NO₃ - N is more mobile than NH₄ - N.

**Slow release N fertilizers**

N losses from sugarcane soils are reported to be in a range of 15-27% and even more than 30% in sandy loam soils (Hunsigi, 1993). To avoid these losses some slow acting N fertilizers have been introduced. Among these, sulphur-coated urea (SCU) and Neem cake coated urea (NCU) are of special mention. By these coating material nitrification losses are considerably reduced. Sona Urea Company in Pakistan has also marketed more recently slow release prilled urea. Urea granules are relatively larger in size and are reported to gradually release N contents in soil.

'Neem' cake is considered a nitrification inhibiter. A significant increase in 'N' uptake was observed using Urea Super Granules – Neem cake coated urea as compared to traditional prilled urea (Yadev et al, 1990, Srinivasan, 1995). Neem cake mixed with common prilled urea gave considerable increase in yield of cane (Zende, 1990).

**Methods of Fertilizer Application**

The most effective method would be the one that makes the most efficient use of fertilizer for the crop. Various methods used for the fertilizer application include basal dressing, broadcast, and side-placement by hand, drilling under the soil surface, aerial or foliar application, fertigation or application in irrigation water.
**Basal dressing**

Basal application is important to place the fertilizer in furrows beneath seed setts. Fertilizer is thus available in close proximity to the root zone of maximum root concentration. Care should be taken to avoid direct contact of fertilizer with seed setts. It has been observed that urea and ammonium chloride affect germination and cane density when placed in direct contact under cane setts (Kapoor, 1993). Germination and crop stand was high when fertilizer is covered with thin layer of soil before seed placement or applied along first irrigation (Kapoor, 1993). It may be applied through fertilizer applicator while ridging or can be placed into open furrows or trenches by hand before the placement of seed setts. In modern system of mechanized planting, cane is planted with tractor driven cane planter, which has built-in box for fertilizer application. Fertilizer is drilled close to seed during seed placement operation.

**Drilling/side dressing**

In standing crop condition fertilizer is generally applied as top dressing. Fertilizer is to be applied on the sides of the cane stool along the furrows. It should preferably be applied through a drill or it should be covered during the process of earthing up.

Urea fertilizer should never be broadcasted and left uncovered on the soil surface. Surface application of urea causes considerable N losses due to ammonia volatilization. Drilling of N fertilizer along cane rows in May-June increases the cane yield significantly as compared with the broadcast method of application (Kanwar, 1991). Field experiments have shown that depending on climatic conditions before and after urea application, extent of N losses may vary from 0 to 50% (Aderson, 1997). Ammonia losses are high under conditions of light shower and very low irrigation, followed by dry condition with bright sunlight and high surface temperature. Losses are low under good rainfall or good irrigation condition and moderate temperature. Incorporating urea in soil to a depth of 5-7 cm can prevent volatilization losses.

Drilling of fertilizer is always preferred, if not managed the fertilizer should be placed on sides of each cane row and be mixed through inter-row cultivation followed by irrigation. The fertilizer may be applied as side dressing on already inter-row hoed field, immediately followed by irrigation. Top dressing should be done during cool part of the day and fertilization should be avoided at noon-time, when the temperature is high.

**Liquid Ammonia**

The latest technique of fertilization is the application of liquid ammonia through well distributed pipes in cane field. Equipment has also been designed to inject ammonia on both sides of furrows two inches deep at planting and at 10 inches depth near to root zone in later stages. The use of ammonia either in anhydrous or as aqua form is a common practice in Hawaii, Puerto Rice, Mexico, Taiwan and many other areas of the world (Humbert, 1968).

**Foliar spray**

Sugarcane has high demand for ‘N’ sprays application that can not meet the full dose requirement. However, as a contingent plan, the fertilizer may be sprayed to meet the ‘N’ deficiency at initial level. And in case the fertilizer could not be applied in time, it is safer
to spray the fertilizer in late season, for rapid uptake by plant and without adverse effect on juice quality. Foliar spray of urea is reported to increase the colour of leaves than by side application. The urea applied as foliar spray is absorbed through stomata opening and guard cells. It is dissolved by transpired water within 24 to 48 hours of spray. Almost 75-80 % of sprayed fertilizer is taken up by plant. For foliar application soil should have adequate moisture that leaves are fully turgid with 80 % moisture in sheath tissues; otherwise urea may cause dehydration and injury of leaf tissues. For increasing efficiency of foliar application, spray should be done when leaves cover the soil surface. Spray should cover the complete canopy of leaves.

**Fertigation**

It is the application of fertilizer with irrigation water. This technique assures the highest nitrogen use efficiency. Fertigation is a usual practice in the region where the crop is irrigated through drip tape system. The fertilizer dissolved in water reaches near to root zone and is taken up by plant without risk of leaching or volatilization.

In case of furrow irrigation a drum fitted with a nozzle and filled with dissolved fertilizer is placed on the point/ head of water flow to cane field. The fertilizer solution is allowed to flow with irrigation water current, drop by drop, at calibrated speed to drench the bordered field.

**Time of application**

Time of N application is of great importance for proper growth and development of cane. For sustainable cane production, plant demand for fertilizer must coincide with growth and development of cane. Determination of dose and time of fertilizer application, however, depends on time of planting, stage of growth and soil condition. Sugarcane should neither suffer through N deficiency early in the growing season, nor should it have surplus N at harvest. In clay or clay loam soils the essential nutrients are adsorbed by the soil particles and the fertilizer applied if not lost is retained in the soil till the roots start taking up the nutrients for latter use. The cane plant has the ability to store excess quantities of N absorbed in the early stages of growth and to utilize it for subsequent development of plant. Still excess N application immediately at planting reduce the excessive development of root system, and due to lesser surface area of roots, plants may become drought susceptible during critical growth stages (Anderson, 1997).

In principle N may be applied once in a crop season, if leaching or de-nitrification losses are minimal and if sufficient NH₄ cation or NO₃ anions are retained in the soil. However, nutrient uptake efficiency increases when N is applied in split doses during the growing season (Anderson, 1997). In case of excessive irrigation or rain it can leach down out of the root zone. It is particularly true for sandy and sandy loam soils whose water and nutrient holding capacity is very low. It is therefore advisable to apply N in split doses so that as much of the added N as possible is retained by soil particles and is available for crop use. Irrigation frequency should also be increased with relatively small irrigation to avoid leaching losses beyond root zone.

In long duration tropical regions fertilizer application timing may not be that critical. In short duration crop of sub-tropical regions, ‘N’ has to be judicially applied to accelerate growth. The fertilizer applied in early period of cane growth helps accelerate an early
growth. However, fertilizer application should better be applied in two or three splits. In the first step it should be applied at planting for its utilization for germinating shoots during 25-45 days of planting. Crop shows maximum requirement between tillering phase and boom period of crop growth during 90-120 days of planting. Hence for an early and short duration crop three splits, at planting, and then at 60 and 90 days after planting seem to be optimum time. In subtropical regions, 'N' application should not be delayed beyond the month of June.

The experiments conducted on loam soils of Faisalabad show divergent results of N application time. The yield differences due to full application of N at planting or its application in two or three split doses were not significant (Fasihi and Malik 1989). However, the cane yields were drastically low when the entire N was applied in June (Fasihi and Malik, 1989). 'N' application has not to be delayed beyond mid June for spring cane and by the month of April to May for autumn planting cane in Punjab and NWFP (Fasihi and Malik, 1989; Kasal et al, 1984). However, the fertilizer in autumn crop should be completed by March and April (Qureshi, 1975; Anon, 1988; Fasihi and Malik, 1989; Kasal et al, 1984).

In the case of autumn planting, 20-30 % of total nitrogen should be applied at planting to accelerate germination and early development of shoots. As the plant growth is checked/reduced during winter, there are ample chances of N losses in case of excess N application. In fact cane crop is very sensitive to low temperature for nutrient absorption. Studies have revealed that at low soil temperature, N, K and chlorophyll in cane leaves is drastically reduced even in the presence of adequate nutrients (Kanwar and Singh, 1979). A temperature of 27°C is considered optimum for growth and nutrient absorption (Burr, 1957). A drop in root temperature from 23°C to 19°C cuts P intake to one third and reduces N intake to one half. At still low temperature absorption is completely curtailed (Burr, 1948). The winters in Punjab, NWFP and upper Sindh are very severe and somewhat mild in lower Sindh. Therefore the second and third dressing of fertilizer to autumn sown crop should be applied at the time when active growth restarts during spring. The entire dose of nitrogen should be completed by the end of April for autumn planting and by mid June for spring planting.

As a general rule no N should be applied 3-4 months before harvesting. As the N applied late in the season may result in excessive growth and suckering with low sucrose yield. Excessive N uptake also increases disease and frost susceptibility (Anderson, 1997). It may however, be kept in view that split application is flexible to the stage of crop growth-the lush or weak growth of crop. The crop condition may be visualized or the plant analysis may help to decide the dose and time of splits.

In sandy or sandy loam soils, nutrients are not fully retained by the soil particles, and are rapidly leached down beyond the root zone by irrigation water or rainfall. In such type of soils it is always advisable to split the fertilizer in three or more doses depending on coarseness of soil and stage of plant development.

The time of nitrogen application plays a dominant role in the maturity of cane crop. To cause early maturity, the nitrogen level of cane plants should be reduced to check the vegetation growth. Therefore, care should be taken pertaining to the time and dose of last N application. The experiments in India have shown that for optimum sucrose production
of a twelve month cane the N application should be completed not latter than three months of planting (Mohan, 1963). It is observed that the late application of fertilizer tends to promote late suckers, tend to grow more vegetative and become more tender leading to lodging, late maturing and low recoverable sugar at harvest.

In one year crop, it may not that difficult to maintain a uniform stand of mill-able cane stalks with a specified dose and timely application of fertilizer. But for a two years crop timing of N fertilization are extremely important. Nitrogen requirements have to be predicted, as unchecked application may induce great variation in primary stalks, age of secondary stalks and population of suckers and percentage of dead stalks at harvest. Different timings of N fertilizers control the different proportion of primary and secondary stalks and suckers. Higher fertilizer doses in early crop season and lower doses in later months are advisable to have high sugar yields.

**Phosphorus**

Phosphorus is one of the major elements essentially required for growth and development of sugarcane. It plays important role in various metabolic activities of plant.

- It is helpful in build up of protein and plays an essential role in cell division, thus controls inter-nodes length, thickness and height of cane stalks.
- It promotes early root formation and growth of cane.
- It is essential to formation of strong and vigorous root system and profuse tillering.
- Have important role in photosynthesis and other metabolic process of plant.
- Phosphorus contents in juice accelerate clarification in boiling process.

**Deficiency Symptoms**

- Leaves are thinner, narrower and shorter than normal and stand abnormally upright.
- Leaves blades show dark green to blue green colour often with red or purple tips margins and necrotic spots.
- Older leaves turn yellow and die back from the tips and along the margins.
- Tillering is poor, young shoots die before emergence on soil surface, and thus stooling is poor.
- Secondary rootlets are poor thus minimum roots surface for soil contacts.
- Rate of growth is slow and inter-nodes are small.
- Length and diameter of stalks is reduced, cane stalks are short, slender and tapering at the growing point.
Phosphorus availability in soils

In natural state, phosphorus is derived from weathering of mineral 'apatite'. Other phosphorus sources include micro-organism and decaying animal and plant residues. Soil characteristic like pH, calcium content and type of clay minerals affect the phosphorus availability to plants. Phosphorus is more available in a pH range of 6-7.5 than in too low or two high pH conditions. Under alkaline soil condition with calcium in solution, the phosphate quickly reacts with Ca forming compound of low solubility, and in acidic soils phosphorus is fixed as iron and aluminum compounds. The precipitated compound has large surface area in contact with the soil solution; as such much of phosphorus is fixed and may be slowly released under favorable environments. The soils of Pakistan are generally calcareous to varying degrees with alkaline pH, low organic matter and available P. These conditions favour P fixation forming calcium phosphate compounds, as such P is not adequately released for absorption by plant roots. The quantity of soil P (400-300 mg P2O5 Kg-1 soil, are much greater than those of available p, yet severe to moderate P deficiency has been recorded in more than 90% of cultivated soils of Pakistan (Rashid, 1994). As such P fertilization is essential for crop production.

Keeping in view the phosphates availability, soils have been grouped with very low available P (< 5 ppm), low P (5-10 ppm), average (10-15 ppm) and sufficiently available P (15 ppm and above). In most of the soils in Pakistan, soil availability of P to plants is inadequate for high yield production. A survey conducted by FFC indicates that 63 to 80% area of cultivated land has P less than 5 ppm. On the whole 24% area fall in P range of 5-10 ppm, 60 % area fall in average P range of 10 to 15 ppm, while only 4% area has satisfactory amount of available P (>15 ppm) (Table-8.10).

Table-8.10  Average exchangeable K in soils of various provinces in Pakistan

<table>
<thead>
<tr>
<th>Province</th>
<th>Percentage area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Pujnab</td>
<td>63</td>
</tr>
<tr>
<td>Sindh</td>
<td>67</td>
</tr>
<tr>
<td>MWFP</td>
<td>80</td>
</tr>
<tr>
<td>Pakistan</td>
<td>66</td>
</tr>
</tbody>
</table>

Anon, (1999)

Uptake by plants Vs P fixation

Phosphorus is absorbed by plants as phosphate ions (H2PO4, HPO4 . ). Phosphorus uptake by cane plant is conditioned by soil reaction, soil texture, moisture, temperature and the 'P' status of soil. Lack of response to 'P' application is often related to the soil’s ability to fix large quantity of 'P'.

1 The 'P' uptake from sandy soils is one third that of clayey soils at equal 'P'
concentration in the soil solution (Olsen and Watanab1963). This is due to relatively higher diffusion rate of 'P' to plant roots in clayey soil.

2 The P uptake is greatly related to temperature as the rate of 'P' uptake is faster at 23°C than at 16°C.

3 Phosphorus is more available at relatively low pH than the high pH conditions. At higher pH the 'P' is fixed with soil and is not taken up by plants.

The 'P' use efficiency by sugarcane is somewhat low due to 'P' fixation properties of fertilizers. Some of the phosphorous applied to soils as phosphates fertilizer is taken up by cane crop, while some reacts with soil minerals to form insoluble compounds and is transformed to unavailable 'P'. In general soil condition, the 'P' utilization efficiency of fertilizer is to the extent of 20 to 30% (Tandon, 1992). Though of course the 'P' applied to the soil is not lost but is fixed with soil particles, and is made available over time in favorable conditions. The ratoon crop may be benefited by the residual effect of previously applied fertilizer. The losses of phosphorous fertilizer by leaching or volatilization are negligible, but the recovery in a crop season may be 20 to 40% (Ray Choudhary, 1988)). Continuous P fertilization results in build up of soil 'P', which later becomes available to subsequent crop. The 'P' uptake by cane plant is augmented with proper application method and suitable soil management practices.

**Forms of P fertilizers**

Different types of commercial fertilizers are available in the market; the main fertilizers available in Pakistan are listed in Table-8.11

<table>
<thead>
<tr>
<th>Common names</th>
<th>Grade</th>
<th>Other nutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single super phosphate (SSP)</td>
<td>0 18 0</td>
<td>20 12</td>
</tr>
<tr>
<td>Triple super phosphate (TSP)</td>
<td>0 46 0</td>
<td>1.4 1.5</td>
</tr>
<tr>
<td>Diammonium phosphate (DAP)</td>
<td>18 46 0</td>
<td>- 0</td>
</tr>
<tr>
<td>Mono-ammonium phosphate (MAP)</td>
<td>11 52 0</td>
<td>1 2</td>
</tr>
<tr>
<td>Nitrophos (NP)</td>
<td>23 23 0</td>
<td>8-1 0</td>
</tr>
<tr>
<td>Complete fertilizer N P K</td>
<td>15 15 15</td>
<td>- 5</td>
</tr>
<tr>
<td>&quot; &quot; &quot;</td>
<td>10 20 20</td>
<td>- 6.8</td>
</tr>
<tr>
<td>&quot; &quot; &quot;</td>
<td>13 13 21</td>
<td>- 6.0</td>
</tr>
</tbody>
</table>

Generally higher water soluble phosphate sources (> 65% soluble) are recommended for alkaline soils. Nevertheless a review of comprehensive data comparing SSP, DAP and NP used in soils of Pakistan revealed no clear cut superiority of any of the phosphate sources over the other when applied with the same dosage of 'N' and 'P' (NFDC, 1986). However, in saline sodic soils use of SSP is more beneficial as compared with DAP, because of gypsum content of the former fertilizer.
Cane response to phosphorus

Response of cane crop to 'P' fertilizer depends on soil reaction, soil type and the soil available 'P' content. In studies of different soil types, cane yield response varied from 0.44 to 1.53 tons mill-able cane per kg applied 'P' at the fertilizer dose of 45 Kg P ha⁻¹ (Yadav and Singh, 1995).

In studies with three levels of 'N' (0, 150, 200 kg N ha⁻¹) in normal and calcareous soils, the effect of 'P' was significant up to 100 kg P₂O₅ in normal soil and 50 kg P₂O₅ in saline alkali soils (Thakur et al, 1979). A basic application of 50 kg P₂O₅, for higher efficiency of 'N', appear to be essential for both types of soils. Nitrogen without phosphate had lower efficiency and phosphate without 'N' had very poor and uneconomic response even at lower doses. It thus shows that salinity and alkalinity reduced the phosphate requirements by 50% in calcareous soil and 'N' and 'P' combination had synergistic effect on yield of cane. Repeated application of 'P' fertilizer builds up the 'P' reserves of soil. The crop may not show good response to 'P' fertilizer in soils, which have ample amount of available P₂O₅, while response is more in soils with very low 'P' reserve (Calcino et al, 2000).

In earlier studies, at sugarcane Res. Station, Faisalabad, different phosphate levels (0, 56, 112, 168 and 224 kg P₂O₅ ha⁻¹) applied at constant level of 78 k N ha⁻¹ did not show marked effect on the yield of cane (Fasihi and Malik 1989). It was due to the reason that consistent yearly application of fertilizer in that soil had build up the 'P' reserves of soil which show negative response to further application. However, studies conducted on 'P' deficient soils showed significant 'P' response to increase yield of cane (Malik et al, 1990; Fasihi and Malik, 1989). Therefore for efficient use of 'P' fertilizer doses of N and K have to be corrected, according to the nutrient status of soil.

Table-8.12 Effect of Phosphorous fertilizer on yield of sugarcane

<table>
<thead>
<tr>
<th>Fertilizer dose Kg ha⁻¹</th>
<th>Cane yield t ha⁻¹</th>
<th>Yield increase t ha⁻¹</th>
<th>Kg cane per kg P₂O₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>N  P  K</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>168  0  84</td>
<td>98.44</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>168  84  84</td>
<td>107.56</td>
<td>9.12</td>
<td>108.57</td>
</tr>
</tbody>
</table>

Fasihi and Malik, 1989

<table>
<thead>
<tr>
<th>Fertilizer dose Kg ha⁻¹</th>
<th>Cane yield t ha⁻¹</th>
<th>Yield increase t ha⁻¹</th>
<th>Kg cane per kg P₂O₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>170  0  93</td>
<td>62.68</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>170  74  93</td>
<td>77.60</td>
<td>14.92</td>
<td>201.62</td>
</tr>
<tr>
<td>170  124  93</td>
<td>86.50</td>
<td>23.82</td>
<td>192.96</td>
</tr>
</tbody>
</table>

Malik et al, 1990

Cane variety response

Varietals differences in tolerance to P deficiency are considerably less evident than in the case of N and K deficiency (Humbert, 1968). However, some cane varieties possess a higher phosphate economy than others, which allow them to produce heavy crop with
low application of P fertilizer. Cane varieties have also shown positive response to P in Australia (Calcino et al, 2000).

**P and cane maturity**

Most of the studies indicate that phosphorus has no direct effect on maturity of sugarcane (Prummel, 1957). Nevertheless under condition of 'P' deficiency, 'N' remains unused in plant tissues, which in turn delays maturity in cane? The beneficial effect of P in relation to quality of cane juice is observed during process house in a factory. This is due to its role to accelerate clarification in boiling process (de Geus, 1973).

**Method of application**

The P fixation property of the 'P' fertilizer demand special care in its application to the crop. After the fertilizer is applied to the soil they are transformed to less available form and is released slowly. For its maximum utilization, the fertilizer should be placed in furrows along side the seed sets or under the cane sets. The 'P' application through broadcast is not recommended for cane crop. Fertilizer application by broadcast during plowing exposes the phosphate to a greater surface area hence more fixation. The fixation of broadcast 'P' is much greater than the fertilizer applied in bands, because of narrow soil-fertilizer ratio in the later situation (Rashid and Din, 1993). Application of 'P' fertilizer after cane planting is also not considered to have much beneficial effect on cane. As the surface applied 'P' is liable to be fixed and due to low solubility the 'P' movement from surface to root zone is very small (Humbert, 1968; Golden, 1968). Surface 'P' fertilizer application to ratoon is always questioned. In more humid areas, where the soils are continuously moist and are covered with trash blanket from the previous crop, the roots grow to the surface and can use the 'P' applied to the surface. But under irrigated conditions where soils are alternately wet and dry, roots do not grow to the surface and are unable to use surface applied 'P' as effectively as when placed in sub-surface position near the roots of cane stools.

**Fertilizer use efficiency**

On soils with high 'P' fixation capacity, 'P' availability is greatly enhanced by the application of super phosphate with FYM or compost (de Geus, 1973). Application of FYM and compost to high pH soils not only supplies 'P' on decomposition, but also provides acidic organic compounds which increase the availability of mineral forms of 'P' in soil. Super phosphates mixed with well rotten FYM in 1: 2 ratio increases the efficiency of applied 'P' reducing its fixation and thereby increase 'P' use efficiency by 30-40% (Rashid, 1994; Sharif and Chaudhery, 1985).

**Potassium**

Potassium is one of the essential elements required for growth and development of cane plant. Sugarcane has the largest demand for potassium. A crop of 100 tons on an average removes 250 kg $k_2O$ ha$^{-1}$ (Humbert, 1968). Thus one tonne of mill-able cane removes two to three kg of $k_2O$ from the soil. The absorption of 'K' is slow at the initial stage of germination and gradually increases with advance in age. The 'K' uptake is quite active
after four months of age and during grand growth period from June to August. By this
time approximately 85% K₂O is absorbed by spring planted cane (Mishra and Singh,
1991). The 'K' uptake varies with soil and ecological conditions, as it was low in
Anakapali (1.3 kg t⁻¹ ha⁻¹) and high under Bihar conditions (3.13 kg t⁻¹ ha⁻¹). The
information available from different sets of soil and crop duration indicates different
amount of 'K' utilized by the cane crop.

<table>
<thead>
<tr>
<th>Author</th>
<th>'K' contents removed kg ton⁻¹ of cane stalks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golden (1960)</td>
<td>0.91 to 1.53</td>
</tr>
<tr>
<td>Barnes (1964)</td>
<td>1.13</td>
</tr>
<tr>
<td>Kilmer et al (1968)</td>
<td>0.40</td>
</tr>
<tr>
<td>Stewart (1969)</td>
<td>0.27 to 2.7</td>
</tr>
<tr>
<td>Andreis (1975)</td>
<td>1.49</td>
</tr>
<tr>
<td>Orlando Filho et al, (1985)</td>
<td>0.64 to 0.70</td>
</tr>
</tbody>
</table>

The potassium removal by leaves is considerably higher than that by cane stalks and the
uptake by ratoon crop is higher than by plant crop (Table-8.13).

<table>
<thead>
<tr>
<th>Plant part</th>
<th>Age - days</th>
<th>120</th>
<th>180</th>
<th>240</th>
<th>300</th>
<th>360</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Cane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stalks</td>
<td></td>
<td>2.46</td>
<td>9.50</td>
<td>16.10</td>
<td>37.39</td>
<td>61.17</td>
</tr>
<tr>
<td>Leaves</td>
<td></td>
<td>37.88</td>
<td>53.19</td>
<td>60.36</td>
<td>88.41</td>
<td>122.07</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>40.34</td>
<td>62.69</td>
<td>76.46</td>
<td>128.8</td>
<td>183.24</td>
</tr>
<tr>
<td>Ratoon Cane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stalks</td>
<td></td>
<td>4.34</td>
<td>35.53</td>
<td>58.33</td>
<td>61.82</td>
<td>77.59</td>
</tr>
<tr>
<td>Leaves</td>
<td></td>
<td>60.01</td>
<td>97.78</td>
<td>114.58</td>
<td>113.94</td>
<td>114.45</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>64.35</td>
<td>131.31</td>
<td>172.91</td>
<td>175.76</td>
<td>192.04</td>
</tr>
</tbody>
</table>

Source: Orlando Filho, (1985)

Role of potassium

- It performs most essential function in plant metabolism. It plays as a catalyst in
carbon assimilation, protein and photosynthesis, formation of sugars from
simple carbohydrates and their conversion into starch.

- It has an important role of translocation of proteins and sugar for other life
processes.

- It promotes the turgidity of the plant cells and thereby maintains the internal
pressure of plant tissues. This role is of great importance in water economy of plants.

- K increases the strength of cell walls in plant tissues.
- It promotes development of better root system.
- It is the major component of cell sap and helps the plant use other nutrients and water more efficiently. It helps increase N utilization and protein synthesis is disturbed with lack of adequate level of K.

Deficiency symptoms

- K is a highly mobile nutrient in the plant as such older leaves exhibit deficiency symptoms before young leaves.
- Young leaves usually stay dark green.
- The upper surface of the mid ribs may show reddish spots limited to the epidermis.
- Sheath of K deficient plants do not detach easily.
- Plant growth is retarded, inter nodes are short, and cane stalks are stunted and slender.
- Plants show yellowing and spotting of older leaves. Orange yellowing starts at the base of the blade and the yellow band taper of towards the tip. Numerous chlorotic spots turning to brown with necrotic centers follow yellowing in leaves. As the spots coalesce, general browning of the leaf results. Later the leaves begin to die back from the margin and tips giving a burned appearance in the final stage.

K availability in soil

Uptake of 'K' by cane plant depends on physical status of soil, soil mineralization and root temperature. Type of soil determines the availability of 'K' to the plant. Many soils may contain a large amount of Potash, but only a small percentage of this amount is available to plants. Potassium in soil exists in three forms.

Unavailable -------- slowly available---- available form

The unavailable form is present in minerals and rocks and constitutes 90-98 % of total soil potassium. The K contents are released very slowly through break down of soil minerals by weathering agencies or soil mining.

The slowly available form also called exchangeable K constitutes up to 10 % of total soil potassium. This form is fixed between clay layers and is slowly released for plant growth. The quantity and the rate of release into soil solution depend on clay content and the nature of soil minerals.

The available form of potash is either found in soil solution or is held in exchangeable form by clay particles or organic matter.
Potassium fertilizer added into the soil dissolves in the soil water quickly and is dissociated into cation K and amines, chlorides or Sulphates. A large quantity of K cations is held to the exchange sites of clay particles and is released slowly. The small amount of K remains in soil solution and is readily available to plant and is liable to leaching.

Generally soils rich in clay have high levels of potassium but release K very slow, while sandy soils have very low levels of potassium but such soils releases K quickly. Concentration of Calcium level limits the availability of K to plants.

Heavy clay soils if not ploughed well may show K deficiency due to compaction and poor aeration. Therefore proper land preparation to fine tilth and inter row cultivation brings the K in more available form. The cultural methods also help improve root development for better uptake of nutrients. Increased response to potassium fertilizer by ratoon crop could be due to soil compaction and consequent restriction in root growth. Physical state of soil has marked influence on the uptake of K. Soils with poor drainage also suffer from K deficiency.

According to Humbert (1968), even though root system is well developed, the uptake of nutrients by sugarcane is reduced as the temperature falls to 18°C or below. If cool season coincides with heavy rains leaching losses of nitrates and Potassium are considerably high.

Crop response to K fertilizer depends on the level of available K in soil. Fertilizer responses are small or non-significant if level of exchangeable K in soil is high; the response is quite obvious in K deficient soils.

Potassium is very mobile in the soil solution and is liable to leaching. Leaching may cause problems in sandy soils, in high rainfall or excessive irrigation.

**K$_2$O fixation in soil**

When added in the soil, potassium is lightly attached to the clay and is not readily leached from the soil and move slowly with water. The potassium applied as fertilizer does not react in soil to make any compound and is therefore easily available for plant use. The K applied on the soil surface is neither volatilized nor fixed in soil but gradually moves down to root zone. However, where drainage and aeration are problems, K uptake by cane is restricted even though the level of available K is high. Under such condition sugarcane shows marked response to the aerial application of K$_2$O?

**K in relation to soil and plant analysis**

Correlation exists for available soil K and yield increase on certain level of K application. A balance of exchangeable K in soil and that need to be applied should be established on soil analysis basis. The actual need of the crop vary with soil types, crop duration and climatic condition. Actual application rate should be determined through experimentation considering the K yield response (Munson, 1985).

A potassium response curve has to be developed in relation to critical values of K in different soil types. Under Pakistan conditions the critical value of K has been determined to be < 100 ppm for poor soils, 100 to 150 ppm for average fertility and more than 150 ppm showing good amount of exchangeable K for crops. On the whole, cultivated soils in
Pakistan are not much deficient in available amount of K. Based on the soil analysis performed by the Fauji Fertilizers Company (FFC) the average exchangeable K in various provinces of Pakistan are presented in Table-8.14.

<table>
<thead>
<tr>
<th>Province</th>
<th>Percentage area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K values (ppm)</td>
</tr>
<tr>
<td>Punjab</td>
<td>15</td>
</tr>
<tr>
<td>Sindh</td>
<td>9</td>
</tr>
<tr>
<td>MWFP</td>
<td>17</td>
</tr>
<tr>
<td>Pakistan</td>
<td>14</td>
</tr>
</tbody>
</table>

Because of the differences in physical, chemical and mineralogical parameters, available K contents vary in different soils. A study showed that 28 % soils in Punjab, 8 % in Sindh and 35 % in NWFP had inadequate plant available K (Ismail, 1994).

Plant analysis is now a good complementary approach to determine nutrient requirements of crops. Leaf sheath would be the best indicator of K status in sugarcane, while the credibility of leaf is the next (Rama Rao and Sekhon, 1989). Leaf sheath do not show specific variation in K with plant age (Lakshami Kantham et al, 1973). They observed a general mean of 2.397% K (3-6 sheaths) for the eight periods of sampling from 60 to 270 days crop. However, sheath K value of 2.0% was considered optimum for realizing high cane yield, though sheath K did not appear to be limiting factor for cane yield. Optimum limit percent dry weight of the first mature leaf for K is more than 1.5 (Anderson and Bowen, 1990). In S. Africa response to K application was reported to be at dry leaf sample value of less than 1.2%, responses are variable or small between 1.2 and 1.5% K₂O and above 1.5% K₂O response are unlikely (Du toit, 1959).

Crop logging is used as a guideline for fertilization of sugarcane. The 3rd to 6th leaves and sheath of cane are sampled at 35 days interval from the time the cane is 2-months old until harvest. Considering the K contents of leaves (excluding mid rib) sheaths schedule is chalked out for application of supplementary fertilizer.

**K nutrient balance in soil**

For a good crop production, a balanced amount of nutrient is essentially required. Due to intensive cropping over years and unscientific soil and crop management practices, some nutrients are drained off affecting the fertility of soil and productivity of crop. This is especially true for K element, the requirement of which is the highest of any other principal nutrient. Continuous cane cropping without K application in soils is likely to decline soil reserves of available potash. Humbert (1968) has reported substantial decline in soil reserves over a thirty years period. Even under optimum rates of K application, crop uptake of K continue to exceed the addition of K resulting in negative Potassium balance due to successive depletion of soil K (Mishra and Singh, 1991).
Work carried out in Pakistan show some striking data on K depletion through long term successive cropping cycle. Considering K addition through fertilizer as well as irrigation water and the K removal through crops, based on wheat, rice, maize, cotton and sugarcane crop cycle, the annual K depletion was reported to be 3.8 mg kg⁻¹ of K per mg of soil (Malik et al, 1989). It was further observed that the average level of available soil K declined from 323 mg to 200 mg of K per kg of soil during 15 years (1971 to 1985) period. Under long term experiments, in a wheat-cotton rotation, a decline in available K contents was reported in the top 15 cm soil from 238 mg kg⁻¹ K to 196 mg kg⁻¹ over an eight years period (1978-1986) in plots receiving N: P application (Bhatti et al, 1989). The depletion was even more pronounced in the 15-30 cm layer (Table-8.15).

Table-8.15 Soil ‘K’ mining in 8 years period

<table>
<thead>
<tr>
<th>Fertilizer level</th>
<th>Soil ‘K’ content (mg kg⁻¹)</th>
<th>1978</th>
<th>1986</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP</td>
<td>0-15 cm</td>
<td>238</td>
<td>196</td>
</tr>
<tr>
<td></td>
<td>15-30 cm</td>
<td>230</td>
<td>160</td>
</tr>
<tr>
<td>NPK</td>
<td>0-15 cm</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>15-30 cm</td>
<td>163</td>
<td>160</td>
</tr>
</tbody>
</table>

Bhatti et al, (1989)

On the basis of seven years of data from long term trials involving sugarcane-sugarcane-Wheat-Guara-Toria rotation, K response was reported to be negative for first five years but became positive during the last two crops (Table-8.16).

In cropping system "sugarcane – sugarcane - finger millet – cotton", the potash removal was much more than the quantity applied through fertilizer (Sundra and Subramanian, 1989).

Although some soils are rich in K, but continued cultivation of exhaustive crops is bound to cause heavy depletion of soil if not replenished regularly and adequately.

Table-8.16 Sugarcane response to K application in a long term rotation trials

<table>
<thead>
<tr>
<th>N P K Fertilize levels kg ha⁻¹</th>
<th>Cane yield t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>170: 110: 0</td>
<td>60.8</td>
</tr>
<tr>
<td>170: 110: 110</td>
<td>35.8</td>
</tr>
</tbody>
</table>

Source: Bhatti et al, (1989)

**Contribution of Potassium from Irrigation Water**

Irrigation water generally contains soluble salts and mineral matter which can contribute to K addition when crops are irrigated. A survey indicated that canal and tube-well waters contain on an average 7.22 and 6.48 mg K per litter (Shakir et al, 1994). Results of another survey identified vermiculite as a major mineral in canal water of Punjab.
(Krauss, et al, 1996). This implies that canal water, instead of supplying K, can fix applied fertilizer in the field (Saleem and Akhter, 1996).

**Integrated nutrients management**

For harvesting optimum yields nutrients have to be applied in balanced proportion. Presence of one element triggers the effect of other. It has already been reported that a ratio in N. K has to be maintained in leaf tissue to harvest good sugar (de Geus, 1973). In some studies at Faisalabad application of potash without phosphorus fertilizer caused a significant reduction in cane yield (Fasihi and Malik, 1989).

Application of both K and N gave a significant increase in cane yield and when applied alone a marked reduction in yield was noticed (Gupta and Shukla, 1974). A significant relationship of K yield response in relation to balance doze of P and N has been reported by Malik et al, 1989 and Sharif and Chaudhary, 1988.

**Table-8.17 Response of potash at various NPK levels in Sindh***

<table>
<thead>
<tr>
<th>N P K level kg ha⁻¹</th>
<th>Cane yield t ha⁻¹</th>
<th>Yield increase %</th>
<th>kg cane per kg K₂O</th>
<th>Soil reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agr. Res. Instt. Tando Jam</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>120:75:0</td>
<td>79.6</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>120:75:75</td>
<td>86.15</td>
<td>6.55</td>
<td>87.33</td>
<td>8 15.5 190</td>
</tr>
<tr>
<td>120:75:120</td>
<td>85.16</td>
<td>5.55</td>
<td>46.33</td>
<td></td>
</tr>
<tr>
<td>Sugarcane Res. Station Sujawal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1168 : 84 : 0</td>
<td>49</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>168 : 84 : 123</td>
<td>66</td>
<td>17.02</td>
<td>138.21</td>
<td>8.25 17 130</td>
</tr>
<tr>
<td>168 : 84 : 185</td>
<td>90.6</td>
<td>41.60</td>
<td>224.86</td>
<td></td>
</tr>
<tr>
<td>168 : 84 : 247</td>
<td>113.6</td>
<td>64.60</td>
<td>261.54</td>
<td></td>
</tr>
<tr>
<td>112 : 84 : 0</td>
<td>79.4</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>252 : 84 : 123</td>
<td>95.8</td>
<td>16.40</td>
<td>133.30</td>
<td></td>
</tr>
<tr>
<td>252 : 84 : 185</td>
<td>113.3</td>
<td>33.90</td>
<td>183.24</td>
<td></td>
</tr>
<tr>
<td>252 : 84 : 247</td>
<td>127.3</td>
<td>47.90</td>
<td>193.93</td>
<td></td>
</tr>
<tr>
<td>Farmers field (Av. of 13 trials)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>225 : 84 : 0</td>
<td>91.36</td>
<td>-</td>
<td>-</td>
<td>8–8.3 12-18 80-120</td>
</tr>
<tr>
<td>225 : 84 : 84</td>
<td>105.78</td>
<td>14.42</td>
<td>171.67</td>
<td></td>
</tr>
<tr>
<td>225 : 84 : 138</td>
<td>112.41</td>
<td>21.05</td>
<td>152.54</td>
<td></td>
</tr>
</tbody>
</table>

Potash and Gane Yield

The experimental work reported by Chaudhary (1986) show positive response of K fertilizer to increase yield of sugarcane (Table-8.17). Since exchangeable K content were considerably high (190 ppm) at Tandojam, the cane yield response to K application was low to the level of 75 kg K\(_2\)O ha\(^{-1}\) only. But at Sujawal there was progressive increase in cane yield with successive increase in K fertilizer level. This significant response was due to low availability of exchangeable K (130ppm) in the soils of this station. Another set of trial with enhanced dose of N has shown the same pattern of K response, but the response is slightly reduced indicating the need for adjustment of N fertilizer with relevance to K. At farmers field as well sugarcane has shown considerable response to K due to low K (80-120) contents in soil.

Recommended dose and fertilizer use

As per estimation 1.2, 0.46 and 1.44 Kg N, P and K are removed from soil to produce one tonne of sugarcane and this accounts for 38.7 % 14.4 % and 46.5 % of total NPK nutrients removed. To meet this requirement the potash fertilizer is recommended to the range of 60 to 175 Kg per hectare depending on fertility status of the soil. But K fertilizer use in Pakistan is extremely low, which is 0.8 Kg K\(_2\)O ha\(^{-1}\). Thus despite the removal of 1.44 Kg K\(_2\)O frrm soil (46.5%) only 0.8 kg is being applied which is hardly 0.72% of total K\(_2\)O demand for the crop (NDFC Anon, 1996).

"K" moisture relationship

Under optimum irrigation or available soil moisture conditions the moisture level in cane remains high. But in the case of K deficiency the moisture level in lower leaves drops, the leaves lose their turgidity and dry prematurely showing typical firing symptoms. The K application increases the moisture content, rendering the cane more succulents (Humbert 1968). It was further reported that if K level in 8-10 stalk leaves is higher than 1.5 %, the stalk moisture level is high, and if the K level falls below 1%, the moisture level drops significantly and at 0.5% or lower K level the lower leaves dry prematurely and die. This K moisture relationship helps to improve juice quality. The spray application of K can make up the deficiency to improve moisture status of plants.

'K-N' relationship for cane maturity and juice quality

There is a significant correlation in K and N for improvement of cane and sugar yields. A balance in leaf tissue levels of N and K has to be maintained for conversion of reducing sugars to sucrose prior to harvesting. The excessive N and low K levels may result into high moisture, high reducing sugars, low sucrose and low juice purity. The K deficiency intensifies the deleterious effect of N on juice quality, while the addition of K improves sugar contents at high N level. Potassium should be adequately available to utilize the N to force the cane to normal maturity. An optimum level of K brought a reduction in reducing sugars, glucose ratio, non sugars and increase in CCS (Mahamuni et al, 1973), while absence of K was reported to result increase in total reducing sugars in leaf, stem and root (Singh and Sinha, 1978). However, where soil is high in exchangeable K no such increase is expected, but where crop shows K deficiency, fertilizer application gives significant increase in sucrose percent cane.
'K' – juice quality

Potash is known to be a quality element. As it has important role in cell structure, carbon assimilation, photosynthesis, protein synthesis, starch formation and translocation of proteins and sugars (Singh and Sinha, 1978). K deficiency reduces photosynthesis rate and restricts newly formed sugars from leaves to storage tissues in stalks as such results in decline in yield and sugar. K application improves sucrose content in cane by reducing the fibre content and improves extraction (Srivastava and Hunsigi, 1978). Juice extraction was reported to increase by two to five percent with K application (Singh and Yadav, 1985). The juice extraction is improved due to high turgidity in cells brought about by K element, and high extraction in turn increases the sugar yield.

Cane crop deficient in K contents is reported to have low sucrose content (Dillerijn, 1952, and Humbert, 1963). As a matter of fact the phenomenon of exchangeable K in soil prevails. Soil deficient in K content show positive response to K application in respect of yield and sugar contents, though of course its N-K relationship has profound effect on maturity. Potash application gave a significant increase in cane and sugar yields wherever exchangeable soil K was less than 91 ppm, between 95 and 120 ppm response was variable, while above 120 ppm K there was no significant K response. Increase in sugar yields for K fertilization is small or negligible, when the level of exchangeable K in the soil is high (Locsin et al, 1956).

Besides its positive effect on enhancing sucrose in juice, there is strong contradiction on the role of potassium in improving sugar recovery. Many evidences show that it would affect the sucrose recovery in sugar processing. Over application of K would cause luxurious uptake in cane tissue without inhibiting growth Since K has the tendency to increase sucrose solubility, thus maintain a certain amount of sucrose in solution, presence of higher percentage of ashes in cane juice makes the exhaustion of syrup difficult. Increased ash content in cane exerts a negative influence on sugar quality and K is the main constituent of juice ashes (Humbert, 1963). Potash application help increase the yield of cane, but increase in tonnes of cane per hectare were nearly nullified in terms of sugar ha\(^{-1}\) due to decreasing sucrose contents with higher rate of K beyond the modest recommended doses (Gascho and Kidder, 1979). The increasing doses of K fertilization beyond recommended level exerted a negative effect on sucrose % cane and promoted linear increase in ash content in the juice (Chapman, 1980; Orlando Filho, 1985; Calcino et al, 2000).

Form of Potash fertilizers

The potash fertilizers are available in either of the following forms shown in Table 8.17. The main sources of commercial Potash fertilizers are Sulphate of Potash (SOP) and Murate of Potash (MOP). The MOP is widely used in sugarcane world as potash fertilizer. The MOP fertilizer accounts for 99% of all the potash fertilizer being used in India (Mishra and Singh, 1991). It was also reported that MOP is as good as SOP but the former is considerably cheaper than the later fertilizer. In Pakistan mainly SOP has been in use in field. Somewhere during nineties MOP was introduced as alternate source of potash fertilizer.
Table-8.17 Forms of Potash fertilizers available in Pakistan

<table>
<thead>
<tr>
<th>Common names</th>
<th>Available grade%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Potassium sulphate (SOP)</td>
<td>0</td>
</tr>
<tr>
<td>Potassium chloride (MOP)</td>
<td>0</td>
</tr>
<tr>
<td>Complete fertilizer N : P : K</td>
<td>15</td>
</tr>
<tr>
<td>&quot;</td>
<td>10</td>
</tr>
<tr>
<td>&quot;</td>
<td>13</td>
</tr>
</tbody>
</table>

The studies conducted at Sugarcane Research Station, Khanpur (Table-18) and by the Potash Development Institute, Islamabad (Akhtar, 1997), indicate that both the fertilizers, SOP and MOP as potassium fertilizer, were equally good as fertilizer source to increase sugarcane crop yield (Anon, 1998).

Table-8.18 Effect of MOP and SOP on cane yield

<table>
<thead>
<tr>
<th>Treatment kg K ha⁻¹</th>
<th>Cane yield t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MOP</td>
</tr>
<tr>
<td>Control (no K)</td>
<td>88.56</td>
</tr>
<tr>
<td>168 - 112 - 100</td>
<td>106.09</td>
</tr>
<tr>
<td>168 – 112 - 150</td>
<td>108.95</td>
</tr>
<tr>
<td>168 – 112 - 200</td>
<td>110.57</td>
</tr>
</tbody>
</table>

Aslam et al, 1999

Time and method of application

Considerable work has been done on time and method of application in Pakistan and elsewhere in the world. The effectiveness of K fertilizer depends on the type of soil and growth pattern of cane variety. There is a general agreement that K should be applied as a basal dressing at the time of cane planting. It was observed that K application at planting and at 90 days of planting in one or 2 splits did not show appreciable differences in cane yield (Fasihi and Malik, 1989). The absorption of K is slow at the initial stage of germination and gradually increases with advance in age and root development. The K uptake is very active after four months of age and during grand growth period. The K applied earlier is gradually utilized with the advance in plant development. In soils having leaching problems it is advisable to give split application. In heavy soils leaching may be slow but in sandy soils K show high leaching losses. Thus the leaching effect may be minimized by split application and proper placement of K fertilizer. For its efficient utilization the fertilizer should be placed near to the zone of maximum root concentration. In sandy soils, K application may be delayed until the cane roots system has expanded into the inter-row spaces. Higher doses of K should be applied cautiously considering soil and plant reaction and
water application. Application of high levels of potassium to relatively narrow bands in the furrow reduced cane yield by soil root damage and potassium leaching. Yield increased by more than 9 % with 120 kg K$_2$O ha$^{-1}$ applied in two splits, 60 kg in furrows at planting and 60 kg during covering. Various studies on K application indicated that its basal dose at planting gave higher cane and sugar yield than split application (Narisimham, 1988; Ahmed et al, 1993).

**Table-8.19. Cane yield response to different levels of K$_2$O at different times of application at Khanpur (Punjab)*

<table>
<thead>
<tr>
<th>Treatment</th>
<th>K$_2$O applied</th>
<th>Mean % Increase in yield</th>
<th>kg cane per kg K$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At planting</td>
<td>90 days of planting</td>
<td></td>
</tr>
<tr>
<td>168 : 112 : 0</td>
<td>75.78</td>
<td>75.78</td>
<td>-</td>
</tr>
<tr>
<td>168 : 112 : 112</td>
<td>108.4</td>
<td>105.72</td>
<td>39.51</td>
</tr>
<tr>
<td>168 : 112 : 168</td>
<td>121.3</td>
<td>144.90</td>
<td>51.89</td>
</tr>
<tr>
<td>168 : 112 : 224</td>
<td>144.89</td>
<td>135.16</td>
<td>79.05</td>
</tr>
</tbody>
</table>

*Ahmed et al, 1993

In India too, the usual recommendation is to apply all the potassium as a basal dressing; however, under varying conditions K may be applied in 2 or 3 splits at planting, 45 days and 90 days of planting (Srivastava, and Hunsigi, 1978). The split application may be given to various growing conditions:

1. Cane varieties having slow tillering and low initial vigor
2. In late maturing varieties
3. In light textured (sandy) soils
4. Where high rates of application are involved.
5. The crop having long crop duration may also receive K in split doses.

Ratoon crop of cane show higher response to K application than plant crop. A single early application is quite comparable to two or three split doses to stubble cane crop. Single application of K at stubble shaving to the ratoon crop growing in sandy loam soils was better than 2 or 3 equal splits (Hunsigi et al, 1974 and Hunsigi, 1975). It may be mentioned that stubble roots remain active for almost 85 to 105 days after harvesting of preceding plant crop. Part of potash may be applied as foliar spray, but foliar spray of K is a contingency plan to supplement the soil application to cover rapid K deficiency (Mishra and Singh, 1991). In such cases potassium sulphate is recommended over potassium chloride to avoid leaf scorching due to chloride compound.

**Potassium under moisture stress conditions**

The cane crop may suffer from moisture stress due to scanty rains or insufficient supply
of irrigation water especially during hot summer months. Potassium helps the plant to sustain growth under drought conditions. It promotes turgidity in cells and develops better root system for water uptake (Humbert, 1968). This element also achieves water economy by reducing the rate of transpiration by the cane crop (Zende, 1984). Potassium increases succulence and help to retain more moisture in plant tissues (Parthasarathy, 1983). Thus potassium has been used as a practical tool to evade drought conditions. Naidu and Srinivasan (1982) observed that trash mulching with additional doses of potash (60 Kg K2O ha⁻¹) improved yield and juice quality under stress conditions. They also made an effective use of potash as foliar spray during drought period either alone (2.5% KCl) or with urea (2.5%) at 60, 90 and 120 days after planting. The effect was more pronounced in sandy loam soil, which gave 30% higher yield than a loam soil that recorded 6% better yield.

**Potash and resistance to insect pests and diseases**

Besides various chemical and mechanical control measures, potash is reported to play a positive role in crop resistance to pests. A significant decrease from 26.5 % to 73.5 % was observed in the incidence of scale insects with increased level of K from 168 to 336 Kg ha⁻¹ (Raghunathan, 1983). Spray application of potash has also been used effectively against shoot borers. The spray of Endrin and potassium decreased shoot borer attack from 21.1 to 16.7% over Endrin spray alone (David and Ananthanarayana, 1984). Potassium increases cuticle thickness as such cane with adequate K levels show higher resistance to eyespot disease caused by Helminthosporium sacharri (van Dillewign, 1952).

Iron chlorosis and lime induced chlorosis in sugarcane was found due to imbalance of potassium. Balanced ratio of K with Fe and Ca brought the leaf to normal level (Joshi and Naik, 1981).

**Lodging damage and potash**

Soft tissues in cane stalk and slender cane can not give mechanical support against lodging. The K element hardens the cane tissue to provide proper mechanical support. K application increases the diameter and height of cane. Lignification of vascular bundles is generally impaired by K deficiency, which makes K deficient crops more prone to lodging (Mengel and Kirthby, 1982). Increased cuticle thickness due to K makes the cane stalk stiff to withstand lodging, while well developed root system increase the anchorage against lodging.

**Soil Organic Matter**

The soils are made up of minerals, air, water and organic matter. The organic matter is formed from residues of plants, soil organisms and remains of animals and their byproducts. The organic matter is present in very small proportion (1-2 %) but has a great role in soil forming process and build up of soil fertility and crop productivity. It plays a role far greater than its share of the volume of the soil.
Functions of Organic Matter

- It has great bearing on physical properties of soil. It gives crumb structure during cultural operations and improves soil tilth.
- It has a direct role in improving cation exchange capacity and is a virtual store house of nutrients. The organic matter releases nutrients into the soil solution and produces acids which affect fixation and slow release of other nutrients. It thus reduces losses of nutrients by leaching.
- The soils added with organic matter are not only the rich source of N for plants; provide other major and micro nutrients to the crop.
- It encourages the build up of soil microorganism, which assists in mineralization and decomposition to release nutrients.
- It enhances the water holding capacity of soil. The organic matter absorbs and retains water and thereby maintains a sufficient amount of moisture in the root zone. This is an important property that can help sustain plant growth during the period of moisture stress. The land having suitable amount of organic matter does not dry up soon and do not show stress symptoms.

The level of organic matter in soil

Soil productivity could be measured by its level of the organic matter. Organic soils are the most productive soils for healthy crop growth. In tropical rain forest areas the organic matter may be as high as 5-7 %. The cultivated soils in tropical regions may contain 1 to 5 % organic matter, while in arid and semi arid areas the organic matter may be as low as 0.6 to 0.3 %. Soil environments like temperature, moisture, air, soil reaction and the type of vegetation determine the level of organic matter in soil. Organic carbon in soil is a measure of organic matter content that is worked out using the formula.

\[
\text{Organic matter\%} = 1.724 \times \text{organic carbon \%}
\]

One percent organic carbon has been taken as the threshold level for soil organic matter (Pal and Jat, 2005). The organic matter is a rich source of N and also contains some amount of other nutrients. All the nutrients in organic matter are not available to plants until the organic matter has broken down to inorganic form through mineralization. The micro-organisms, fungi and bacteria play active role in decomposition of the organic matter through mineralization. The rate of organic matter decomposition depends on climate, soil texture and crop husbandry. The decomposition is rapid at high temperature in tropical and sub tropical climate. It is slower in clayey soils than in loamy and sandy loam soils because of good aeration favorable for microbial activities; excessive cultivation also promotes break down of organic matter.

It may be emphasized that the organic matter in soil is never stable in constant amount. With passage of time it decreases due to decomposition and this action is hastened by oxidation at high temperature. The organic matter in soil has to be replenished through incorporation of farm yard manure; crop residues and sugarcane filter press cake at repeated intervals in crop cycles.
Cane fields in Pakistan are generally deficient in organic matter. About 90% of cultivated soils in Pakistan have organic matter less than one percent, and the organic matter ranges between 0.3 to 0.6% in most of these soils. The instances of 0.6 to 0.8 are quite a few, and very little percentage of soils contains 1.0% (Table-8.20).

<table>
<thead>
<tr>
<th>Organic matter</th>
<th>No. of samples and percent composition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Punjab Sindh NWFP Pakistan</td>
</tr>
<tr>
<td>Organic matter &lt; 1.0</td>
<td>90 79 97 90</td>
</tr>
<tr>
<td>&gt; 1.0</td>
<td>10 21 3 10</td>
</tr>
</tbody>
</table>

Source: FFC- Fertilizer Guide Book

Farmers have been using farm yard manure (FYM) in the past. With increase in crop intensity and advance in mechanization, followed by elimination of livestock power (Bullock/ horses) in the field, the practice of adding FYM to cultivated areas is now minimized. Use of FYM is now confined to small land holdings, preferably for vegetable crops. In areas growing field crops soil has been depleted of organic matter. Rotational legumes are constrained by the need to grow more profitable crops. Green manuring is not considered worth while comparing the value of other cash or fodder crops and the economy of irrigation water.

In Pakistan, farmers mostly depend on inorganic fertilizers and for this too main thrust lies on the use of nitrogen fertilizer. A survey of cane fields in Mardan (NWFP) indicated that only 13% and 5.75% of the growers applied the recommended doses of N and P respectively, while K was not used at all (Ayaz et al, 1997). Such a practice gradually depletes the soil of essential nutrients and gets exhausted. It badly affects the sustainability of cane yields. For improving land productivity through organic manures a number of alternatives are available. Soil organic matter can be improved by adopting any of the following measures.

3. Growing green manure crops in sequence or as inter crop.
4. Burying crop residues- the tops, trash, in cane fields.
5. Biological fixation of 'N' and 'P'

The farmyard manure, green manure and filter press cake are considered the natural organic N sources, which also contain sufficient amount of macro and micronutrients. However, these organic N sources greatly vary in composition, N contents, plant vigor, market supply and manufacture sources. The variation in N contents could be due to the favorable or unfavorable environments for mineralization process, ammonification and de-nitrification during handling and field operations. While working out the fertilizer requirements for the crop, the available N, P and K contents have to be checked through laboratory analysis. The quantum of manure to be applied has to be adjusted considering its composition, moisture, irrigation and rainfall, soil salinity level and the soil type.
Farm Yard Manure

Farm yard manure (FYM) has been the traditional source of organic matter, used for enriching soil productivity since time immemorial. Besides improving organic status of soil, FYM provides most essential plant nutrients (NPK) along with microelements, like Na (1000 mg), Cl (2000 mg), Fe (180 mg), Mn (20 mg), Cu (k mg), B (4 mg) Co (0.3), Mo (0.3) I (0.5 mg) each, per kg of manure (Anon, 1976). The NPK composition of common sources of FYM is shown in Table-8.21.

The composition indicated in Table-8.21 presents the NPK content of manure preserved under ideal storage conditions. Normally the livestock manure is not stored/preserved in suitably designed pits and is kept in heaps in open air; thus a substantial amount of N is volatilized as ammonia. As such nutrient level of farm yard manure is considerably low. To preserve the nutritive value of manure it should be collected in deep pits (6 m length x 2 m wide x 1 m deep) and compacted and plastered with slurry of cow dung and earth to reduce the amount of air pockets and to slow the decomposition rates. It is also advisable to keep the manure relatively moist as the moisture holds the gaseous ammonia against evaporation losses.

Table-8.21 Mean composition of different types of FYM

<table>
<thead>
<tr>
<th>Types of manures</th>
<th>% composition (fresh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Cattle dung</td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>Urine</td>
<td>0.9-1.2</td>
</tr>
<tr>
<td>Horse dung</td>
<td>0.4-0.7</td>
</tr>
<tr>
<td>Urine</td>
<td>1.2-1.5</td>
</tr>
<tr>
<td>Sheep dung</td>
<td>0.5-0.7</td>
</tr>
<tr>
<td>Urine</td>
<td>1.5-1.7</td>
</tr>
<tr>
<td>Poultry manure</td>
<td>1.0-1.8</td>
</tr>
<tr>
<td>Night soil</td>
<td>1.0-1.6</td>
</tr>
<tr>
<td>Human urine</td>
<td>0.6-1.0</td>
</tr>
</tbody>
</table>

Source: Gupta, P.K (1999)

Farm yard manure is often recommended for improving land productivity for better crops yields. Enough data is available to conclude that to obtain potential yields; 50 % of total N requirements should be made available in the form of FYM and 50 % applied in the form of fertilizers (Fasihi and Malik, 1989). This combination gave higher yield of cane than application of either the manure or fertilizer alone. In some later studies it was concluded that N application @ 112 kg N ha⁻¹ in the form of chemical fertilizer in addition to a basal dressing of FYM @ 56 kg N ha⁻¹ was an optimum dose to obtain good yield of cane. The FYM gave definite indication of residual effect on ratoon yields suggesting a slow release of nutrients. The FYM if applied alone may be considered as a good soil improver rather than nutrient supplier.

The FYM supplies macro and micro nutrients to cane plants and also improves the physical, chemical and biological properties of soils (Sing and Yadav, 1992). They reported that though N affectivity of organic manure is 40 to 50 % of Ammonium
sulphate, yet residual effect of the manure to ratoon has far reaching effect in manifesting the soil productivity. The yield of first, second and 3rd ratoon decreased by 13.4, 27.9 and 33.2 % when manured, while that of un-manured ratoon declined by 58.7, 68.7 and 74.3 % respectively, over the yield of plant crop.

In sugarcane based cropping system, the residual effect of fertilizer and decomposition of crop residues is of great consideration. The superiority of FYM over the inorganic fertilizers (NPK) is due to more favourable effect of former on soil aggregation resulting into better physical condition of the soil (Rebindra et al, 1985). The FYM alone and with NPK fertilizer considerably improved the water holding capacity of soil, while the continuous application of Ammonium sulphate decreased the water holding capacity (Singh and Yadav, 1994).

High pH soils are known to pose problem of P fixation thus reducing nutrient availability to plants. Farmyard manure is known to improve cation exchange capacity of soils, which has a direct bearing on the availability of nutrients. Application of inorganic fertilizer to soils, after thorough mixing with well rotten FYM, has been found to reduce the fixation of applied phosphorus and enhances crop yields (Sharif et al 1966; Chaudhary, 1974; Chaudhary and Qureshi, 1980). It was observed that FYM mobilizes other nutrients especially P for better uptake by plant. The FYM @ 350 kg ha<sup>-1</sup>applied in furrows at planting in conjunction with basal fertilizer dose of 225:84:168 NPK ha<sup>-1</sup>, followed by later application of N @ 175 kg ha<sup>-1</sup>, gave the highest yield of cane and sugar over NPK fertilizer alone treatment (Sharif and Chaudhery, 1985) - Table-8.22.

**Table-8.22 Effect of N P K fertilizer applied with and without farm yard manure on the yield of BL 4**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N</th>
<th>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</th>
<th>K&lt;sub&gt;2&lt;/sub&gt;O</th>
<th>Cane yield t ha&lt;sup&gt;-1&lt;/sup&gt;</th>
<th>% increase over control</th>
<th>Benefit cost ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>141.45</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>T2</td>
<td>225</td>
<td>0</td>
<td>0</td>
<td>151.72</td>
<td>7.26</td>
<td>2.0</td>
</tr>
<tr>
<td>T3</td>
<td>225</td>
<td>84</td>
<td>0</td>
<td>160.33</td>
<td>13.34</td>
<td>2.9</td>
</tr>
<tr>
<td>T4</td>
<td>225</td>
<td>84</td>
<td>168</td>
<td>165.90</td>
<td>17.79</td>
<td>3.2</td>
</tr>
<tr>
<td>T5</td>
<td>T4 + FYM 350 Kg ha&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>177.00</td>
<td>25.13</td>
<td>4.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Soil Analysis**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>TSS</th>
<th>pH</th>
<th>OM</th>
<th>N%</th>
<th>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt; ppm</th>
<th>K&lt;sup&gt;2&lt;/sup&gt;O ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>0.48</td>
<td>8.30</td>
<td>1.28</td>
<td>0.08</td>
<td>4.8</td>
<td>165</td>
</tr>
<tr>
<td>T2</td>
<td>0.40</td>
<td>8.30</td>
<td>1.20</td>
<td>0.07</td>
<td>3.8</td>
<td>163</td>
</tr>
<tr>
<td>T3</td>
<td>0.40</td>
<td>8.30</td>
<td>1.27</td>
<td>0.07</td>
<td>7.0</td>
<td>160</td>
</tr>
<tr>
<td>T4</td>
<td>0.46</td>
<td>8.28</td>
<td>1.27</td>
<td>0.08</td>
<td>8.0</td>
<td>160</td>
</tr>
<tr>
<td>T5</td>
<td>0.46</td>
<td>8.20</td>
<td>1.30</td>
<td>0.08</td>
<td>9.5</td>
<td>180</td>
</tr>
</tbody>
</table>


Post harvest soil analysis treated plots indicate that combination of FYM with fertilizer while gave higher yield of cane, lowered the soil pH, increased organic matter and released higher amount of nutrients that could be utilized for subsequent ratoon.
The problems being faced in farm yard manure are its lesser supplies and unscientific management for its storage in open, leading to ammonia losses. Efforts have to be made for its proper storage in desired pits and effective utilization for crop production. The latest technology available is to prepare bio-gas from the cow dung for domestic consumption so as to utilize the digested slurry as organic fertilizer in fields. This technology not only produces valuable gas but improves the nutrient value of organic matter (biogas slurry). This practice is quite common in China. The Appropriate Department of Ministry of Science and Technology has also introduced some of the bio-gas plants in Pakistan. The composition of farmyard manure and bio-gas slurry reported by Ray Chaudhary (1988) indicates that the bio-gas slurry is far more nutritive than FYM (Table-8.23.).

### Table-8.23. Composition of farm yard manure and bio-gas slurry as fresh material

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Percent composition</th>
<th>Farm yard manure</th>
<th>Bio-gas slurry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>0.60%</td>
<td>1.4 - 1.8 %</td>
<td></td>
</tr>
<tr>
<td>Phosphorus (P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;)</td>
<td>0.30%</td>
<td>1.1 - 2.0 %</td>
<td></td>
</tr>
<tr>
<td>Potash (K&lt;sub&gt;2&lt;/sub&gt;O)</td>
<td>0.70%</td>
<td>0.8 - 1.2 %</td>
<td></td>
</tr>
<tr>
<td>Magnesium (Mgo)</td>
<td>0.04%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Calcium (Cao)</td>
<td>0.20%</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Dry matter</td>
<td>23.00%</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

### Green Manure

Continuous monoculture in cane or cereal cropping system has detrimental effect on soil productivity. Nutrient imbalance in soil is one of the major reasons for decline in yields. The other effects include the loss of organic matter, degraded soil structure, increased soil erosion and increased need for external inputs. Growing crops to use as green manure offer the best tool to maintain organic matter contents of soil.

Sugarcane based cropping system prolongs for 3-4 years duration and shows complex mechanism for its N use pattern. The crops in rotation may be exhaustive or restorative of nutritional requirement and affect the additional nutritive needs of cane crop. Exhaustive crops deplete the soil fertility and land productivity has to be replenished by incorporating organic manures, including farm yard manure, crop residues, press mud or green manure in soil. Since other organic manures are not available in desired quantity, green manuring is the best option to sustain the productivity of land. Bio-mass of any crop could be used for green manuring, but the best selection would be a legume crop with good vegetative growth.

Fallow period, exhausts the soil due to oxidation of any available organic matter in the soil. The green manure crop helps arrest the oxidation losses of organic matter. The
shading effects of green manure crop reduce the soil temperature and activate the microbes in mineralization of organic matter.

The use of legume crop as green manure is due to its ability to trap atmospheric nitrogen in its roots through complex bio-chemical process. The atmosphere contains unlimited wealth of carbon dioxide and nitrogen. Plant avails of CO₂ through respiration, while nitrogen is conserved through nitrifying bacteria called as Rhizobium embodied in root nodules of legume crops. These bacteria collect N from the soil air and through bacterial activity this N is converted into a form that can be used by legumes. This process is called as symbiotic fixation of N in soil. In return plants supply carbohydrates to the bacterial growth and development. The N fixed by the legume crop, is then added to the soil following the decomposition of organic matter supplied by legume crop.

Besides the supply of N, legume crops add up organic matter in soil, which on decay supply readily available nutrients to the cane crop. The organic matter also binds the soil particles to improve the physical condition of soil and improve aeration and drainage. The deep root system of legume crops also helps in mobilizing fixed P for use in cane crop.

Different crops have different potential to fix N in soil. The N contents available from different legume crops on decomposition are expressed in Table-8.24.

The legumes in sugarcane farming system are grown either in sequence during fallow period or as intercrops in inter row spaces of cane. Green manuring legumes, preceding sugarcane, give a benefit of 14-34 % increase in the yield of sugarcane and contribute 41-85 Kg N ha⁻¹ through biological N fixation (Yadav, 2000).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Quantity of Biomass t ha⁻¹</th>
<th>Expected Nitrogen%</th>
<th>Nitrogen Kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer Legumes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dhaincha (Susbanina eculata)</td>
<td>27.6</td>
<td>0.52</td>
<td>86</td>
</tr>
<tr>
<td>Sun hemp (Crotalaria juncea)</td>
<td>29.1</td>
<td>0.43</td>
<td>75</td>
</tr>
<tr>
<td>Guara (Cyanopsis tetragnoloba)</td>
<td>27.7</td>
<td>0.62</td>
<td>103</td>
</tr>
<tr>
<td>Mung (Vigna radiata)</td>
<td>11.0</td>
<td>0.53</td>
<td>35</td>
</tr>
<tr>
<td>Mash – Urd (Vigna mungo)</td>
<td>16.7</td>
<td>0.41</td>
<td>41</td>
</tr>
<tr>
<td>Cow peas (Vigna unguiculata)</td>
<td>17.0</td>
<td>0.49</td>
<td>50</td>
</tr>
<tr>
<td>Arhar (Cajanus indicus)</td>
<td>9.8</td>
<td>0.66</td>
<td>39</td>
</tr>
<tr>
<td><strong>Winter legumes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berseem (Trifolium alexandrinum)</td>
<td>20.0</td>
<td>0.43</td>
<td>52</td>
</tr>
<tr>
<td>M. pariflora</td>
<td>32.3</td>
<td>0.51</td>
<td>99</td>
</tr>
<tr>
<td>Lentil (Lens culinaris)</td>
<td>16.2</td>
<td>0.33</td>
<td>32</td>
</tr>
</tbody>
</table>

In Australia it is mandatory to grow a green manure crop - legume fallow rotation, after termination of 4-5 crop cycles (Calcino et al, 2000). Leguminous plants, such as cow peas, soybean, peanuts and beans add considerable amount of nitrogen and organic matter after incorporation in soil. A well grown crop of cow peas is capable of supplying about half the 'N' requirements of the following plant crop, whereas a well grown crop of
soybean can supply the total 'N' requirements. Leguminous residue on incorporation in soil decomposes very easily. Data indicate that 200 kg 'N' /ha can be mineralized from soybean residue within 70 days of incorporation; however half of it is leached down to soil reserves (Calcino et al, 2000).

In some regions of the world, sugarcane is grown continuously for years as a monocrop. This practice leads to soil degradation due to compaction and draining nutrients from soil resulting into yield decline. Breaking of sugarcane monoculture with fallow legume can have important effect on the yield of subsequent sugarcane crop due to improvement of soil health and through symbiotically fixed nitrogen (Garside and Bell, 2003). Green manuring in the fallow period is reported to result in increased field porosity and addition of organic matter in the soil. In the subsequent plant crop yields were improved by 16 – 29 % after bare fallowing and 40 – 54 % after green manuring, compared to continuous cropping of sugarcane (Nixon, 2003).

To avail of maximum organic N and organic matter the green manure crops should attain vigorous growth to produce maximum bio-mass. All the leguminous crops can be used as green manure but a crop requiring lesser irrigation water and that can flourish well in poor soils to give vigorous growth in shortest growing period should be preferred. Dhaincha, guara and cowpeas are usually planted as green manure during summer season. However, water requirements of jant ar are relatively high, while guara get ready with 2-3 irrigations only. In some previous studies in India, sunhemp proved to be a superior green manure crop with respect to yield of biomass (to be ready within 60 days), production of carbohydrate and the nitrogen content (Anon, 1959). The amount of nitrogen turned in was the highest at 50 days, followed by incorporation after 60 days growth. Phaseolus bilbous was next best as Green manure crop. The green manure crops Dhaincha, Guara, Lobia and sunhemp were reported to add 55, 44, 71 and 70 Kg N/ ha respectively and gave a corresponding increase in cane yield by 30.4, 27.5, 43.0 and 42.8 % over control (Singh and Yadav, 1992).

Legume crop should be utilized as green manure by incorporating complete foliage, stem and root portion in soil. Taking a fodder crop or to allow the green manure crop to seed if grown as inter crop was found to have deleterious effect on the yield of cane (Anon, 1959). Improvement in cane yield is brought about by both the above ground vegetative part of green manure crop and its root system. In experimental study tops, roots and tops + roots components of sunhemp weighed 23.3, 2.3 and 26.3 tonnes per hectare and
contributes 56 Kg, 14 kg and 85 Kg N per hectare. The contribution of tops, and roots to cane yield was to the extent of 63 % and 42 % respectively (Singh and Yadav, 1994). They also concluded from some previous work that on equal N bases green manuring is as effective as fertilizer and twice as effective as FYM in increasing cane yield.

It has been observed that an integrated use of fertilizer each with green manuring in plant cane and its residues in first ratoon increase the N use efficiency in terms of cane yield by 7.1 % in plant cane and 15.8 % in ratoon cane (Singh et al, 1993). In this context the yield increase for plant and ratoon cane in conventional planting, without organic matter, was 3.4 % and 11 % respectively. Studies of Singh and Yadav (1994) reveal that application of fertilizer increased cane yield over non-fertilized field, but it failed to maintain the initial yield levels in continuous growing of sugarcane over time (1953-1983). However legume crops of sunhemp and Lucerne in cropping system with sugarcane proved helpful to sustain the initial yield levels in chemical fertilized field and even the un-fertilized cane crop. It was further observed that green manuring the field helped to raise the initial P level of soil. It was argued that the decline in cane yield at constant rate of N application without addition of organic matter is due to depletion of soil fertility leading to inadequate supply or deficiency of nutrients other than N in soil.

For N addition, in soil green manure crops differ in their performance depending upon the crop species, varieties, quantity of bio-mass, portion of green manure crop incorporated, stage of crop growth, time gap for decomposition after turning in of green manure before cane planting and its impact as residual effect.

Legumes are grown to trap bacteria in nodules, but least care is taken to check nodules formation on root system. Nodulation takes place in the presence of bacteria (Rhzyzaobium) in the suitable soil environment. Nodules turn purple when fully developed. Crop may flourish vegetatively without nodulation, but in this phase is not able to fix nitrifying bacteria in roots. To assure proper nodulation in roots, the legume seed must be treated with Rhizobium culture before planting.

Time of turning over of green manure crop is very important for proper conversion of organic matter in soil. For rapid decomposition it should be incorporated in soil when it is succulent just prior to flowering. According to Singh and Yadav (1994) green manure showed enhanced rate of decomposition under higher supplies of moisture. They further observed that phosphate manuring of sunhemp and soybean showed a progressive increase in the N content with increasing levels of P2O5 application up to a maximum of 100 Kg ha⁻¹.

The green manure crop can best be churned with rotavator followed by soil turning plough. In the absence of rotavator, disc plough or any mould board plough can help in burying down of green manure crop. After turn over of green manure crop, it should be irrigated. About two or three weeks period should be allowed for proper decomposition before planting cane. If cane is planted before proper decomposition of green manure, the soil organism utilize available soil N as well as a part of applied N fertilizer, thus the cane crop on germination show pale colour. To accelerate the rate of decomposition urea fertilizer @ 50 Kg ha⁻¹ may be applied during incorporating green manure. Urea acts as feed for bacteria.
Legumes as inter crop in sugarcane

The germination in cane normally takes 30 to 45 days and the initial growth is slow, as such lateral spread of cane foliage or canopy cover is not much up to about 100 days of planting. This period can be utilized for planting legumes as inter crop/companion crop in inter row spaces of cane. Short duration, erect growing and dwarf varieties of some legumes have been developed that can be successfully grown in inter row spaces. Autumn planted cane provides longer duration to accommodate successful inter cropping of legumes. For spring cane as well some useful combinations are available. A list of suitable crops for inter cropping is given as under.

List of some legume crops that can be grown as inter crop in sugarcane

<table>
<thead>
<tr>
<th>Autumn cane</th>
<th>Spring cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berseem</td>
<td>Mung</td>
</tr>
<tr>
<td>Senji</td>
<td>Mash</td>
</tr>
<tr>
<td>Metha</td>
<td>Alfalfa</td>
</tr>
<tr>
<td>Lentil</td>
<td>Cow peas</td>
</tr>
<tr>
<td>Gram</td>
<td>Beans</td>
</tr>
<tr>
<td>Peas</td>
<td>Urd</td>
</tr>
</tbody>
</table>

Divergent information is available on increase or decrease of cane yield following inter cropping with legumes. Among the winter legumes, inter cropping of berseem, gram, lentil and peas reduced cane yield by 31.6, 27.6, 24.3 and 17.3% respectively over the yield of autumn cane alone (Singh and Yadav, 1992). But when some of the autumn fodders were grown as green fertilizer they increased yield of cane. Fodder legume crops like Berseem, Lucerne and Metha when incorporated in inter-row spaces during December and January gave a significant increase in yield of cane over cane alone. Juice quality was also improved (Table-8.25).

Table-8.25 Cane and sugar yields as influenced by inter cropping with winter green manure crops

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cane yield t ha⁻¹</th>
<th>CCS% cane</th>
<th>CCS t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone</td>
<td>107.46</td>
<td>11.88</td>
<td>12.76</td>
</tr>
<tr>
<td>Cane + Berseen</td>
<td>118.88</td>
<td>12.57</td>
<td>14.94</td>
</tr>
<tr>
<td>Cane + Lucerne</td>
<td>114.58</td>
<td>12.30</td>
<td>14.09</td>
</tr>
<tr>
<td>Cane + Metha</td>
<td>114.50</td>
<td>12.19</td>
<td>13.95</td>
</tr>
<tr>
<td>Cane + Senji</td>
<td>109.96</td>
<td>11.97</td>
<td>13.16</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>2.15</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Aslam et al., 1999
Among the summer legumes, mung, urd and cowpeas are popular inter crop with spring planted cane in India and have been reported to increase cane yield besides producing substantial quantity of grain (Singh and Yadav 1992). Companion cropping of mung and urd tend to reduce not only the N needs of cane by 30 % but also reduce leaching losses of nitrate nitrogen beyond potential root zone of cane crop (Yadav, 1982). In most of the cases summer legumes inter cropped with spring sugarcane do not affect the yield of sugarcane adversely (Singh and Yadav, 1994). The legume as inter crop has residual effect on ratoon cane yield which was increased by 18 %. Inter cropping legume increases N use efficiency by checking the losses of nitrate nitrogen and by increasing N uptake. This also improved the utilization efficiency of applied P, which was 4.5 %, in sugarcane alone to 20-22 % and 9.5-11.3 % in sugarcane inter cropped with mung and urd respectively.

**Crop Residues**

The crop residues include sugarcane residue and the plant parts remains of other crops. The sugarcane residue constitutes the under ground portion of cane, the stubbles and roots and the trash that constitutes dry leaves from aerial parts of cane stalks.

**Cane trash**

During cane harvesting, cane trash is left on surface of the fields, and cane growers some times get rid of the trash by burning, while the stubbles are up rooted. Burning cane trash is a usual practice in Indo-Pakistan sub-continent. Burning of cane crop residue after harvest results in losses of 90-95% of carbon, nitrogen and sulfur as gases to the atmosphere. Eighty to ninety percent phosphorus, potassium, calcium and magnesium can also be lost as air born ash. And, if trash and stubble roots are turned under this mass acts as valuable organic matter.

In a review paper it was reported that trash blanket can recycle nutrients back into soil (Ridge, 2003). Trials conducted in Sao Paulo, Brazil, showed recycling of 85 – 93 % of potassium, 20 % 'N', 40 – 60 % Ca & Mg, 11 % S and negligible amount of P from trash in 12 months period. In the wet tropics of Queensland, 80 % K was found to be released within 80 days of harvest and release of N in 90 – 180 days period resulted in flush growth.

Cane stubble to the extent of 6.9 tons with 4.3 tons roots were reported to be left over from a sugarcane crop of 116.4 tons mill-able cane per hectare. The underground portion (stubble and roots) on decomposition contain 0.59 % N, 0.26 % P2O5 and 0.23 % K2O which is equal to 29 kg N, 13 kg P2O5 and 11 kg K2O. Besides the major elements roots also contribute 8.12 kg Fe, 1.08 kg Mn, 0.07 kg Ca and 0.10 kg Zn per hectare (Singh and Srivastava, 1964).

The amount of nutrients released by cane trash depends on the volume of sugarcane biomass-cane yield, harvesting time and the cane variety. Some varieties are more vigorous in growth while others shed their leaves easily as they enter into maturity phase. Generally, cane trash which is almost 10 % of cane produced contains 68 % organic matter, 0.42 % N, 0.15 % P, 0.57 % K, 0.48 % Ca and 0.12 % Mg, besides 25.7, 2045, 236.4 and 16.8 ppm Zn, Fe, Mn and Ca, respectively (Shrivastava et al, 1992).
In Mauritius, standing crop of cane is de-trashed before harvesting and trash is piled in alternate rows. Later this trash is turned under and buried down as organic matter. It is estimated that 15 tons of dry cane trash per hectare breaks down over about one year to form 2.5 tons of organic matter (Calcino et al, 2000). The left over biomass (trash and roots) is more or less 10% of total biomass of cane crop.

In countries having mechanized harvesting system, using chip cutter harvesters, tops and trash is automatically turned into small shreds and is simultaneously blown away to settle on cane field in a uniform layer as a blanket, called as green cane trash blanket (GCTB). Later on as the shoots start emergence, GCTB is slightly removed aside from cane rows with specially designed implements and staked along stubbles. Thereafter as the stubbles complete sprouting the GCTB is incorporated in the inter row spaces of the field.

The GCTB contains the following quantum of dry matter and nutrients per hectare (Calcino et al, 2000):

<table>
<thead>
<tr>
<th>Dry matter</th>
<th>Calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-15 tonnes equivalent</td>
<td>30-50 kg</td>
</tr>
<tr>
<td>Carbon</td>
<td>Magnesium</td>
</tr>
<tr>
<td>3000-65000 kg</td>
<td>15-25 kg</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Sulfur</td>
</tr>
<tr>
<td>50-100 kg</td>
<td>8-11 kg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>Trace elements</td>
</tr>
<tr>
<td>5-10 kg</td>
<td>Very small amount</td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
</tr>
<tr>
<td>30-90 kg</td>
<td></td>
</tr>
</tbody>
</table>

For most of the major nutrients, the quantities contained in the GCTB represent about a quarter to half of the total annual crop uptake. However this is not available immediately. Most of the GCTB decomposes within 12 months after harvest. On decomposition of GCTB the carbon and nutrients become part of the soil reserve or total soil pool of nutrients. With decomposition of carbon microbial growth activity is stimulated.

For significant increase in organic matter and soil moisture level, GCTB incorporation in soil should be a continuous practice for 5 years crop cycle, as only 1-2 years trash blanketing may not show a residual effect. Green manure crop in rotation and GCTB practice keep up the organic status of soil to the required level.

Trash is composed of hemi cellulose and lot of lignin, is therefore not easily decomposed, if spread as such in cane field. Decomposition can be attained by spreading trash within cane rows and sprinkling cow dung or press mud @ 10 t ha\(^{-1}\). Addition of N\(_2\) fixer hastens the process (Hunsigi, 2000).

The decomposition of trash and root mass in soil gives appreciable build up of N, P and K in soil after harvest of plant cane. Cane trash, on decomposition, adds to the soil 5.3 kg nitrogen, 1.1 kg phosphorus and 5.8 kg potash per tonne of trash (Varma, 2002). Ratoon crop can utilize the benefits for which N requirements can considerably be reduced. As such recommended N doses of 225 kg ha\(^{-1}\) for ratoon can be reduced to 150 kg ha\(^{-1}\) without detriment to normal cane yields (Yadav, 1983). The cane yield was reported to increase by 37.5% over control when 5 t ha\(^{-1}\) trash was incorporated with 75 kg N ha\(^{-1}\). The cane yield obtained was equal to that obtained with 150 kg N ha\(^{-1}\), thus showing an economy of 75 kg N ha\(^{-1}\) (Singh and Yadav, 1994).

The information available shows that sugarcane crop residue can help a great deal to
build up the organic reserves of soil. It is, in fact, the proper management of ratoon crop in ameliorating the trash and stubbles for thorough decomposition in soil. Use of proper equipment for turning under of trash and timely inter-row cultivation and fertilizer application can help conserve organic matter and enrich N content in soil. Trash may have further advantage to increase soil temperature in winter months and lowering the temperature in summer months, which is beneficial for microbial activities. Trash also conserves soil moisture and evades the crop from moisture stress. Disc type trash incorporator is universally used for mixing of trash within inter-row spaces of sugarcane. The equipment has been introduced in some tracts of Pakistan that chops the cane trash in two passes and then churns and incorporates the residue in soil. It can work well at cane row distance of four feet.

**Crop Residue**

In a sequence cropping system, crop residues other than sugarcane have also to be met with. In a series of rotation in different regions sugarcane may follow crops like, rice, cotton, wheat and potato. Wheat and potato may also be grown as inter crop. Wheat and rice straw remained in the fields after crop harvest can be incorporated in soil; cotton sticks can also be chaffed and mixed. The compositions of different crop residues shown in Table-25 indicate their nutritive value to enrich the soil.

<table>
<thead>
<tr>
<th>Crop residue</th>
<th>% Composition (oven dry basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>0.49</td>
</tr>
<tr>
<td>Rice straw</td>
<td>0.58</td>
</tr>
<tr>
<td>Cotton stalks/ leaves</td>
<td>0.88</td>
</tr>
<tr>
<td>Banana</td>
<td>0.61</td>
</tr>
<tr>
<td>Sugarcane Trash</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Ahmed and Rashid, 2003

Green manuring foliage of inter cropped potato produced an effect equal to 70 kg N ha$^{-1}$ (Verma and Yadav, 1988). In some other study potato foliage containing 2.59 to 2.68 % N contributes 31 kg N ha$^{-1}$ when used as green manure. It increased the cane yield by 5.1 t ha$^{-1}$ whereas inter cropping of potato increase the cane yield by 6.7 t ha$^{-1}$ over sugarcane alone. The response equation shows that green manuring through potato foliage economies 46 Kg N ha$^{-1}$ for sugarcane (Singh and Yadav, 1992). The effect was attributed to the availability of other essential plant nutrients to the cane crop, upon foliage decomposition in soil.
Filter Press Cake

In a sugar factory filter press cake (FPC) is derived during the process of clarification of cane juice. It constitutes the suspended and dissolved impurities removed in filtration process. The suspended impurities are in colloidal form and include the dispersed soil, bagasse particles, wax, fats, proteins, gums, pectins, tannins and coloring matter expressed from the cane during milling. The dissolved impurities include the reducing sugars and inorganic salts. This is a sort of cake that contains much of colloidal organic matter that precipitates during clarification. Composition of FPC varies with cane variety, cane harvesting system, weather condition, temperature of imbibitions water and the clarification process.

In sugar industry, two types of clarification processes viz., sulphitation and carbonation are commonly used to purify cane juice. In sulphitation process lime and sulphur dioxide are used to purify cane juice. In this case press mud contains calcium sulphate with impurities. In the carbonation process lime and carbon dioxide are used to purify cane juice and the calcium carbonate is precipitated along with impurities. The carbonation process leaves FPC as much 8-10 % of cane weight, while the weight of sulphitation FPC is about 3 to 4 % on the weight of cane crushed (Manohar Rao, 1997). Since carbonation FPC contains large quantities of calcium carbonate used during clarification process and has pH around 9, is not useful as organic fertilizer in soils of this sub-content. The sulphitation FPC, using sulphur dioxide in the clarification process has pH less than 6, is very valuable organic manure. Considering the comparative composition of sulphitation FPC and the carbonation FPC (Table-8.27), the former is more useful as slow release organic fertilizer due to high organic matter and higher N P K contents. The chemical composition of FPC of some of the sugar mills in Pakistan and some other countries is given in (Table-8.28 & 8.29).

<table>
<thead>
<tr>
<th>Process</th>
<th>% (oven dry base)</th>
<th>ppm (oven dry base)</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient</td>
<td>N</td>
<td>P</td>
<td>K</td>
</tr>
<tr>
<td>Sulphitation</td>
<td>1.7</td>
<td>3.6</td>
<td>1.4</td>
</tr>
<tr>
<td>&quot;</td>
<td>1.1</td>
<td>2.6</td>
<td>1.8</td>
</tr>
<tr>
<td>&quot;</td>
<td>2.4</td>
<td>1.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Carbonation</td>
<td>0.6</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>&quot;</td>
<td>0.9</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

1. Yadavanshi and Yadav (1990)
2. Kumar and Mishra (1991)

Generally the FPC contains large amount of N, P and other elements that can enrich the soil with nutrients. The N is present in proteins and other more simple amino acids or in
nitric form. The N content becomes available on microbial degradation of FPC. Thus amount of N varies on the environments favorable for decomposition and the stage of decomposition. The phosphorus is present as complex organic compounds such as phospholipids, nucleoproteins and calcium phosphate formed during clarification process. Potassium content is low to the extent of 0.4 to 0.8 %, unless enriched by addition of distillery waste the vinase and or fly ash.

### Table-8.28 Mean nutrients (%) contained in filter press cake of sugar mills in some selected countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Organic Matter</th>
<th>Lipids</th>
<th>Proteins</th>
<th>Ash</th>
<th>N</th>
<th>P2O5</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aregentina</td>
<td>73.3</td>
<td>6.6-13.7</td>
<td>8.4-14.6</td>
<td>29.1</td>
<td>1.3-2.3</td>
<td>5.3-6.3</td>
<td>6.2-7.7</td>
<td>-</td>
</tr>
<tr>
<td>Brazil</td>
<td>77-85</td>
<td>-</td>
<td>6.9-8.8</td>
<td>18.5</td>
<td>1.1-1.4</td>
<td>0.7-1.0</td>
<td>4.8-5.5</td>
<td>0.2-0.6</td>
</tr>
<tr>
<td>S. Africa</td>
<td>-</td>
<td>9.5-12.0</td>
<td>-</td>
<td>1.5-1.9</td>
<td>0.7-1.3</td>
<td>2.1-3.1</td>
<td>0.6-0.8</td>
<td></td>
</tr>
<tr>
<td>Mauritius</td>
<td>87.3</td>
<td>9.1-16.5</td>
<td>11.4-12.0</td>
<td>12</td>
<td>1.8-2.1</td>
<td>1.8-2.0</td>
<td>2.8-3.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Philippines</td>
<td>83.7</td>
<td>11.2</td>
<td>7.0</td>
<td>16.2</td>
<td>3.1</td>
<td>3.6</td>
<td>4.6</td>
<td>-</td>
</tr>
<tr>
<td>Taiwan</td>
<td>74</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.8-2.8</td>
<td>0.7-2.5</td>
<td>1.2-3.9</td>
<td>0.6-1.2</td>
</tr>
</tbody>
</table>

 Ramirez, J.H (Edit) 1988

### Table-8.29 Macro and micro nutrients contained in sugarcane filter press cake of some selected sugar mills in Pakistan

<table>
<thead>
<tr>
<th>Sugar mills</th>
<th>% Moisture</th>
<th>% dry filter press cake</th>
<th>mg/ gm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH</td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Shakarganj</td>
<td>74</td>
<td>5.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Hussain</td>
<td>71</td>
<td>5.6</td>
<td>2.0</td>
</tr>
</tbody>
</table>

 Ibrahim et al, 1990

The nutrient availability in the FPC of the Queensland Sugar Industry with and without ash is reproduced in Table-8.30. The data in Table-8.30 indicate that FPC can provide substantial amount of nutrients to cane crop. Almost 100 kg of N and 80 kg of K are available for cane growth in the year of application, while the rest is utilized by the ratoon crop. The available N corresponds to 60 – 80 % of the nitrogen fertilizer requirements and the K availability is equivalent to 80 – 100 of the potassium fertilizer requirements (Calcino et al, 2000).

In the entire sugar world the sugarcane FPC is mainly used as organic fertilizer in sugarcane fields. In Pakistan however, its use as fertilizer is still confined to quite a few factory areas. Several studies have confirmed the effective use of FPC to improve the yield of cane. FPC produced best results in Latin American and Caribbean countries when it was applied directly in furrows covering it with thin layers of soil (Manohar Rao, 1997). The practice is reported to maintain high cation exchange capacity along with some amount of N and other elements. Ibrahim et al, (1992) used FPC as a source of P comparing it with TSP fertilizer. Four levels (0.40, 80,100 kg P₂O₅ ha⁻¹) of P equivalent were tested on fodder Maize and their residual effect was observed on wheat grain and
straw. The overall effect of TSP was greater than that of press mud. The residual effect of FPC was similar to fertilizer. Recycling of FPC would return some of the plant nutrients removed from soil and remaining could be met from inorganic fertilizer source (Ibrahim, 1992). Statistically, 40 kg P₂O₅ from TSP was as effective as 80 kg P₂O₅ from FPC. It may be due to slow release of nutrients as well as short season crop of Maize.

### Table-8.30 Nutrients applied in to the soil by application of fresh -wet sugarcane by-products

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>FPC 150 t ha⁻¹</th>
<th>FPC-ash 150 t ha⁻¹</th>
<th>Ash 150 t ha⁻¹</th>
<th>Molasses 10 t ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>465</td>
<td>360</td>
<td>60</td>
<td>69</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>360</td>
<td>300</td>
<td>120</td>
<td>5</td>
</tr>
<tr>
<td>Potassium</td>
<td>120</td>
<td>195</td>
<td>390</td>
<td>397</td>
</tr>
<tr>
<td>Calcium</td>
<td>645</td>
<td>600</td>
<td>435</td>
<td>88</td>
</tr>
<tr>
<td>Magnesium</td>
<td>135</td>
<td>165</td>
<td>235</td>
<td>47</td>
</tr>
<tr>
<td>Sulfur</td>
<td>80</td>
<td>50</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: (Calcino et al, 2000)

The FPC mud has been used to supplement the chemical fertilizer. An integrated use of 10 t/ha sulphitation press mud (80 % moisture) with 75-100 kg N ha⁻¹ increased the N use efficiency by 4-8 % (Yaduvanshi and Yadav, 1991). In some other studies application of 30 t/ha FPC (80 % moisture) with 150 kg N t/ha increased the height, population and yield of mill-able cane by 32.3, 29.3 and 65.6 % respectively over control (Singh and Yadav, 1992). An economy of 50 to 75 kg N ha⁻¹ has been reported. It was also reported that application of FPC saves about half the P requirements of the crop.

The FPC with N fertilizer increased the response and uptake of applied N significantly (Yaduvanshi and Yadav, 1991). Over a range of N fertilization (0, 75, 100 Kg) with and without FPC (0, 10, 20, 30 t/ha) tried, addition of 150 kg N and 30 tons FPC ha⁻¹ separately increased the yield of cane by 38 % and 27 % respectively, whereas combined application enhanced yield by 65% over control. Addition of 75 kg N with 10 t FPC/ha yielded equal to that of 150 kg N t/ha alone and gave maximum cost benefit ratio.

**Enrichment of filter press cake (FPC)**

While the FPC is kept lying in heaps it looses nutrients and carbon compound. With rise in temperature in open environment it may catch fire and gradually burn to ashes. For its proper utilization it should either be enriched to make it a stable compound or it should be shifted to field a fresh as it is hauled out of the factory.

From the studies carried out at Sugarcane Breeding Institute, Coimbatore (India), it was observed that FPC contains fairly rich population of organisms like fungi, bacteria and actinomycetes (Naidu, 1992). These organisms enhanced the nutritive value of FPC with additives like cow dung and urea. Under natural environment, it took 45 days for proper
enrichment. It involves microbial degradation of FPC leading to complete mineralization to give a stable compound with enhanced N, P, K and organic carbon. Besides improving physical properties of soil, it also enhances the activities of antagonistic organisms in the soil; which in turn suppress the soil borne pathogens and nematodes. About 10 to 15 tons of enhanced FPC may be added per hectare. The press mud so enriched also is used as starter for subsequent enrichment of FPC.

Trend has now been developed, in different countries, to prepare bio-fertilizer by composting FPC with cow dung and cane harvest residues in various ratios. As quoted by Manohar Rao (1997), Cuban Institute of Research on Sugarcane Derivatives has developed a bio-fertilizer in a ratio of FPC (40 %), cow dung (35 %), cane harvest residue (22 %) and ash (3 %), adjusting the moisture to 60 %. A complete fertilizer “Hara Bhara” is manufactured in Riga Sugar Company in India. This fertilizer contains N P K in the ratio of 18:18:16, where in air dried press mud to the extent of 12-15% is coated on a mixture of urea, DAP and MOP with small quantity of spray water to give it a granular shape (Manohar Rao, 1997).

An EM (Effective microorganism) solution is reported to accelerate the composting process in FPC (Hussain et al, 1998). The EM solution is claimed to contain some photosynthetic and lactic acid bacteria, yeast, actinomycetes and fermenting fungi, which accelerates the fermentation and decomposition process of FPC.

Composting of distillery effluent with press mud has so far given the best results in enhancing the nutritive value of the compound. The press mud is treated with distillery effluent in open area and it almost takes 30 days for stabilization of composting process. At Shakargang Sugar Research Institute, Jhang (Pakistan), Bio-compost was developed in an open tank containing slurry of FPC and stillage water. Using stillage water @ 25 % of the volume of FPC, and the mixture was composted under anaerobic condition under the stillage suspension in open large earth dug tanks. The experimental studies have shown that nutritional value of Bio-compost is far greater than the nutrient value of FPC and farmyard manure (Table-8.31).

| Table-8.31 Comparative nutritional value of Bio-compost, Filter Press Cake and Farm Yard Manure |
|-----------------------------------------------|---------|----------|----------|
| pH                                           | 5.90    | 6.21     | 6.25     |
| N %                                          | 1.61    | 1.55     | 0.68     |
| P %                                          | 1.45    | 1.21     | 0.35     |
| K %                                          | 3.7     | 0.85     | 0.55     |
| Cu (ppm)                                     | 140     | 55.4     | 21.5     |
| Zn (ppm)                                     | 950     | 800      | 155      |
| Mn (ppm)                                     | 400     | 300      | 900      |
| Fe (pp)                                      | 4980    | 4050     | 422      |
| Organic matter %                             | 70      | 74.25    | 76       |

Afghan and Qureshi (1994)
The bio-compost (20 t/ha) applied alone and with fertilizer (100 kg N ha\(^{-1}\)) gave a significant increase in yield of cane (Table-32). The bio-compost increased the fertilizer use efficiency of NPK thus saving in the use of costly fertilizer through complimentary effect.

Table-8.32 Effect of bio-compost on nutritional status of soil and cane yield

<table>
<thead>
<tr>
<th>Fertilizer kg acre(^{-1})</th>
<th>Bio-Compost t ha(^{-1})</th>
<th>Soil analysis pH N P K O.M</th>
<th>Cane yield t ha(^{-1})</th>
<th>% Yield increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0 0</td>
<td>0</td>
<td>8.10 0.03 5.5 115 0.6</td>
<td>58.50</td>
<td>-</td>
</tr>
<tr>
<td>100 0 0</td>
<td>0</td>
<td>8.15 0.029 5.3 118 0.58</td>
<td>112.8 92.82</td>
<td></td>
</tr>
<tr>
<td>0 0 20</td>
<td>20</td>
<td>7.80 0.34 6.3 135 0.68</td>
<td>131.0 123.93</td>
<td></td>
</tr>
<tr>
<td>100 0 20</td>
<td>20</td>
<td>7.90 0.033 6.1 132 0.67</td>
<td>147.7 152.48</td>
<td></td>
</tr>
</tbody>
</table>

Afghan and Qureshi, 1994.

The composting of filter cake with stillage improved the physical soil structure, nutritional status of soil and enhanced the yield of cane (Afghan and Qureshi, 1994). The data in Table-8.33 indicate that the N, P, K and the organic matter content of the soil treated with bio-compost were considerably increased. The bio-compost @ 25 and 50 t/ha incorporated in soil with and without fertilizer, increased yield by 15.64 % and 26.70 % over no bio-compost respectively, (Nasir and Querishi 1999). The bio-compost showed a residual effect on ratoon crop, whereas the ratoon crop treated with the bio-compost in the preceding year (plant crop) showed a 32 %, increase in yield.

Volume of filter press cake available in a factory

A sugar factory with 10,000 TCD has the potential to crush as much as 1.5 million tonnes cane per crushing season. On the mean FPC production rate of 3.5%, almost 52,500 tonnes FPC can be made available each year. Considering the usual recommended rate of 25-30 tonnes FPC per hectare, more or less 2000 hectares can be enriched with this organic manure each year. However, problems being faced with their application in the field are the quantities needed, moisture content, transport distance and lack of proper arrangement for transport to grower's fields. The volume of FPC can however, be reduced when enriched through composting into bio-fertilizer. The value of the mud can be worked out by the quantity of nutrients contained in the mud. Based on the season composition of FPC with 70 % moisture and N P K contents of 1.55 %, 1.21% and 0.85 % respectively, one ton of FPC would contain 4.65 kg N, 3.63 kg P\(_2\)O\(_5\) and 2.55 kg K\(_2\)O. On the other hand one ton of bio-compost contains 4.83 kg N, 4.35 kg P\(_2\)O\(_5\) and 11.10 kg K\(_2\)O.

FPC as ameliorant for problem soils

The FPC contains large amounts of Ca (carbonation process) and S (sulphitation process) and may serve as an ameliorant for acidic and saline-sodic soils. Carbonation process FPC contains 60-70 % CaCO\(_3\) thus increase soil pH and exchangeable Ca and Mg and is effectively used for amendments of acidic soils. This type of mud is considered as effective as lime stone in increasing cane yields in acid soils (Yadav, 2003).
Table-8.33 Effect of bio-compost and NPK fertilizer on the yield of plant and ratoon crop and nutrient status of soil.

<table>
<thead>
<tr>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Bio-compost t ha⁻¹</th>
<th>Cane yield t ha⁻¹</th>
<th>% yield increase over T₂</th>
<th>Soil analysis</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pH</td>
<td>Total N %</td>
</tr>
<tr>
<td>kg/ha</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7.56</td>
<td>0.03</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>112.10</td>
<td>-</td>
<td>7.60</td>
<td>0.034</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>50</td>
<td>0</td>
<td>115.70</td>
<td>-</td>
<td>7.65</td>
<td>0.035</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>127.40</td>
<td>10.11</td>
<td>7.50</td>
<td>0.038</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>50</td>
<td>25</td>
<td>133.80</td>
<td>15.64</td>
<td>7.54</td>
<td>0.04</td>
</tr>
<tr>
<td>100</td>
<td>100</td>
<td>50</td>
<td>50</td>
<td>146.60</td>
<td>26.70</td>
<td>7.50</td>
<td>0.042</td>
</tr>
</tbody>
</table>

Ratoon crop

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>7.80</th>
<th>0.034</th>
<th>4.0</th>
<th>115</th>
<th>0.68</th>
<th>&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>150</td>
<td>0</td>
<td>0</td>
<td>78.56</td>
<td>-</td>
<td>7.80</td>
<td>0.034</td>
<td>4.0</td>
<td>115</td>
<td>0.68</td>
<td>&quot;</td>
</tr>
<tr>
<td>150</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>70.15</td>
<td>-</td>
<td>7.85</td>
<td>0.032</td>
<td>3.0</td>
<td>116</td>
<td>0.65</td>
<td>&quot;</td>
</tr>
<tr>
<td>150</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>90.28</td>
<td>28.70</td>
<td>7.55</td>
<td>0.033</td>
<td>5.0</td>
<td>145</td>
<td>0.67</td>
<td>&quot;</td>
</tr>
<tr>
<td>150</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>91.26</td>
<td>32.70</td>
<td>7.56</td>
<td>0.033</td>
<td>5.1</td>
<td>147</td>
<td>0.67</td>
<td>&quot;</td>
</tr>
<tr>
<td>150</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>93.45</td>
<td>33.21</td>
<td>7.52</td>
<td>0.035</td>
<td>5.5</td>
<td>150</td>
<td>0.70</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

Source: Nasir and Qureshi, 1999
The filter press cake obtained from sulphitation process is a good source of P and S and can reclaim saline soils. The application of sulphitation press cake up to 30 t ha\(^{-1}\) in alkaline soil reduced soil pH and enhanced nutrient uptake (Yaduvanshi and Yadav, 1990; Nasir and Qureshi, 1999).

The stillage application if properly managed can be effectively used for soil reclamation and cane yield improvement. The stillage (988 t ha\(^{-1}\)) with 9.88 and 4.98 t ha\(^{-1}\) of gypsum applied to fallow sodic soil, 4 months before cane planting, reclaimed the soil by lowering the soil pH from 9.12 to 8.2. The combination of stillage water with gypsum reduced 50 % gypsum requirements of soil and increased cane yield due to soil reclamation. In another study, concentrated stillage was diluted in fresh water in a ratio of 1: 20 and applied to field with standing crop of cane. The treatment lowered the soil pH from 8.10 to 7.10 and increased the organic matter (0.3 to 0.9 %), P (3 to 12 ppm), K (105 to 350 ppm) and N (0.01 to 0.04%). The treatment increased the cane yield from 32 to 42 % over N: P: K fertilizer level of 170: 100: 50 Kg ha\(^{-1}\) (Nasir and Qureshi, 1999). It is postulated that half of the S requirement to reclaim saline soils is met through S contained in the FPC and the rest is compensated through the beneficial effect of organic matter and the actions of organic acids synthesized during decomposition of FPC (Yadav, 2003).

The practice of incorporating organic matter in the form of legume crops, crop residues and farm yard manure or filter press cake can help in increasing organic status of soil; however, the organic matter can't be increased substantially on permanent basis. In conditions where temperatures are high, field undergoes excessive cultivation followed by intensive cropping, rate of organic matter break down is high and it is difficult to maintain its level. Such conditions demand application of organic manure/compost in soil after each crop cycle.

**Time of application**

It may be noted with concern that FPC if kept in heaps is gradually dried and get fumes and is burnt with rise in temperature. Therefore fresh mud should be transported to cane fields. As it is hauled out of a factory mud when fresh is sticky and is cumbersome to spread in the field due to excessive moisture. After about a week time it can be uniformly spread without any nutrient loss. However, when fresh mud is applied in the field, nutrients are not readily available. It takes some times for its decomposition and mineralization in soil. The FPC should be uniformly spread and plough mixed for thorough incorporation in soil. For proper and rapid decomposition, the field should be irrigated followed by usual cultivation operations.

Well decomposed FPC is preferred over a fresh mud; however, fresh mud may be used without any adverse effect on crop. In ratton crop band application in inter-row spaces is considered five times more effective than broadcast (Yadav, 2003). To be on the safe side suitable pesticide may be used as a guard against termites. Nevertheless, some workers recommend prior decomposition of FPC due to its wax contents (8-15 %). According to Hunsigi (1993), curing of FPC for 4-6 weeks is necessary before its application to soil.
**Biological N Fixation**

There exist tremendous amount of nitrogen in atmosphere as nitrogen gas (79 %). The fertilizer manufacturing factories trap this 'N' source to produce ammonium sulphate and urea. But this source of nitrogen can also be trapped by certain bacteria associated with roots of plants and the process is termed as biological N fixation. Some bacteria are associated with root nodules of leguminous crops, called rhizobium and are already mentioned in green manuring section. There are some other microorganisms which are associated with roots and rhizosphere of non-leguminous crops like sugarcane and have been termed as bio-fertilizer.

Bio-fertilizers are the micro-organisms that improve soil and plant health by additions and conservation of biological nutrients in soil. The bio-fertilizers so far developed belong to bacteria and blue green algae group. Different types of microorganisms have been isolated; most commonly met are:

- Rhizobacteria like Azotobacter and Azospirillum not only fix N2 but produce substances of growth promoting properties of auxins and gibberellins and fungicidal properties (Marwaha, 1995, Jones 1998, Mahesh Kumar et al, 1999).
- Acetobacter diazotrophicus releases organic acids in-vitro which reduces soil pH 1.0 to 1.5 unit and besides N2 fixation solubilize 'P' (Mahesh Kumar et al, 1999).
- Glnconectobacter dizeotrophicus were obtained from leaf sheath, nodes, internodes, roots and trash of sugarcane. These were found in fields that had not received any 'N' application for several years (Moutia et al, 2005).
- Herbaspirillum rubrisubalbican is 'N' fixing bacteria but is also the causal agent of mottled stripe disease of sugarcane and is widely present in cane fields of Mauritius (Moutia et al, 2005).
- Besides N fixing bacteria, there are some bacteria and fungi which change the soil available 'P' from insoluble to soluble form, and are called 'P' solubilizer.
- The bacteria are the Bacillus megatherim and pseudomonas while the fungi belong to Aspergillus and penecillum.
- Acetobacter diazotrophicus also solubilize 'P' in soil.

The symbiotic 'N' fixation takes place through bacteria Azotobacter or Acetabacter directly associated with sugarcane roots. The symbiotic 'N' may be added to the order of 50-60 Kg N ha⁻¹ (Ray Chaudhary 1988). Azotobacter culture is quite effective in fixing N into the soil and increasing germination, tillering, growth and yield of cane crop (Kanwar, 1991). Biological N fixation through bacteria like Azotobacter, Azospirillum and bacillus economizes N in sugarcane to the extent of 50 % (Singh and Yadav, 1995).

Nitrogen use efficiency is around 33 % and the rest of the 'N' is lost through leaching as nitrate or by volatilization as N₂O / NO₂. Generally the nitrification losses are not of economic significance, major losses of N are in liquid form as nitrate. These losses were greatly reduced by soil application of N₂ fixers "Azotobacter chroococcum, Azospirillum brazilense and Acetobacter diazotrophicus" @ 2.5 kg ha⁻¹ (Hunsigi and Shankariah,
Application of associative N2 fixers can help reduce the fertilizer rate by 20 percent.

It has further been reported that different isolates of bacteria have different capacity for N fixations and cane varieties have different response to different culture and these have to be categorized before applying the technique (Moutia et al, 2005). Once the varieties are standardized, the isolates can be collected from Rhizospheres of varieties to prepare bacterial culture. Different application techniques have been used that include soil application of 2 kg Azospirillium culture, soaking setts in Azospirillium and smearing of Azotobacter culture to single eye bud setts at planting. One of the isolates of Gluconacetobacter diazotrophicus, 'I S 100 ' was found to be the most efficient in promoting plant growth and nutrient uptake in sugarcane (Archna et al, 2005).

Mismanagement in the use of irrigation water and fertilizer may decline the yield or the practice may not be cost effective. The recent approach is to focus attention on the use of bio-fertilizers. Soil application of Azotobacter – Azospirillium @ 2.5 kg /ha improved growth and yield of plant and ratoon cane. Growth and yield was not affected by sett inoculation of these bio-agents (Shankariah and Hunsigi, 2001). Data also indicate a saving of 25 % N (50 kg ha^{-1}) and 25 % P (25 kg P_{2}O_{5} ha^{-1}) due to soil application of N2 fixer and P solubilizing micro-organisms.

The studies carried out in Brazil as well, indicate that 20 to 25 % of plant nitrogen can be derived from associative fixation of some micro-organism. The nitrogen fixer reported in Brazil has been identified as Herbespirimill sp. and Acetobacter diazotrophicus. However cane varieties are reported to be specific to the fixation of biological nitrogen.

The diazotrophic can not survive in the soil and is considered to be endophytic. It is unable to infect sugarcane plant directly and can be inoculated through VAM spore; the inoculation with these bacteria along with VAM spores showed excellent results in minimizing the fertilizer 'N' application.

Phosphorus is a difficult nutrient to manage because of its fixation and extremely low mobility in the soil. As generally about 10-15 % of P applied through fertilizer is made available to the plant and the remaining is fixed in soil reserves in un-available form (Humbert, 1968).

This is made possible by the acidic nature of bacteria. Since our soils have mostly alkaline reaction, these bacteria change the micro-climate of soil to acidic nature thus bringing the soil P in soluble form for uptake by plant roots. These bacteria are called bacillus and pseudomonas. The funji are called Aspergillus and Pencilium.

The phosphorus solubilizing bacteria (PSB) – Bacillus megatherium Var. Phosphaticum applied @ 10 kg/ha of lignin base culture increased the PSB population in the rhizosphere and the plant available P status in the soil. The culture enhanced tillering, stalk population and stalks weight and leads to a cane yield increase of 13 % over no application. When used in conjunction with P fertilizer, the PSB reduced P dosage by 25 % (Sundara et al, 2001). The influence of PSB was striking when used in conjunction with rock phosphate; 50 % of super-phosphate could be replaced by rock phosphate (Sundara-2001).
Chapter-9

Inter-Cropping

The increasing needs for food and fibre for growing population is getting a serious burden on limited land and irrigation resources. Further, that enhanced energy and labour cost is increasing the production cost of farm products. The production of farm produce at economic cost demand multiple use of available land, labour and capital resources. Now the key to increasing food production is to improve the productivity by multiple cropping systems. Multiple cropping is a philosophy of maximum crop production per unit area of land in a time span. Nevertheless, multiple cropping is governed by multiple factors:

1. Estimated potential for crop intensification
2. Farm resources: land, labour, cash, power and equipment
3. Socio-economic conditions: product prices, input and marketing costs
4. Customs reflecting performance for certain food and management practices.

In Pakistan, for example, sugarcane now faces challenges of competing crops in open market. Various economic forces may divert cane area to certain other competing crops like cotton, rice, maize, and sunflower in spring and mustard and wheat in autumn season. Pakistan Agriculture has faced such situation time and again, when cotton gained importance due to more dividends from cotton produce. Cane area is diverted to cotton crop resulting into short supply of cane to sugar industry. In some years of low cane prices banana replaces considerable area of cane in Sindh. Since the sugar industry has widely expanded, it can not face the reduction in cane acreage under unfavorable price war. The most feasible situations could be, not to abandon the cultivation of cane at the cost of other crops. The solution to the problems lies either in stabilizing cane production through improved yields or improving cash flow per unit area by adoption of multiple cropping systems. For economic viability of sugar industry, cane production must be stabilized on economic prices with improved cash returns per unit area for growers. Some sugarcane based inter-cropping system offers prospects of good cash return.

Sugarcane is a long duration crop. It occupies land for more or Less 10-12 months in case of spring and ratoon crop and 15 to 18 months in case of autumn planted crop. The initial growth of cane plant is very slow during germination and tillering phase. During spring season it takes three months and for autumn crop it takes 5 months before the crop canopy covers the field effectively. As such a short duration crop can be accommodated in inter row spaces as inter cropping, mixed cropping and companion cropping or relay cropping.

Generally, the growers have to wait for return of their investments on cane for a pretty long period, as they receive cane payment much after the supplies of cane to sugar mills. Thus for the capital flow in the interim period, farmers may take full advantage of slow growth period in initial stages of cane growth by growing an additional crop in the inter row spaces.
In Pakistan, sugarcane based inter cropping is not a common practice. Nevertheless small growers having subsistence farming do adopt the system to meet their family needs for fodder and cash. Under advanced farming practices, multiple and relay cropping has also been adopted in some regions. The cropping systems applied or applicable under Pakistan conditions are discussed. Studies conducted on different inter cropping systems during cane planting seasons of autumn and spring are discussed in the following sections.

**Autumn Season Crops**

It has been established that autumn planted cane gives 20-30 percent higher yields over spring planting. Autumn cane, due to longer growing season, has special advantage of increased sugar recovery over spring cane. The adoption of autumn planting is optional to different climatic regions and growers own socio-economic conditions. Growers have their own parameters of economics and customs reflecting preference for certain crop management practices. In lower Sindh, due to mild winter, cane is mainly grown as an autumn crop, while in upper Sindh and Punjab winter is chilly, growers having small holdings follow intensive cropping, autumn cane hardly covers 5 to 10 percent area.

Growers are generally reluctant to plant cane in September due to its long growing season and that the cane is to be planted at the cost of some other field crops. On the other hand, long growing season provides the opportunity of higher cane yield grown as mono crop and to take an additional crop when grown as intercrop. Sugarcane takes about 30 to 45 days to complete its germination. The initial growth is slow and due to winter season plant development is checked. Cane crop regains profuse tillering and growth after February. Thus it takes further 100-120 days to develop full canopy to cover inter-row spaces. So long as cane canopy covers the ground some winter crops can be grown in inter row spaces. Practically an intercrop can avail of 4-6 months period in September – October planted cane. Thus it is a system of availing time and space for increased productivity.

**Wheat**

There are a number of options in adopting cane + wheat intercropping system.

a. Planting cane in September and growing wheat in inter-row spaces after cane germination.

b. Planting cane in October – November and growing wheat in inter-row spaces, soon after cane planting, when soil comes in proper moisture stage.

c. Planting cane in October – November and growing wheat as broadcast, soon after cane planting as the soil comes in proper moisture stage.

d. Planting wheat in October – November and relay cropping of cane in inter-row spaces during December – February period.

e. Planting wheat in October – November, followed by cane after wheat harvest in April as a sequential planting.
In various studies carried out in cane + wheat inter cropping systems; wheat had depressing effect on the yield of cane. Compared to 133.97 tonnes cane obtained from sole cane crop, cane + wheat combination gave 118.04 + 3.385 tonnes produce per hectare, respectively, showing cane yield reduction of 11.9 % (Bukhtiar and Muhammad, 1988). However, additional crop of wheat compensated the cane yield losses giving the EMV of 1.08 (Table-9.01). The yield reduction in cane was due to shading effect of wheat that reduced tillering and mill-able canes (Bukhtiar, 1988 and Fasihi, 1970). However, besides significant reduction in yield of cane, there were no significant differences in gross income from cane alone and cane with wheat inter cropping system (Rehman et al, 2000). Cane + wheat inter cropping was economically much better than the cane planted after wheat harvest (Bukhtiar and Muhammad, 1988). The former combination gave an EMV of 1.08 against 0.77 observed in later case.

**Table-9.01 Economics of intercropping September cane + wheat and cane alone planted in March**

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Yield t ha⁻¹</th>
<th>% Variation in cane yield</th>
<th>Cost benefit ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90cm in Sep.</td>
<td>133.97</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cane in Sept. + wheat in Nov.</td>
<td>118.04</td>
<td>3.385</td>
<td>-11.89</td>
</tr>
<tr>
<td>Cane alone in March</td>
<td>106.48</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Cane after wheat harvest</td>
<td>72.49</td>
<td>3.954</td>
<td>-31.92</td>
</tr>
</tbody>
</table>

* Bukhtiar & Muhammad (1988); EMV; estimated monitory value

In various intercrop options, planting time, row space and the growing time availed by each crop are of great significance for economic yields. And so are important planting methods and the varieties of cane and wheat.

Planting time should be given prime consideration to reduce the competition during initial growth. September is the ideal time for cane planting, as the crop completes its germination and initiates tillering before the wheat grows and covers the inter rows space. Studies conducted at Faisalabad indicate that September planting gave the highest yield of cane in association with November wheat. With delay in cane planting till October and November, due to advances in low temperature, cane germination is delayed, while the wheat grows at faster rates and gradually shadows young cane shoots. Tillering and growth of cane is depressed and cane crop picks growth after wheat harvest. As such cane yield is markedly reduced. (Table-9.02).

In some areas wheat is planted in October / November, while cane is planted after germinations of wheat, in December, in furrows already left open, while planting wheat. In this practice the philosophy is to save seed cane from expected frost. Seed cane remains in dormant phase during December and January and buds sprout within wheat rows with rise in temperature in February - March. Germination of cane is low and tillering is suppressed. After wheat harvest cane receives light and space to resume growth and tillering. Lack of light and unsuitable inter-row space hamper the growth and tillering phase of cane and yields are adversely affected.
Inter row spaces and plant density have an important role on the yields of either of the inter-crops. Two rows of wheat in cane row space of 90 cm reduced yield of cane by 22.32 % while wheat stand of three rows dropped cane yield to the extent of 47.12 % (Fasihi and Malik, 1985). The two rows of wheat in cane gave an EMV of 1.05, while three rows of wheat had much depressing effect on yield of cane that dropped the EMV to 0.79 (Table-9.03). It could further be noticed that by increasing the cane row distance from 90 to 120 cm, three rows of wheat could be adjusted without much reduction in EMV.

In another set of experiment cane row space of 3’ was compared with dual row planting of cane 2’ with 4’ inter-row space (2’-4’-2’). The dual row planting gave 33.24 % higher yield of cane with EMV of 1.26.

As relay cropping cane planted in standing wheat in mid February gave significantly higher yield of cane than planted during mid January (Khaliq, 1988).

It indicates that for efficient use of input resources and to avoid excessive competition to light / shade, plant population and inter rows space for inter crop and sole crop have to be judicially adjusted.
Cane and wheat varieties play important role in adjusting light and space. A quick germinating fast growing cane variety with erect stand is desirable. In case of wheat short duration and dwarf variety would exert lesser competition with cane and would cause minimum adverse effect due to lesser shading effect on cane. Data in Table-4 support the view as Mexi-Pak wheat variety which was relatively tall growing had depressing effect on cane yield than Pari-73, a dwarf variety (Table-9.04). Similarly erect growing (SPSG 26, Th. 10) cane variety would have lesser competition with wheat than a variety with spreading habit like BL 4.

Table-9.04 Cane yield affected by intercropping tall and dwarf growing varieties of wheat*.

<table>
<thead>
<tr>
<th>Inter-crop combination</th>
<th>Yield t ha⁻¹</th>
<th>% Variation in cane yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane at 90 cm in Sep. + wheat Mexi Pak.</td>
<td>95.59</td>
<td>4.00</td>
</tr>
</tbody>
</table>

* Fashi & Malik (1985)

Primitive methods of planting cane in standing wheat suppress growth and yields of cane to a great extent. Similarly sowing wheat by broadcast has adverse effect on cane sprouting and growth and later cause problem in wheat harvest. Appropriate row distance warrantee substantial crop stand and yields.

For planting wheat ‘Wattar’ planting should be followed. Cane field should be irrigated and as the field comes in proper moisture condition” inter row space should be cultivated with bullock driven Tarphali or tractor drawn cultivator. One or at the most two such cultivations given one after the other may be enough for seed bed. The ‘N’ and ‘P’ needs of wheat crop should be met by incorporating fertilizer along with cultivation operation. The wheat seed should be drilled in two rows within 90cm space or three rows within 120 cm or 60-120-60 cm spaces. Drill has to be modified to inter row planting in wheat. The second ‘N’ application has to be given at boom stage of wheat crop. Soon after wheat
harvest, cane crop has to be given thorough inter rows cultivation followed by fertilizer application, that tillering and growth of cane is expedited.

For raising successful crop of wheat and cane, weeds have to be kept in check. The cane crop should be treated with suitable pre-emergence herbicide. It would control weeds in cane field and within cane rows as well. After germination of wheat, herbicide appropriate to wheat crop should be manually sprayed on wheat after first irrigation to wheat crop.

From the information available on the cane + wheat inter cropping systems; wheat crop depresses the yield of cane to the range of 10 to 27 % depending on environments and inputs made available to both the crops. However additional crop of wheat economically compensates the cane yield losses. On the other hand yield of wheat is not much affected while planted in inter-row spaces of cane with suitable technique. As such wheat area can be economically brought under September cane without much loss of wheat production. On the other hand if cane is planted in a wheat field as intercrop in December or after wheat harvest or wheat is broadcasted in October-November planted cane, wheat - cane sequence has a deleterious effect on the yield of cane.

### Lentil

Lentil crop give reasonably good profit margin as inter crop without affecting the productivity of cane. It has least competition for light and nutrients and has no shadings effect on cane. It was further observed that lentil also helped in cane yield improvement due to symbiotic fixation of ‘N’. An EMV of 1.33 and 1.20 was obtained from cane + lentil inter-cropping (Table-9.05).

Lentil is planted in the 3rd or fourth week of November in well-established crop of September planted cane. The soil within 90cm or 120 cm inter row space should be well pulverized and two rows of lentil should be drilled with 15-20 cm inter row space. In case the cane is planted in trenches lentil be drilled on both sides of trenches.

#### Table-9.05 Intercropping cane + lentil

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t ha⁻¹</th>
<th>% variation in cane yield</th>
<th>EMV</th>
<th>Source Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90 cm</td>
<td>145.55</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cane at 90 cm + lentil (3rows)</td>
<td>152.41</td>
<td>1.332</td>
<td>+4.71</td>
<td>1.33</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>114.72</td>
<td>-</td>
<td>-</td>
<td>Gill et al. (1994)</td>
</tr>
<tr>
<td>Cane at 90 cm + lentil</td>
<td>115.29</td>
<td>0.637</td>
<td>+0.52</td>
<td>1.20</td>
</tr>
</tbody>
</table>

Weeds cause serious competition with lentil if not properly controlled. Weeds in cane are controlled by pre emergence herbicide. For lentil as well herbicide should again be applied as pre-emergence? Selective herbicides are available for effective control of weeds. Gesapax combi for sugarcane and “Topo guard” for lentil have shown good results.
Inter-Cropping

Vegetables

Potato

Among various inter cropping systems cane + potato combination is the most profitable, provided planting time, fertilizer needs, weed control and earthing up operations to potato crop are properly taken care of. Considerable work has been done on this inter cropping system.

September planted Potato on ridges followed by cane in furrows was compared with potato alone in September followed by cane in March. The highest yield of cane was obtained from September cane at 90 cm (101.16 t ha \(^{-1}\)) with potato (10.45 t ha \(^{-1}\)), closely followed by cane at 120 cm with potato (Malik and Kamoka, 1992). Cane + potato inter cropping gave 14.93 % increase in yield of cane due to excessive inter culture operations given to potato crop, which in turn accelerated the biological activities in soil for enhanced cane yield. Intercropping potato depressed the yield of cane by 14.9% but the gross income from cane + potato was 28.57% higher than the sole crop of sugarcane (Muhammad et al, 2000). Wider row planting gave low yields due to low Plant population of either of the crops. Sole crop of October potato followed by March cane gave yields of 13.65 and 77.04 t ha \(^{-1}\), respectively. The September cane + potato gave EMV of 2.03 compared to 1.79 recorded for sole crops sequence of October Potato + March cane, thus the former combination was more profitable (Table 9.06).

In a number of inter crop studies autumn cane + potato gave the highest net profit per hectare (Singh et al, 1986; Yadev, 1985; Kanwar, 1982; Verma and Bhoj, 1980). The highest net return was reported from autumn cane + potato, followed by spring cane planted after autumn potato, and that potato had no adverse competitive effect (Kanwar et al, 1975; Rathi et al, 1974; Singh et al, 1986). In fact inter cropping is adjustment of time and space with input resources. Simple negligence or oversight of operation can revert, the results. Planting time has pronounced effect on the yield of cane.

**Table 9.06 Effect of different inter-row spaces on the productivity of cane and potato intercropping**

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yields t ha(^{-1})</th>
<th>% variation in cane yield</th>
<th>EMV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone in Sep. at 90 cm</td>
<td>88.02</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cane at 90 cm + potato</td>
<td>101.16</td>
<td>10.45</td>
<td>14.93</td>
</tr>
<tr>
<td>Can at 120 cm + potato</td>
<td>87.74</td>
<td>7.65</td>
<td>-1.00</td>
</tr>
<tr>
<td>Cane at 60-120-60 cm + potato</td>
<td>92.24</td>
<td>6.08</td>
<td>4.99</td>
</tr>
<tr>
<td>Potato alone in Sep. at 75 cm + cane alone in March at 90 cm</td>
<td>77.04</td>
<td>13.65</td>
<td>-12.47</td>
</tr>
</tbody>
</table>

Malik and Kamoka (1992)

The commercial Potato growers in Pakistan have adopted this inter cropping technique. Potato is mechanically planted at 75 cm rows spaces through tractor operation and cane setts are placed in furrows through manual labour.
The N: P: K dose of 150: 100: 100 and 250: 180: 180 is recommended for cane and Potato intercropping, respectively. All the P and K and half of N for Potato should be broadcasted before furrow making and the remaining N to be applied at the time of side dressing during earthing up. As to sugarcane all the P and K should be applied in furrows before seed placement and the N share of cane should be applied after Potato harvest, in two split doses.

Herbicides offer satisfactory control of weeds both to cane and potato crop. Sencor has given good results for this inter-cropping system. Due care should be given to keep the potato crop free of pathogens. To have good yields earthing up is mandatory for inter crop.

Garlic

Cane + garlic are the most profitable inter cropping combination. Garlic has not much competition with cane for light and shade. A companion crop of cane and garlic gave 111.47 t ha⁻¹ cane and 4.18 tonnes garlic that shows a cane yield decline of only 5.3 % over sole crop of cane. This combination reflected an E M V of 1.93 (Bukhtiar and Muhammad, 1988). Similar observations were reported by Ali et al, 1987 and Ahmed, et al, 1991 (Table-9.07).

In these studies 90 cm was the optimum inter-row space for cane with two rows of garlic. Dual rows of cane at 45 and 30 cm with 135 and 150 cm inter-row strips for five or six rows of garlic slightly reduced cane population hence the yield. Nevertheless, all the combinations were remunerative with higher EMV ratios.

Cane should be planted in September, while garlic to be sown at its optimum time in inter-row spaces in the first week of November.

Table-9.07 Yield and monetary benefits from various intercropping options of cane + garlic.

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yields t ha⁻¹</th>
<th>% variation in cane yield</th>
<th>EMV</th>
<th>Source Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90cm</td>
<td>117.7</td>
<td>-</td>
<td>-</td>
<td>Bashir and Muhammad (1983)</td>
</tr>
<tr>
<td>Cane at 90 cm + garlic 2 rows.</td>
<td>111.5</td>
<td>4.18</td>
<td>-5.29</td>
<td>1.93</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>168.0</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>Cane at 45-135-45 + garlic 5 rows</td>
<td>165.0</td>
<td>16.00</td>
<td>-1.78</td>
<td>1.85</td>
</tr>
<tr>
<td>Cane at 30-150-30 + garlic 6 rows</td>
<td>152.0</td>
<td>10.00</td>
<td>-9.52</td>
<td>1.44</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>119.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cane alone at 90 cm + garlic 3 rows</td>
<td>113.4</td>
<td>6.48</td>
<td>-5.06</td>
<td>1.15</td>
</tr>
</tbody>
</table>

Inter rows spaces of cane should be well pulverized with a cultivator. Fertilizer @ 75 kg each of N, P and K ha⁻¹ should be incorporated in inter row spaces during soil
Inter-Cropping

pulverization. Garlic is to be sown in between cane rows at 90 cm. Three rows of garlic are maintained at 15 cm distance with plant to plant distance of 10 cm. For 120 cm cane row spaces, garlic could be planted in four rows. Selective herbicides are available for effective control of weeds.

Radish, Carrot, Turnip

These crops have short growing period and are harvested in winter much before the active growth of cane. Inter cropping of these root crops gave substantial yield of their produce without markedly affecting the yield of sugarcane. Estimated monetary values (EMV) of 2 to 3 have been reported from inter cropping radish, carrot and turnip (Table-9.08).

Root crops should be planted on sides of trenches, while cane is planted in furrows. Plants should be properly thinned out at 3-4 leaf stage of growth. Good yields are expected in heavy soils. Intercropping gave EMV around 2-3. Fertilizer requirements of each crop are to be met both as basal dressing and at boom vegetative growth period.

Table-9.08 Economics of inter-cropping radish, carrot and turnip in cane

<table>
<thead>
<tr>
<th>Inter cropping combination</th>
<th>Yield t ha⁻¹</th>
<th>% variation in cane yield</th>
<th>EMV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90 cm</td>
<td>84.66</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>Cane at 90 cm + radish</td>
<td>79.87</td>
<td>41.73</td>
<td>3.02</td>
</tr>
<tr>
<td>Cane at 90 cm + carrot</td>
<td>80.86</td>
<td>25.12</td>
<td>3.07</td>
</tr>
<tr>
<td>Cane at 90 cm + turnip</td>
<td>80.46</td>
<td>20.13</td>
<td>2.03</td>
</tr>
</tbody>
</table>

Source: Nayyar et al (1987)

Onion

This inter cropping system is very remunerative, without much deleterious effect on cane yield. Intercropping onion in cane at 90 cm row space gave an EMV of 1.22, (Ahmed et al, 1988). Strip planting at 30'-150'-30' reduced yield of cane by 13 %, and gave EMV of 1.04 (Table-9.09). The onion has two crop seasons, autumn and spring. Onion can be inter-cropped on ridges or on flat in between cane row. During autumn, seedling nursery is prepared in June and the seedlings are transplanted on sides of ridges in August-September. When seedlings get established field is irrigated and when yet muddy wet cane sets are placed in furrows with the foot pressure. For spring crop onion seed is sown in November – December and the seedlings are ready for transplanting during January-February; onion bulbs mature during May. In flat planting cane is planted in the 1st week of February and three rows of onion transplanted in between cane rows.

The autumn crop has not depressing effect on the yield of cane as the onion crop is harvested in December-January. The spring crop may affect cane growth if planted on poor soil. If onion is to be harvested and picked green, bulbs give good cash return, without affecting the yield of cane. The onion Variety “Phulkara” has shown good results. Nevertheless, bulbs can also be harvested on maturity without much reduction of cane yield.
Table-9.09 Economics of intercropping onion in cane at various row spaces*

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t ha⁻¹</th>
<th>% Variation in cane yield</th>
<th>EMV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90 cm</td>
<td>107</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>Cane at 90 cm + onion 3 rows</td>
<td>107</td>
<td>6.15</td>
<td>0.00</td>
</tr>
<tr>
<td>Cane at 30-150-30 + onion 6 rows</td>
<td>93</td>
<td>4.67</td>
<td>-13.08</td>
</tr>
<tr>
<td>Cane at 45-135-45 + onion 4 rows</td>
<td>94</td>
<td>2.35</td>
<td>-13.00</td>
</tr>
</tbody>
</table>


Cabbage

The seedlings have to be transplanted in September along sides of trenches, while cane is planted in furrows. All the species of cabbage give good yields; nevertheless knolkohl proves lesser competitor to cane than cauliflower. Manual weeding is however necessary to keep the crop free of weeds.

Miscellaneous Vegetables

Other vegetables including coriander / lettuce give very profitable return when planted as companion crops. Carrot roots can also be dibbled on sides or tops of trenches during December, wherein cane already been established in furrows. However plant population of carrot roots should be thin to minimize shading effect on cane. The funnel crop can be successfully raised in similar fashion.

Oilseed Crops

Oil seed crops have important role in cropping pattern due to its economics in production of vegetable oils. But due to better market prices of other food and fiber crops, oilseeds has not become a preferred commodity, as such area under these crops remains unstable. Inter cropping oil seeds crops in between cane row spaces offer a number of options to stabilize oil production without utilizing extra land for their cultivation.
Raya

In conventional farming system cane + mustard is a generalized practice in autumn crop season. Growers just broadcast the seed in cane fields and get mixed cropping. A reasonable yield of oilseed is obtained, but the inter crop intercepts light and space as such tillering and growth of the main crop is adversely effected. There is experimental evidence to show that cane + mustard inter crop may prove profitable if it is grown as a row crop with suitable inter space.

Fodder and seed crop of raya was inter-cropped in cane, with different plant density during September and these combinations were compared with a rotation of sole crop of raya (seed/fodder), followed by cane planted in March. Raya inter cropped both as seed and fodder over-shadowed the cane crop and affected cane stand adversely. Inter cropping decreased cane yield by 9.63 to 12.96 percent; however gross and net income were significantly higher than cane alone in September, showing on E M V of 1.07 to 1.63 in different treatments (Malik and Kamoka, 1987). Seed crop was much more remunerative than fodder crop of raya. On the other hand cane planted after the harvest of raya fodder gave a yield drop of 17.35 percent, however, both the crops gave a substantial cash return with E M V of 1.52. Bukhtiar and Muhammad, (1988) and Nayyar et al, (1987) also raised profitable inter crop of cane + Raya and reported E M V of 1.11 and 1.28 respectively (Table-9.10).

Table-9.10 Economics of intercropping cane and raya

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t ha⁻¹</th>
<th>% Variation in cane yield</th>
<th>EMV</th>
<th>Source reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone in Sep. at 90cm</td>
<td>88.02</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
</tr>
<tr>
<td>Cane (Sept.)+ raya fodder one row</td>
<td>75.33</td>
<td>52.32</td>
<td>-14.41</td>
<td>1.16</td>
</tr>
<tr>
<td>Cane (Sept.)+ raya fodder two rows</td>
<td>75.16</td>
<td>55.24</td>
<td>-14.11</td>
<td>1.16</td>
</tr>
<tr>
<td>Cane (Sept.)+ raya seed (one row)</td>
<td>78.39</td>
<td>1.84</td>
<td>-10.94</td>
<td>1.63</td>
</tr>
<tr>
<td>Raya(fodder) alone in Sept. followed by cane in March</td>
<td>72.75</td>
<td>58.57</td>
<td>-17.35</td>
<td>1.07</td>
</tr>
<tr>
<td>Raya(seed) alone in Sept. followed by cane in March</td>
<td>72.43</td>
<td>2.20</td>
<td>-17.71</td>
<td>1.52</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>111.70</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
</tr>
<tr>
<td>Cane + Raya</td>
<td>90.120</td>
<td>2.28</td>
<td>-19.32</td>
<td>1.11</td>
</tr>
<tr>
<td>Cane alone in Sept.</td>
<td>84.66</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>Cane + Raya</td>
<td>80.61</td>
<td>0.813</td>
<td>-4.78</td>
<td>1.28</td>
</tr>
</tbody>
</table>

Planting time of raya is of vital importance not only to its own growth but for the growth of the main crop as well. Raya planted in September would mature earlier and would be ready for harvest by December. In case the planting of Raya is delayed, its maturity and harvesting would extend to March, which completely covers the main crop to exert deleterious competitive effect. Therefore profitable inter crop combination is assured
from September planting, that the main crop is saved from the shading effect of raya inter crop.

An erect growing, less bushy and early maturing variety should be selected for inter cropping. For lesser competitive effect the inter crop should get mature for harvesting by the month of December. One row of canola planted as inter crop in mid September gave significantly higher gross and net income than cane alone (Rehman et al, 2001). Mustered and canola maturing in April have drastic shading effect and hamper the tillering and growth of cane.

After planting sugarcane, as the soil moisture comes in field capacity inter row space should be cultivated. As the need be one or at the most two passes of cultivation are enough to pulverize the inter-row spaces. Raya seed should be drilled in shallow depth. Whether cane is plated at 90 cm or 120 cm, raya should be planted in single row. Two rows with thick population of inter crop have excessive shading effect on the main crop. The plants reaching at 4-5 leaves stage after 1\textsuperscript{st} irrigation should be thinned out to 10 cm inter-plant distance.

On completion of germination of raya, first irrigation should be delayed. Three irrigations should be enough to attain timely maturity of inter crop. Excessive irrigation increases vegetable growth and delay maturity. Sometimes, recurring rain and humid weather delays maturity. Once the vegetable stage is extended beyond December, maturity gets delayed till March which hampers the growths of cane.

Soon after planting, as the field comes in proper moist condition, herbicide should be applied just on cane rows. In the absence of chemical control, one or two manual hoeing is needed to keep the cane and inter crop free of weeds. Soon after the harvesting of inter crop, main crop of cane should be managed giving inter row cultivation followed by application of nitrogen fertilizer and irrigation.

The oil seed crop has to receive its own share of fertilizer @ 60 kg N per hectare. First dose should be applied before sowing, during inter row cultivation and the remaining dose should be top dressed just before second irrigation.

Linseed

It is a minor crop but fetches good cash return to growers. It is short stature; shallow rooted and has lesser shading effect on main crop. Two rows of linseed inter cropped within 90 cm row spaces of cane crop produced 1.236 t ha\(^{-1}\) linseed and 82.91 t ha\(^{-1}\) cane, showing a cane yield drop of only 2.07% (Nayyar et al, 1987). Two rows of linseed gave additional harvest without much effect on cane yield and the combination gave EMV of 1.29 (Table-9.11). Some other studies showed cane yield drop of 11-14 %, however, income from cane + linseed combination was at par with income from cane planted alone (Bukhtiar and Muhammad, 1988; Ahmed et al, 1991).

Cane is to be planted in September/October, while linseed is to be planted in early November. The inter row spaces should be cultivated at the stage of proper field capacity. Two rows of linseed to be drilled within 90 cm inter row space and for 120 cm inter row space three rows of linseed can be accommodated. The row spaces for linseed to be kept at 15 cm.
Pre-emergence herbicide should be applied on cane as per recommendation. For linseed one or two manual hoeings are needed to keep the weeds under check.

**Table-9.11 Table showing monetary benefits from cane + linseed intercropping**

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t ha⁻¹</th>
<th>% Variation in cane yield</th>
<th>EMV</th>
<th>Source reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90 cm</td>
<td>84.66</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cane alone + linseed (one row)</td>
<td>81.77</td>
<td>1.05</td>
<td>3.41</td>
<td>1.19</td>
</tr>
<tr>
<td>Cane alone + linseed (2 rows)</td>
<td>82.91</td>
<td>1.25</td>
<td>2.07</td>
<td>1.29</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>117.70</td>
<td>-</td>
<td>-</td>
<td>Bashir and Muhammad, (1988)</td>
</tr>
<tr>
<td>Cane + linseed (2 rows)</td>
<td>98.98</td>
<td>1.12</td>
<td>11.38</td>
<td>1.03</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>119.45</td>
<td>-</td>
<td>-</td>
<td>Ahmed et al, (1991)</td>
</tr>
<tr>
<td>Cane at 90 cm + linseed (3 rows)</td>
<td>101.64</td>
<td>1.43</td>
<td>14.91</td>
<td>1.11</td>
</tr>
</tbody>
</table>

**Berseem**

Berseem is basically an important fodder crop, but being leguminous builds organic status of soil and improves land productivity. Some times small growers are not in a position to spare separate area for sugarcane. To meet the fodder requirements of livestock, berseem has more importance for growers than sugarcane. As a conventional approach sugarcane is planted in standing crop of berseem, as spring cane, for which furrows are made with bullock driven plough and seed sets are placed. To study the economics of cane + berseem inter cropping system, a number of studies have been conducted by different research agencies.

In various studies on cane planted in berseem, yield of cane was considerably reduced. Nevertheless, cane planted in February after burying in of berseem gave significantly higher yield than the cane planted in association with berseem (Table-9.12). Cane planted in berseem during February and March gave higher cash return with E M V of 1.30 to 1.38 (Ahmed et atl, 1987). Cane planted after removal of berseem in March was not as
profitable. A cane yield reduction of 23.9% was reported from berseem (September) + cane (February) inter cropping but this combination also gave an EMV of 1.26 (Bukhtair, 1988). Strip planting of berseem in between cane rows at 90 cm planted during September, though showed a cane yield reduction of 16.6% but the combination was profitable with EMV of 1.26 (Nazir et al, 1985). It was reported that berseem inter crop improved physical condition of soil and maintained soil fertility after its harvest through biological N-fixation. This combination would have decided advantage on ratoon crop.

**Table-9.12 Different options of intercropping cane and berseem**

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t/ha</th>
<th>% Variation</th>
<th>EMV</th>
<th>Source reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90 cm in Sept.</td>
<td>107.33</td>
<td>-</td>
<td></td>
<td>Nazir et al, (1985)</td>
</tr>
<tr>
<td>Cane alone + berseem (strips in inter-row spaces)</td>
<td>89.51</td>
<td>82.27</td>
<td>-16.6</td>
<td>1.26</td>
</tr>
<tr>
<td>Cane alone in Sept at 90 cm.</td>
<td>133.97</td>
<td>-</td>
<td></td>
<td>Bukhtiar, (1988)</td>
</tr>
<tr>
<td>Berseem alone in Sept.</td>
<td>-</td>
<td>60.9</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>Berseem in Sept. + cane at 90 cm in Feb.</td>
<td>53.00</td>
<td>50.00</td>
<td>-8.78</td>
<td>1.38</td>
</tr>
<tr>
<td>Berseem in Sept. + cane at 90 cm in Mar.</td>
<td>48.7</td>
<td>50</td>
<td>-16.18</td>
<td>1.30</td>
</tr>
<tr>
<td>Berseem in Sept. followed by cane alone in Feb.</td>
<td>58.1</td>
<td>-</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Berseem in Sept. followed by cane alone in Mar.</td>
<td>44.6</td>
<td>24.5</td>
<td>0.00</td>
<td>0.998</td>
</tr>
</tbody>
</table>

**Spring Cropping**

Spring crop of cane avails of a short season of favourable temperature from early February to the end of March. Owing to slow germination, and low initial rate of growth, it takes 90 to 105 days for cane canopy to cover the inter row spaces. During this span of early growth short season crops can be accommodated as inter crops. Studies have been conducted on prospects of intercropping pulses like mung, mash, soybean, vegetables like onion, ladies-finger, cash crop like tobacco, fodder and grain crop like maize.

**Mung**

Mung is a short duration legume crop and has important position in pulses. The crop yields a reasonable return as inter crop in cane. Mung intercropping though depressed yield of cane from two to six percent, but still had economic gain with EMV of 1.06 (Aslam, 1994). Fasihi (1978) also reported an additional income of 16% over sole crop of cane. However, crop management plays a pivotal role in affecting the yield of either of the crops. Variable reductions in cane yields have been reported, however, cane yield losses were compensated by additional yield of the mung crop, as cane + mung inter cropping were relatively profitable than sole crop cane (Fasihi, (1978); Nayyar et al,
Inter-Cropping

(1987); Chatha (1986); Ahmed et al, (1993); Narwal and Bhel (1978); Narwal and Malik (1981); Sethi and Presher (1981); Yadav (1985). Dual row planting at 45-135-45 cm grow cane within wider inter row space and had low depressed effect on yield of cane than the usual inter row ridges of 90 and 135 cm (Chatha, 1986).

Mung is to be intercropped in well prepared seed bed in inter row spaces and in proper soil moisture (water) condition. It can be sown on trenches or flat surface with in cane rows. For trench planting both the crops can be planted at the same time. After making trenches, cane is to be planted in furrows and the inter crop seed is to be manually dibbled on the sides or tops of the ridges followed by irrigation. In case of flat planting cane is planted in shallow furrows and then irrigated. As the soil comes in proper moisture conditions (field capacity) inter rows spaces are cultivated to develop seed bed for moong seed is sown with single row drill within inter row spaces. Further irrigation is delayed till germination of cane and mung is completed.

Table 9.13: Economics of intercropping cane + mung in different row spaces.

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t ha⁻¹</th>
<th>% variation in yield</th>
<th>EMV</th>
<th>Source reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90 cm in Feb.</td>
<td>112.29</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>Cane in Jan. + mung in Feb.</td>
<td>109.77</td>
<td>0.43</td>
<td>-2.24</td>
<td>1.058</td>
</tr>
<tr>
<td>Mung in Jan. + cane in Feb.</td>
<td>104.65</td>
<td>0.55</td>
<td>-6.8</td>
<td>1.041</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>144.56</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>Cane + mung (2rows)</td>
<td>117.62</td>
<td>0.99</td>
<td>-18.63</td>
<td>0.97</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>72.13</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>Cane + mung</td>
<td>63.38</td>
<td>0.66</td>
<td>-12.2</td>
<td>1.06</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>91.84</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>Cane at 90 cm + mung 2 rows</td>
<td>77.74</td>
<td>0.54</td>
<td>-15.35</td>
<td>0.95</td>
</tr>
<tr>
<td>Cane at 90 cm + mung broad cast</td>
<td>72.40</td>
<td>0.43</td>
<td>-19.44</td>
<td>0.89</td>
</tr>
<tr>
<td>Cane at 90 cm + mung</td>
<td>73.92</td>
<td>0.55</td>
<td>-17.92</td>
<td>0.92</td>
</tr>
<tr>
<td>Cane at 45-135-45 cm + mung 4 rows</td>
<td>88.05</td>
<td>0.52</td>
<td>-3.79</td>
<td>1.09</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>107.39</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
</tr>
<tr>
<td>Cane + mung</td>
<td>97.65</td>
<td>1.25</td>
<td>-9.06</td>
<td>1.16</td>
</tr>
</tbody>
</table>

It is very crucial to observe optimum planting time of mung. Planting should preferably be completed by 2nd or 3rd week of February. The germinated plants of moong should establish their stand along with the germinated shoots of cane.

Erect growing variety of cane would have lesser inter space effect on moong. The intercrop variety as well should be short stature, erect and should have short growing season.

The spreading variety with lush growth would depress tillering of cane and crop maturity
and picking is not uniform. The pods should mature at one time, as more than two pickings are not manageable and economical.

The cane row spaces of 90 – 135 cm should be maintained for suitable crop stand and proper sowing and cultivation operations of both mung and cane. One or two rows of mung with 15 cm inter row space have to be accommodated within cane rows. Each crop of cane and mung has to receive its respective dose of fertilizer at recommended time. All the P and K and 1/3 dozes of ‘N’ recommended for cane are to be applied in cane furrows before seed set placement. While N and P @ 25:50 kg ha⁻¹ are to be incorporated in soil while giving inter row cultivation as seed bed for mung sowing. The remaining doze of ‘N’ for cane has to be applied soon after the harvest of mung crop.

Excessive irrigation promotes more of vegetative growth delaying maturity of mung which may also reduce yield. Sometimes very frequent irrigation or untimely rains may invite ‘mosaic virus’ causing server yield losses. Therefore utmost care should be taken in regulating the irrigation and soil moisture in cane.

One or two hoeing may be applied to keep the crop free of weeds as well as to create mulch to preserve soil moisture.

**Soybean**

Owing to its impotance as oil seed or protein rich beans, soybean has an important place in cropping pattern of several countries. The crop can be accommodated as a companion crop in inter row spaces of sugarcane. A cane yield decline of only 8.03 % (Ahmed et al, 1993) and 4.13 % (Aslam et al, 1997) was reported from Soybean + cane planting system. The combination was not much profitable and gave EMV of slightly lower than 1.00.

Chougule and Sanghari (1977) reported higher income from cane + Soybean than from sugarcane alone, while Jayabal et al, (1990) showed that Soybean inter cropped treatment produced cane yield just comparable with sole crop of cane.

For profitable cash return, it is important to select short stature high yielding soybean variety. Proper attention has to be given to planting time, row spacing, timely irrigation and fertilizer application.

**Table-9.14 Intercropping cane and soybean**

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t ha⁻¹</th>
<th>% Variation in cane yield</th>
<th>EMV</th>
<th>Source reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90 cm</td>
<td>144.56</td>
<td>-</td>
<td>-</td>
<td>Ahmed et al, (1993)</td>
</tr>
<tr>
<td>Cane + Soybean</td>
<td>132.95</td>
<td>0.711</td>
<td>-8.03</td>
<td>0.93</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>112.29</td>
<td>-</td>
<td>-</td>
<td>Ahmed et al, (1993)</td>
</tr>
<tr>
<td>Cane in Jan. + Soybean in Feb.</td>
<td>107.69</td>
<td>0.54</td>
<td>4.10</td>
<td>-</td>
</tr>
<tr>
<td>Soybean in Jan. + cane in Feb.</td>
<td>100.00</td>
<td>0.75</td>
<td>10.94</td>
<td>-</td>
</tr>
</tbody>
</table>
Ladyfinger

Ladyfinger + cane inter cropping has proved much profitable combination always giving EMV of more than one (Nayyar et al, 1987; and Ahmed et al, 1988). A cane yield reduction of 6 to 17 % was reported, however monetary return from ladyfinger compensated the yield decline (Table-9.15). The shading effect of inter crop was minimized by planting cane in dual rows strips of 45-135-45 cm. Thus the wider inter row spaces reduce light and shade competition, and two adjacent cane rows at 45 cm make up the plant population of cane.

Cane is to be planted in second fortnight of February or 1st week of March. After first irrigation to cane field, as the soil moisture comes to field capacity, the inter rows space is cultivated and field is planked. The lady finger seed is drilled in one or two rows in inter-row spaces of cane. In case of trench planting, vegetable seed may be dibbled on sides or top of the inter row beds. Since vegetables need frequent irrigation, trench planting is preferred over flat planting. As the ladyfinger grows to 3-4 leaf stage, it is thinned out to maintain 8-10 cm plant to plant distance.

Table-9.15 Economics of intercropping cane and ladyfinger in various rows spaces

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t ha⁻¹</th>
<th>Variation in yield</th>
<th>EMV</th>
<th>Source Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90 cm</td>
<td>72.13</td>
<td>-</td>
<td>1.00</td>
<td>Nayyar (1987)</td>
</tr>
<tr>
<td>Cane + ladyfinger (green vegetable)</td>
<td>65.38</td>
<td>1.403</td>
<td>9.36</td>
<td>1.78</td>
</tr>
<tr>
<td>Cane + ladyfinger + seed</td>
<td>-</td>
<td>0.366</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>107.00</td>
<td>-</td>
<td>1.00</td>
<td>Ahmed et al, (1988)</td>
</tr>
<tr>
<td>Cane at 90 cm + lady finger one row</td>
<td>93.00</td>
<td>4.45</td>
<td>-13.08</td>
<td>1.16</td>
</tr>
<tr>
<td>Cane at 30-150-30 cm + ladyfinger 2 rows</td>
<td>88.00</td>
<td>1.91</td>
<td>-17.75</td>
<td>1.94</td>
</tr>
<tr>
<td>Cane at 45-135-45 cm + ladyfinger 2 rows</td>
<td>100.00</td>
<td>2.15</td>
<td>-6.54</td>
<td>1.07</td>
</tr>
</tbody>
</table>

Fertilizer requirement of each crop should be met at recommended time and rate. The ‘N’ application to ladyfinger should be splitted at planting and then at first batch of flowering.

Two or at the most three pickings of vegetable are to be made. Vegetable crop should not be made to stay in cane field beyond May, or other wise cane tillering and growth is adversely affected. Soon after inter crop harvesting inter rows space should be cultivated and fertilized to make up the cane crop stand and growth.

Maize

Maize is a very fast growing crop and as an inter crop has proved very exhaustive in depleting soil fertility and competing for light source. Still when area is a limiting constraint for small growers, maize seed is some times broadcasted in cane field to raise
fodder crop. The data reveal that maize as fodder depressed yield of cane by 11.36% and when the crop was retained further to mature cobs for grain a cane yield reduction of 19.23% was noticed (Nayyar et al, 1978). However additional crop of maize grain and fodder recorded on E M V of 1.23 and 1.18, respectively. In another study, against a sole crop of cane planted at 100 cm, maize fodder depressed yield of cane by 26.95% and the additional crop of fodder did not enhance grain and net cash return (Aslam et al, 1994). Depressing effect on yield of cane and the lowest economic return from cane + maize has also been reported by Dhoble and Khuspe (1983).

To raise a profitable combination of cane + maize, both the crops should be planted earlier in the season. As such the crops should be planted in the first fortnight of February. Thus the maize would grow fast and mature before the tillering phase of cane. Cane is to be planted at inter rows spaces of 90 to 120 cm and on irrigation as the field comes in ‘wattar’, the inter row spaces of cane are to be cultivated as seed bed for maize. The maize seed should be drilled in one row in case of 90 cm cane row space and two rows in 120 cm spaces, keeping plant to plant distance of 15 cm. In case of trench planting maize seed should be dibbled on both sides of trenches.

Table-9.16 Economics of intercropping cane and maize

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t ha⁻¹</th>
<th>% variation in yield</th>
<th>EMV</th>
<th>Source reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 100 cm</td>
<td>135.54</td>
<td>-</td>
<td>-</td>
<td>Aslam et al, (1994)</td>
</tr>
<tr>
<td>Cane + maize</td>
<td>99.00</td>
<td>22.91</td>
<td>-26.95</td>
<td>0.86</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>80.70</td>
<td>-</td>
<td>-</td>
<td>Nayyar et al, (1987)</td>
</tr>
<tr>
<td>Cane + maize fodder</td>
<td>71.53</td>
<td>22.86</td>
<td>11.36</td>
<td>1.18</td>
</tr>
<tr>
<td>Cane + maize (grain)</td>
<td>65.18</td>
<td>2.82</td>
<td>19.23</td>
<td>1.23</td>
</tr>
</tbody>
</table>

The author is of the view that if circumstances of the growers compel to intercrop maize, the cane field should be incorporated with excessive quantity of farm yard manure. The maize planting should be so adjusted as to harvest maize before the active stage of tillering and growth in cane. Fodder population should be thin as not to have depressing effect on tillering in cane.

For proper health and vigor of the main crop i.e. sugarcane, it is advisable to maintain shallow population of maize. Maize should just substitute for fodder requirements of grower in the critical period of fodder scarcity; it should not aim to give a boom crop. Sugarcane rows should avail sufficient space to grow without light interception. Excessive shade cover would hamper the growth of cane.

For effective weed control suitable herbicide should be sprayed, as pre-emergence herbicide. Maize crop at 3-4-leaf stage may also need pesticide spray application against borers.

First irrigation to maize has to be delayed to allow the germination and establish stand of cane crop. For rapid growth of fodder, crop would need light irrigation at frequent intervals.
The nitrogen and phosphorus needs of maize should be incorporated in soil @ 150:75, N: P ha\(^{-1}\) during seed bed; second dose to be applied when the maize crop is knee high. Cane crop has to be fertilized at sowing as per recommendation. The second N dose should be given soon after harvesting of maize, on giving interrow cultivation.

Fodder should be harvested when it is flush green. Harvesting of maize should not be delayed to exert undue competetion for light and nutrients.

**Sunflower**

Besides its importance in edible oils, sunflower could not occupy much area in cropping pattern of Pakistan. However, sunflower, to some extent fits in inter row spaces of sugarcane. Sunflower grows rapidly and its leaf canopy covers the soil very fast. Due to heavy adventitious root system this crop proves nutritionally exhaustive in inter-cropping system. A cane yield reduction of 40-50 % was recorded when sunflower was planted in 90 cm cane row space (Table-9.17). This combination gave an EMV of only 0.76 (Nayyar et al, 1987). For 90 cm inter row space similar drastic effects on yields were reported by Chatha et al, (1986). However yield losses were some what compensated (EMV 0.98) when cane was planted in dual rows strips at 45-135-45 cm and sunflower planted in 4 rows within wider row space.

### Table-9.17 Economics of intercropping cane and sunflower in different row spaces

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t ha(^{-1})</th>
<th>% variation in yield</th>
<th>EMV</th>
<th>Source reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cane alone at 90 cm</td>
<td>72.13</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cane + sunflower</td>
<td>42.92</td>
<td>1.215</td>
<td>-40.5</td>
<td>0.76</td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>91.82</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Cane at 90 cm + sunflower-2 rows</td>
<td>58.21</td>
<td>1.44</td>
<td>-36.6</td>
<td>0.78</td>
</tr>
<tr>
<td>Cane at 30-150-30 cm + sunflower (4 rows)</td>
<td>50.4</td>
<td>1.56</td>
<td>-45.11</td>
<td>0.76</td>
</tr>
<tr>
<td>Cane at135-45 cm + sunflower (4 rows)</td>
<td>63.5</td>
<td>1.83</td>
<td>-30.84</td>
<td>0.93</td>
</tr>
</tbody>
</table>

For spring season, Early February is the most suitable time for sowing sunflower in cane. The sunflower plants develop well in time to mature before tillering phase in early May. With some more adjustments in planting time and plant population this inter cropping system can be made somewhat acceptable to growers. The author observed successful growing of sunflower in autumn cane in mild climate of lower Sindh. The sunflower sown at 60-120-60 in October/early November, in September/October planted cane, matures during February. After the harvest of sunflower, cane avails enough time for tillering and growth. Dual row planting of cane at 60-120-60 cm provides suitable space
to accommodate two rows of inter crop. If preference is given to edible oil and early cash flow, emphasis should be on thin stand of sunflower.

Flat planting within furrow bed 90-120 cm space could be adopted. Planting should be done in a moist seedbed as for maize crop. The most crucial feature in successful inter cropping is the plant population. Due to broad leaves shading effect is more pronounced. Data in Table-18 indicate that increase in plant density of sunflower at 30, 60, 90 and 120 cm inter plant space was inversely related to the yield of cane (Chathha, et al, 1999). Dual row planting at 60-120-60 cm may not prove much exhaustive in autumn planted cane. For 120 cm row spacing sunflower may be planted in two close (20 cm) rows.

Sunflower should not be grown to expect a bumper yield at the cost of cane production. The crop should give just a reasonable yield of oilseed to compensate fully the cane yield losses. A thin intercrop population with wider cane row space would have lesser effect on cane growth.

Besides weeds and insect pests control the sunflower’s rosettes at seed setting stage have to be secured from parrots. Guards have to be deputed for about 20 days. Stretching color cellophane strip in field also offers a good repellent measure.

Fertilizer needs of sunflower should be met at sowing and fertilizer to be incorporated in soil during seed bed preparation. The second doze of N to be applied at flowering stage. Since sunflower is an exhaustive crop, nitrogen doze for cane should be increased by 10-15 %. Soon after harvesting of inter crop soil should be well pulverized and nitrogen should be applied for accelerated growth.

**Tobacco**

In kharif season Tobacco inter-cropped in cane proved a profitable combination. The cane + tobacco intercrop gave significantly enhanced income with EMV of 1.23, than a sole crop of cane (Fasihi, et al, 1978). Tobacco is a high value cash crop and to gain good yield main emphasis has to be laid to establish the stand of tobacco nursery seedlings, inter row hand hoeing and removal of inflorescence at proper time. Due attention has to be given to plant protection and fertilizer application.
Table 9.18 Economics of intercropping tobacco in sugarcane

<table>
<thead>
<tr>
<th>Inter crop combination</th>
<th>Yield t ha$^{-1}$</th>
<th>% Variation in yield</th>
<th>EMV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cane</td>
<td>Inter crop</td>
<td></td>
</tr>
<tr>
<td>Cane alone at 90 cm</td>
<td>107.39</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cane + tobacco</td>
<td>96.62</td>
<td>672</td>
<td>-10.42</td>
</tr>
</tbody>
</table>

* Fasihi et al (1978)

Economics of Inter Cropping

There are a number of motives to practice inter cropping in field and garden crops.

1. To attain maximum economic gains per unit area
2. For a regular cash flow in the transitory period of long growing crop
3. To meet the essential family needs of a grower and its livestock.

Economic gains per unit area

Marketing price and economic gain is the main motive behind the inter cropping. If price is not much attractive for sugarcane, growers may divert its cane area to other commodities which earn more cash return. Thus to assure better income from cane area, it would be worthwhile to grow some short duration crop in inter row spaces. Intercropping help stabilize production of cane and is an economic motive not to switch to other cropping.

Grower’s economy may not allow planting September cane at the cost of some Rabi crops. To keep the cane in cropping system ‘Rabi’ crops may be adjusted as inter crop for overall benefits of grower as well as the sugar industry.

Regular cash flow in transitory period

Sugarcane has long growing season and income from cane produce is obtained after the harvested cane is supplied to mills. In case timely payment is not warranted by mills, cash return is further delayed. In such cases growers get reward of his investment on cane after 15-18 months or even later in exceptional cases. Therefore to meet their livelihood and day to day recurring expenses, inter cropping assures cash flow in transitory period of cane crop season.

Essential needs of farmers’ community and livestock

Farmers with small holdings can not spare separate area for fodder of livestock and vegetables for the home consumption. The inter-cropping becomes an essential system of its cropping. In view of his requirements, growing fodder becomes his compulsion. So what is needed is to follow a scientific system of inter cropping that farmer’s requirements are fulfilled with the minimum losses in yield of cane. It involves the efficient use of land, labour and input. It is the system of the use of family labour for
increasing his cash returns.

**Selection of crops for intercropping**

The commodity prices and growers own socio-economic features play parts in selecting crop for intercropping.

**Vegetable:** During ‘Rabi’ season almost all the vegetables can be accommodated profitably in sugar cane. Market forces, the commodity price, nearness to market and the availability of labour determine to choose the economically suitable field or vegetable crops. For green vegetables like radish, carrot, turnip, peas and cabbage very specialized labour is required for regular picking/ harvesting, according to market need. While potato and garlic can be stored and marketed at will. Ladyfinger and onion are good paying vegetables however specialized labour arrangement is needed for hoeing and picking.

**Wheat:** Wheat crop has not proved much profitable combination with September cane. Nevertheless, if cane is given preference owing to better prices, wheat crop can be accommodated in September cane at equitable income level. Technology is available to select varieties, suitable planting time and space that impose lesser depressing effect on cane yield.

**Oilseeds:** Raya offers good monitory advantage if planted early in the season, and the variety is such that matures by December. Any variety or technique that delays harvesting to April is much detrimental to cane crop. Canola and mustards maturing in March-April may not be that profitable. However linseed yields better cash return.

**Pulses:** In spring crop of cane, mung has some variable results. As inter crop pulses can give good profitable return, if planted early in the rows, plant population is monitored and irrigation is restricted to control mosaic virus, and that the variety is of short stature and matures in one picking. Same conditions hold good for Soybean. The crop demand good management and critical watch.

**Key points for successful inter cropping**

A successful inter cropping system demand inter season crop and land management programme for optimally utilizing the physical resources like air, light and space under available inputs of labour and capital. However, while picking up the system and selecting the crop, economic implications have to be assessed. Total inputs required from crop production, and the value of each crop yields and anticipated net profits from each crop in the system, have to be critically looked into. It demands advanced planning before any field operations are undertaken and thorough considerations have to be given to the following basic facts.

Seed germination to establish a suitable initial crop stand is the critical phase in intercrops. For this optimum soil moisture and optimum seed bed condition must exist. However, it should entail minimum tillage operation and soil displacement.

More competitive and exhaustive crop may not be desirable as it reduces sugarcane yield considerably. The intercrop that set low degree of competition and which are shade tolerant may be chosen by changing the geometry of intercropping system.

Row spacing and optimum plant population is important for both the crops. Intercropping
in strips is always desired, and should be sufficiently wide to facilitate mechanized cultivation and planting operations. The recent innovation of dual row cane planting at 60-120-60 cm row space can accommodate all types of inter crops except those planted on trenches.

Planting time of each crop has to be given prime importance to ensure optimum germination, stand and growth of inter crop with out any detrimental effect on the main crop.

Adequate fertilizer has to be assured for optimum soil fertility and maximal productivity of crop. The inter crop and the main crop have to receive their requisite fertilizer needs at appropriate time; fertilizer timing are extremely important.

Multiple cropping is highly labour intensive. Most of the operations during planting, hoeing, earthing up, plant protection and harvesting are done by manual labour. For successful cropping timely availability of skilled labour is to be assured. Utmost care is to be taken that the inter crop is not damaged during hoeing and harvesting.

Soon after harvesting of inter-crop, inter-row spaces of cane should be thoroughly cultivated. The cane crop to be fertilized and irrigated to accelerate tillering and growth of cane. Mismanagement inducing delay in these operations is likely to dissipate the income from cane and the intercrop.
Any plant out of its proper place is a weed. For weed control purposes, weeds are unwanted plants growing among crop plants. The distribution, vigour and abundance of weeds vary in different regions due to soil types and climatic conditions. For ease in morphological description weeds are classified into groups:

<table>
<thead>
<tr>
<th>Annual</th>
<th>Monocot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dicot</td>
<td></td>
</tr>
<tr>
<td>Perennial</td>
<td>Monocot</td>
</tr>
<tr>
<td>Dicot</td>
<td></td>
</tr>
</tbody>
</table>

Annual weeds are plants that die after completing their seasonal cycle from seeding to flowering and seed shedding, while perennial weeds continue to grow in successive years. Each group includes monocot and dicot type of plants. Monocots (monocotyledons) include grasses having long and narrow leaves with leaf sheath around stem. Dicots (dicotyledons) on the other hand are mostly broad leaved weeds. In general perennials are much more difficult to control and monocots are more resistant to herbicides than dicots.

Weeds cause tremendous loss to crop plants mainly due to their competition with crops for light, water and nutrients. Weeds also affect crop by way of inefficient use of land, irrigation and fertilizer, higher cost on control of insects and diseases, more water management problems, poor quality products and lower crop yields. Weeds harbor a number of insect pests and diseases and thus cause indirect loss to cane crop. Sometimes this loss is of great significance. Cynodon dactylon has been noticed to be the alternative host of black smut, and Cyperus rotundus for white web mite. Bermuda grass is also known to be the alternative host of RSD (Steindl, 1967).

The annual weeds are short lived so they grow very fast. In early stages, due to slow growth of cane, weeds if not checked grow fast and mask the ground all around cane shoots. The aerial portion of weeds may exceed in growth and create light problem for cane, while the vigorous root system extract moisture and nutrients from soil. If not controlled they may steal around 40% of the nutrition applied to the crop (Yadava, 1981). Under controlled conditions weeds have been reported to remove soil ‘N’ to the extent of 64 Kg ha⁻¹ (Verma et al, 1983). Cane plants get pale and the growth and vigour is drastically affected. Weed infestation, during first 3-10 weeks of planting, exerts detrimental competition and this is the stage of shoot development and tiller formation. Weed infestation brings significant reduction in tillering and mill-able canes (Fasili & Malik, 1989 and Afzal et al, 1994). As the cane plants close in, growth of some of the weeds is checked due to shading effect of cane canopy. However, some weeds like that produce seeds from its successive axillary's buds and twinning weeds continue to grow and pose problems. The rhizomatous weeds like nut sedge, bermuda grass and Johnson
grass may not show active aerial growth due to mechanical or chemical control measures, but the mat of their root mass developed by weeds remain dormant and exert effect on cane root development. These weeds in later stages depress the shoot and root development of ratoon crop. Cane yield decrease due to weed competition has been reported to the extent of 14 -74% (Singh and Moolani, 1975). The variation in yield losses varies due to intensity and type of weed flora and the stage of crop infested. In general field condition un-controlled weed growth caused 32% reduction in cane yield (Malik et al, 1986; Kanwar, 1986).

Sugarcane is a long duration crop and covers the field both during winter and summer season. As such all types of weeds, growing in autumn and spring season, annual or perennial, may have the chance to infest cane field.

**Critical time of weed control**

In the early stage, germination and growth of cane is slow, while weeds grow fast and soon cover the ground. If not checked timely, early tillering and growth of cane is likely to be severely affected by weed competition. The critical period of weed control in sugarcane was reported to be between 30 and 120 days after planting (Singh et al, 1980). Maximum yield of cane was obtained when the crop was kept weed free from one to three months after planting. The yield data reveal that weed competition up to one month after planting had no significant effect on yield decline, competition for two months reduced yield by 15% and for the whole season by 55% (Punzelon and Cruzz, 1981). In another study it was observed that weed competition started its drastic effect right from 14 days after planting till the stage of cane formatting. A weed free period of 56, 42, 28 and 14 days after planting reduced the cane yield by 7.70 %, 12.0 %, 18.1% and 21.6 % respectively (Nayyar et al, 1994). The un-weeded check gave a yield reduction of 35.7%. In some studies in Australia, weed growth 4 weeks after spiking caused a yield reduction of 11 %. Delaying weed control until 8 and 12 weeks resulted in cane yield losses of 23 % and 34 %, respectively (McMahon et al, 2000).

Considering these data, the weed control measures should start prior to weeds emergence, soon after cane planting. It will, however, depend on the method of planting, irrigation practices and nature of weed infestation. Weed population is high when cane crop receives irrigation at frequent intervals, while in case of dry planting weed emergence is a little late.

**Weed Control Measures**

For successful crop production man has been active, since ages, in destroying unwanted plants from main crop. Various methods have been employed from hand pulling of weeds to the use of hand hoeing tools, use of livestock-bullocks and horses and utilizing modern farm machinery for mechanical control of weeds. The latest device in this category is the use of chemicals, the herbicides, for control of weeds. Biological Control of weeds through transgressive induction of resistant genes in crop plants may also find Its way in future. The modern day technology is the integrated methods of weed control, including the use of cultural and chemical means. As, for a long growing season crop like sugarcane single method of hoeing or chemical weed control is not sufficient to attain the goal of complete weed control.
Weeds can be controlled with a full package of technology including crop rotation and combination of mechanical and chemical methods to curb weeds from cane fields. Various weed control measures are taken keeping into consideration the following conditions.

1. **Season of the year**: Spring, autumn, hot & dry or rainy season.
2. **Crop stage**: Fallow or cane crop cycle.
3. **Types of weed flora**: Annual, biannual, perennial, monocot or dicot.

The weed control methods mainly in use are the mechanical and chemical.

**Mechanical Methods**

For effective mechanical control of weeds, the device could be grouped into three phases:

(a) **Pre-planting phase** (b) **Post planting phase** (c) **Post harvesting phase**

**Pre-planting phase**

Weed control measures start with land preparation for cane cultivation. Cultivation helps to destroy the annual and biannual weeds already growing in the field or exposing their seeds to birds. Cultivation practices while help eradicate weeds, stimulate germination for eradication in next run of cultivation. The effective eradication depends on the length of fallow period availed and number of cultivation before cane planting. During the process of cultivation dicots are easy to eradicate. Monocots are easily eradicated so long as they propagate by seed and are yet in young seedling stage, but when their rhizome are established their control becomes problematic. For the control of rhizomatous perennials this is the real time to eradicate the rhizomes root stumps through desiccation. Rhizomatous weeds are very hard and sustain environmental stresses. They withstand mechanical injuries and segregate on fragmentation during cultivation. If not properly picked and collected and or exposed to dry sun they may further multiply. Hot dry season is the best time for their eradication. Chisel and mould board/disc ploughs should dig out the rhizomes established to deeper soil layers. The field may then be cultivated for rhizome collection and exposures to sun.

Special attention should be paid to the eradication of nutsedge and rhizomes of Bermuda grass, Johnson grass and Arundo donax. Nuts and rhizomes are very hard and can persist in dry environment for a number of days. Nevertheless, their desiccation for longer period destroys these weeds. Thorough cultivation before cane planting provides the most effective check on excessive weed growth in cane field. Mechanical weed control is preferred to the use of herbicides, however, correct time and cultivation operation has to be chosen to destroy weeds during pre-planting season and post sowing cultural operation.

Normally shallow ploughing is better than deep ploughing of soil. However, to eradicate deep-rooted stumps of rhizomatous weeds, deep ploughing is helpful and it should be followed by manual rouging and picking of shredded rhizomes to avoid their resetting.

Deep ploughing is useful to dig out deep-rooted stumps of some perennials and some hard grasses. Nevertheless, deep ploughing for burying rhizomes and weed seed is not
advisable. In most of the cases the rhizomes establish in the soil and seeds remain alive for years to sprout or germinate in favourable environments. Therefore shallow cultivation is better than deep ploughing. Exposure of weed seeds to soil surface is helpful in their destruction by germination followed by hoeing, drying out to loose viability or are picked up by birds and rodents.

Correct timing of cultivation is important in achieving efficiency in weed control at the minimum cost. Cultivation or hoeing is more effective when done in early stage of weeds emergence. In later stage plants get hard to be rouged. Cultivation at proper stage help prevent the weeds to seed, and seeds already buried in the soil are brought near the surface. They may either germinate and they’re destroyed by next run of cultivation or may be picked by birds if on the soil surface.

Fallow period should be availed of to eradicate weed through cultivation, manual operations and chemical control as the case may be. However, un-necessary mechanical operation to control weeds through tractor drawn implements should be avoided. Repeated run of tractor in cane rows creates hard pan for moisture retention and suppresses the soil to reduce aeration thus retarding plant and root development.

**Post-sowing cultural operations**

During initial stages of cane planting, germination and growth is slow. In the first 100 days of planting or till the tillering is complete and leaf canopy cover the inter-row space, weeds have the opportunity to avail of favourable environment to germinate.

Weeds grow very fast and if are allowed to establish they compete with cane and having fast growth mask the cane shoots, as such suppress the growth of cane. At this stage the cane crop for its proper growth and tillering needs weed free environment and proper aeration in soil for root development. As such weeds should be rouged out by mechanical means.

Inter-row cultivation while control weeds, move the soil to fill in cane furrows. Different types of inter-row cultivator are used for hoeing. Bhoj and Shukla (1960) recommended one hoeing after each of the irrigation during tillering phase. In all 3 to 4 hoeings are recommended up to tillering stage (Kanwar, 1980). According to Verma et al, (1984) two hoeings at early and late tillering stage are enough to give good yields.

The number of hoeing depends on the stage of weed growth, soil moisture condition and growth of cane. With close in of the crop the practice of hoeing is stopped. However, spot hoeing would be needed where excessive weeds prevail. Some spots may even require hand pulling of grown up weeds established in scattered isolated places. The cultivation should be carried out as soon as the weed seedlings start emerging. They should not be allowed to establish, otherwise they become harder to eradicate and kill. Weeds should not be allowed to stay long in the field after all they rob nutrients and moisture. To restrict their further propagation weeds must be destroyed before seeding.

**Mode of Hoeing**

Hoeing is to be done either by manual labour, farm implements drawn by livestock or tractors. It all depends on the availability of cheap labour force and the machinery and technology available at the farm.
**Manual weeding**

Hand hoeing is the conventional method of weed control, employed soon after planting and as well as hoeing cane crop in inter-row spaces. In the past blind hoeing was a usual practice before seed set germination. Hand tools Khurpa and Baguri are used for the purpose. In dry method of planting, hoeing is done after planting and is completed within 12 - 15 days of planting. Germinating weeds are destroyed; soil surface gets loose that help accelerate the germination. Early emergence of cane shoots help to close in fast to suppress weed growth in later stages.

Following irrigation, on completion of germination, weed growth is rapid. To culminate weeds manual hoeing is done in inter row spaces and around cane stumps. Hoeing is required on alternate irrigation till the cane canopy covers the inter-row spaces. Different types of hand tools have been devised under local conditions, spade and long handle Kasolas are most commonly in use. For excessive weeds, close to cane stump, use of “Khurpa” “Ramba” is a common practice.

![Manual weeding](image1.jpg)

![Bullock drawn “Tarphali” used for hoeing in inter-row spaces of sugarcane](image2.jpg)

**Bullock Cultivation**

Hand hoeing is practiced in small holdings where labour is cheap and is easily available. In large cane plantations, bullock cultivation is common as a conventional approach to hoeing in inter row spaces. Depending on inter row spaces three or four tined harrows (“Tarphali or Charphali”) have been locally designed to serve the purpose of hoeing.

Manual weeding and bullock cultivation are workable for small areas, are not efficient for large cane plantations’. It is labour intensive and get expensive. Availability of labour is also getting a limiting factor. However during mechanized cultivation labour may be involved for weeding corners of fields, marshy places and the portions not covered by tractor operations.

**Tractor and Farm Machinery**

With advances in cultivation techniques, use of tractors is getting common. Inter row cultivation is done with tractor drawn cultivators. In conventional planting at 75 cm row distance, two or three tined cultivators are used, however for wider row spacing at 120 and 135 cm, three or four tined cultivators have been designed to cover two rows of cane at a time. The objective is efficiency and effectiveness in hoeing operations for which different kinds of farm machinery is being used in various countries.

Dry hoeing, prior to first irrigation, after germination, gives very effective control of weeds. Subsequent inter row cultivation are recommended after every alternate irrigation, till the
close in of the crop. The number of hoeings depends on the stage of weed growth and the
growth of cane crop. The critical growth stage during which the cane plant is most sensitive
to weed population is from third to 10th week after planting, in spring sown crop. This stage
may be prolonged in autumn planting. During this phase the crop may receive 2 to 3
hoeings. The inter-row space regulates the weeding by tractor operation. Closer space of 60
– 90 cm does not allow repeated run of machinery in inter-row spaces. However, tractor
operation is convenient in wider row spaces of 120 to 135 cm, till the growth of cane
beyond the clearance of the body frame of the tractor. Excessive use of farm machinery
should be avoided as repeated inter-row cultivation may create impervious hard pan to
offset water intake, nutrient absorption and root development. Therefore soil type must be
kept into consideration while using farm machinery for weed control.

In some situations with heavy infestation of weeds within cane rows, a rotary weeder or
spinner is used for aggressive removal of weeds in cane rows. This is a best implement to
operate in sugarcane ratoon. However, for a plant crop weeding depth should be
controlled so as to avoid pulling out of seed setts.
Post-harvesting phase

Trash mulching

During harvesting operation, cane trash left in the cane field is uniformly spread on the field surface as mulch. Trash mulching is a best approach to check growth of weeds in ratoon fields. The practice not only suppresses weed growth, enriches the soil with organic matter, when incorporated in soil, on decomposition of trash. However, one has to be cautious about the type of weed flora. Trash mulching is questioned, if cane field is heavily infested with noxious weeds such as nut grass, coach grass, grass and vines.

Chemical Weed Control

Hoeing has been considered an essential cultural operation for control of weeds. But many a times field conditions do not permit timely hoeing and some noxious weeds get established. Some short-lived weeds produce seed at regular succession and some seeds are brought carried by irrigation water. As such weeds grow with each turn of irrigation, and it makes the repeated hoeing very expensive. Further that the hoeing of weeds within cane shoots is very cumbersome, and nuts and grasses are difficult to control. The modern philosophy of mechanization is the least tillage operation - zero tillage within cane rows. To cover these problems a numbers of herbicides have been developed which give very effective and efficient control of weeds. The herbicidal control of weeds is now a regular practice throughout the sugarcane world.

Type of herbicides

According to the mode of action the herbicides may be classified into three groups.

**Contact:** When applied on to the foliage they kill the plant tissues coming in contact with the chemicals; they do not move from the site of application. These herbicides are used to control annual weeds and young perennials. In advanced stage of weed growth only top exposed parts of the plant are killed and plant later survives to re-grow. For effective action of the herbicides, the young annual weeds should receive good spray coverage of chemical using higher water rates.

**Trans-located:** On application to the foliage enter the tissue and trans-locate through cell sap from the site of application to other parts of the plants. They are systematic in action and their movement is with the flow of metabolites through the phloem tissues. They disturb photosynthetic function of plant, food synthesis is checked, and plants get pale and ultimately die. They are effective for controlling perennial weeds. They are selective (2, 4-D amine salt) or non selective (Glyphosate).

**Trans-located and residual:** They are applied on to the soil surface and act mainly on germinating weed seed; absorbed by young shoots and roosts. They are trans-located to other plant parts through xylem tissues. They are more persistent and have residual action for several weeks. Some of these are also called soil sterilent. Some have very low water solubility and decomposability, thus they are resistant to leaching by rains and break down by microorganisms. They remain active in soil until completely decomposed. They kill weeds on germination.

They may be applied before the crop is planted or applied to the foliage of weeds just
after emergence. When applied after crop is planted, but before weeds emergence, are called **pre-emergence**. They are also trans-located in grown plants when absorbed by roots or leaves and are called early **post emergence**. They may be selective (trifluralin) or non-selective (Diuron). At higher dosage rates even the selective becomes the non-selective.

The effectiveness of the herbicide is conditioned by favourable environments of temperature, moisture and undisturbed uniform soil surface to promote germination. Some of the systematic and trans-located herbicides are selective for one kind of plant, while others are non-selective. They may be selective for broad leaf crops but non-selective for grasses and vice versa. Some are very short lived while others are more persistent having long residual effect.

**Table-10.02 List of different types of herbicides**

<table>
<thead>
<tr>
<th>Contact herbicides:</th>
<th>Penta-chlorophenol-PCP, Oil, arsenic compounds, diquat, paraquat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Trans-located:</strong></td>
<td>Chlorophenoxy compounds; MCPA, 2, 4-D, dalapan, amitrole, fenac, 2, 3, 6 TBA</td>
</tr>
<tr>
<td><strong>Trans-located and Residual:</strong></td>
<td>Chlorophenoxy compounds: MCPA, 2, 4-D Triazines: atrazine, simazine, ametryne, metrabuzin, substituted ureas: diuron, linuron, tebuthiuron, napropamide: fenac (2, 3, 6 TBA), trifluralin, asulam, amiben</td>
</tr>
</tbody>
</table>

The herbicides to be effective are selected keeping these characteristics in view. Quick action herbicides would kill the weeds that emerge very fast, while late emerging crop plant would escape the effect of herbicides. As by that time the chemical is decomposed and its action is lost. Shallow rooted weeds are destroyed by herbicide action but the main crop is saved due to deep penetration of its roots. Pre-emergence application of Gesapax combi was reported to be superior to Actril DS, lasso and sencor giving yield increase of 51.3%, 46.11 %, 36.11 % and 22.71 % over the yield obtained from hand hoeing; afalon and diuran reduced the yield by 9.78% and 1.92%(Fasihi and Malik, 1989).

**Time of application**

The time of herbicide application has a great significance in the effective and economic control of weeds. While applying the herbicide consideration is given to the stage of crop growth and the weed emergence. The term referred to in chemical weed control is the **pre-emergence** and the **post-emergence** treatments. The pre emergence herbicides are applied within 3 – 5 days while post emergence sprays within 20 – 25 days of planting cane.

Pre-emergence refers to the application of herbicide on cane field surface before the emergence of weed seedlings, irrespective of stage of crop growth. Generally the pre-emergence sprays are done soon after the planting of cane, at the stage when both the cane shoots and weeds have not emerged. The herbicides generally used as pre-emergence spray are atrazine, simazine, 2, 4-D, MCPA, TCA, fenac, monuron and diuron.
For effective use of the chemical, in pre-emergence spray, the soil surface should not be disturbed after the treatment. By disturbing the soil surface the protective coating/layer of the chemical is broken and weeds may emerge in surface stirred areas. Thus hoeing or cultivation should be delayed as far as the residual effect of the chemical remains on soil surface. Long periods of effective weed control are obtained from the use of a number of commercial mixtures. Atrazine, simazine and ametryne in recommended doses are known to have 8 – 10 weeks of residual effect. With spray of 2, 4, -D and MCPA, only short-term control is obtained, but these chemicals are relatively cheaper and treatments can be repeated if necessary.

If pre-emergence spray could not be made, early post emergence application can also be effective to control weeds by foliar absorption of the herbicide, as well as cover the soil surface to prevent the establishment of further weed seedlings on appearance. For herbicide efficiency, it is however essential that the weeds seedlings are very young to allow the chemical to penetrate the foliage as well as cover the soil surface. Contact herbicides can cause damage to young cane unless the spray is direct to avoid drift of the chemical to young cane shoots. PCP and mineral oils are included in the group.

Products of number of companies have been tried, but somehow Gesapax combi (Atrazin + ametryne) got monopolized in cane fields of Pakistan. Efficiency of this product has also been reported in India (Hunsigi, 1993). In principle trade name does not matter much, it is the actual chemical compound with specific formula that works. These chemical compounds are marketed in different commercial trade names. (Table-10.03). Very specific characteristics of some popular herbicides are described here under.

**Triazines**

The ametryne, atrazine and simazine belong to the group Triazine. Triazines control the growth of weeds due to their absorption through foliage or roots. They have residual effect and exert photo toxic effect on weed seedlings by inhibiting photosynthetic action on leaves.

*Ametryne*: it has a dual action of upward translocation through roots and downward translocation through absorption by leaves (Peng, 1998, Anon. Ciba Geigy). It has a stronger foliar action and is better suited for post-emergence treatment. At recommended rates it controls most annual dicot and monocot weeds. For the control of perennial weeds *Atrazine and Simazine*: they act mainly through root absorption and to a lesser extent through leaves. At the recommended rates, their residual effect lost for 8 -10 weeks that is the period till cane crop closes in. This group is mainly suited for pre-emergence application against dicots and monocots including main grasses.

*Sencor*: a residual herbicide with a slight contact action; controls grasses and broad leaved weeds; suitable for use in wide range of climate.

*Diuron*: a residual herbicide effective against grasses and broad leaved weeds; to be used as pre-emergence.

*Velpar K4*: a mixture of velpar (a residual herbicide with a good contact action) and Diuron in the ratio of 1 : 4, effective against grasses, broad leaved weeds and sedges; can be used in either pre- or post-emergence phase of weeds. It is a good preparation for
### Table-10.03 Herbicides commonly used in sugarcane fields over the globe

<table>
<thead>
<tr>
<th>Group</th>
<th>Herbicide</th>
<th>Trade name</th>
<th>Dosage Kg ha(^{-1})</th>
<th>Pre-emergence</th>
<th>Post emergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophenoxy compounds</td>
<td>2, 4-D</td>
<td>Fenoxone</td>
<td>2.0-2.5</td>
<td>2.0-2.5</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>MCPA</td>
<td></td>
<td></td>
<td>2.0-2.5</td>
<td>2.0-2.5</td>
</tr>
<tr>
<td>Carbamates</td>
<td>Asulam</td>
<td>Asulox</td>
<td>2.0-2.5</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>&quot;</td>
<td>Barban</td>
<td></td>
<td>2.0</td>
<td></td>
<td>-</td>
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<tr>
<td>Substituted ureas</td>
<td>Diuron</td>
<td>Karmex</td>
<td>2.0-2.5</td>
<td>2.0-2.5</td>
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<tr>
<td>&quot;</td>
<td>Isoproturon</td>
<td>Graminon</td>
<td>1.0</td>
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<tr>
<td>Triazines</td>
<td>Atrazine</td>
<td>Gesaprim</td>
<td>2.0-2.5</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>&quot;</td>
<td>Prometryne</td>
<td></td>
<td>1.0</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>&quot;</td>
<td>Metribuzin</td>
<td>Sencor</td>
<td>1.0-1.5</td>
<td></td>
<td>-</td>
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<tr>
<td>&quot;</td>
<td>Cyanazin</td>
<td>Bladex</td>
<td>1.0-1.5</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>&quot;</td>
<td>Hexazinone</td>
<td>Velpar</td>
<td>1.5</td>
<td></td>
<td>-</td>
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<tr>
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<td>Simazine</td>
<td>Gesatop</td>
<td>1.5</td>
<td></td>
<td>-</td>
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<tr>
<td>Chlorinated aliphatic acids</td>
<td>Dalapon</td>
<td>Dowpan</td>
<td>2.0-2.5</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Amides</td>
<td>Alachlor</td>
<td>Lasso</td>
<td>2.0-2.5</td>
<td>2.0-2.5</td>
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<tr>
<td>&quot;</td>
<td>Metachlor</td>
<td>Dual</td>
<td>1.5-2.5</td>
<td></td>
<td>-</td>
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<tr>
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<td>Propanil</td>
<td>Stam F 34</td>
<td>2.00</td>
<td></td>
<td>-</td>
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<tr>
<td>Uracils</td>
<td>Terbacil</td>
<td>Sinbar</td>
<td>1.5</td>
<td></td>
<td>-</td>
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<tr>
<td>Pyridines</td>
<td>Paraquat</td>
<td>Gramoxone</td>
<td>-</td>
<td>2.0-2.5</td>
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<tr>
<td>&quot;</td>
<td>Diquat</td>
<td>Reglone</td>
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<td>2.0-2.5</td>
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<td>Benzoic acids</td>
<td>Chloramben</td>
<td>Amiben</td>
<td>1.5-2.0</td>
<td></td>
<td>-</td>
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<tr>
<td>&quot;</td>
<td>Fenac (chlorofenac)</td>
<td>Tri-fene</td>
<td>2.0-2.5</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>&quot;</td>
<td>2,3,6 TBA (trichloro benzoic acid)</td>
<td>TBA</td>
<td>2.5</td>
<td>2.0-2.5</td>
<td></td>
</tr>
<tr>
<td>Organophosphorus compound</td>
<td>Glyphosate</td>
<td>Glycil, roundup</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Nitro</td>
<td>Trifluralin</td>
<td>Treflan</td>
<td>1.0 (soil incorporation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>Pendimethalin</td>
<td>Stamp</td>
<td>1.0</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Nitrophenyl ethers</td>
<td>Nitrofen</td>
<td>TOKE-25</td>
<td>1.0-1.5</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>&quot;</td>
<td>Oxyfluoren</td>
<td>Goal</td>
<td>0.6-1.0</td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>
ratoons, plant cane may show phyto-toxicity

**2, 4-D amine salt:** It is a phenoxy compound. It is absorbed through leaves and has a good foliar action against broad-leaved weeds and some grasses like Cyperus. It has a short residual effect.

2,4-D and triazine compounds gives effective control. The mixture of these compounds is reported to have a marked synergistic effect against weeds (Peng, 1984).

**Gramoxone:** A contact herbicide effective against grasses, broad-leaved weeds and sedges. It has no residual effect and can also be mixed with other chemicals. It scorches cane leaves and should be used with shield to avoid canopy contact.

**Roundup:** A translocated herbicide without residual effect; controls grasses, broad-leaved weeds and sedges. It is highly phytotoxic to cane leaves; could be used with a shield under a well developed cane.

**Scope:** A product of Ali Akbar Group in Pakistan; is a combination of Atrazine and Ametryne in 1:1 ratio and is effective against monocot and dicot weed. Its formulation is the same as for Gesapax Combi, formerly a product of CEBA GEIGI.

Besides Triazine group and 2, 4-D, a number of other compounds has been used for weed control in sugarcane. The chemicals in main commercial use in the sugarcane weeds include dalapon, dowpan diuron sencor, asulox, paraquat and roundup. They have been used singly or in combination. Monocot or dicot weeds, emerged from seeds are easy to control. The grasses further propagating through stools and rhizome once established after germination get noxious and problematic for control of various noxious grasses. Nut grass (Cyperus rotundus), Bermuda grass (Cynodon dactylon) and Johnson grass (Sorghum halepense) need special mention, as these are of common occurrence in cane fields.

Pre-emergence application of simazine 50 wp and diuron 80 WP is most effective against broad leaf weeds as well as annual grasses (Kanwar, 1980). Cyperus rotundus, however, could be controlled by post-emergence application of 2, 4-D (sodium salt) @ 2 kg ha⁻¹. The efficiency of metribuzine, atrazine, diuron, dicomba, gramoxone, 2, 4-D, saturn and
asulox was compared in controlling weeds in sugarcane (Kanwar, 1986). Uncontrolled weed growth caused 32% reduction in cane yield. Pre-emergence application of metribuzine @ 2 Kg a.i ha\(^{-1}\) gave effective control of monocot (Cyperus rotundus) as well as dicot weeds compared to other herbicides. Pre-emergence application of atrazine @ 1.00 kg a.i ha\(^{-1}\) and 2, 4-D (Na salt @ 1.00 kg a.i ha\(^{-1}\)) applied 60 days after planting were equally effective. The herbicide asulox, saturn and taurus proved ineffective. The hand weeding (three) gave the highest number of mill-able canes and higher cane yield followed by the metribuzine, atrazine, atrazine + 2,4 -D and 2, 4-D + gramoxone.

Pre emergence application of Gesapax combi @ 3.00 Kg a.i ha\(^{-1}\) proved more effective than other herbicides (Shafi et al, 1994; Khan, 1989). Post emergence application of Gesapax combi (1.85 kg ha\(^{-1}\)) + 2-4, D (0.65 kg ha\(^{-1}\)) + triton (0.6 lit ha\(^{-1}\)) as surfactant exhibited an effective control of both broad and narrow leaf weeds in sugarcane (Afghan, 1996).

**Phyto-toxic effect of herbicides**

1. Herbicides sprayed before the cane emergence are far less damaging than sprayed post-emergence.
2. The chemical should be applied when the grass is in 2-3 leaf stage and cane shoot is not unfurled. In advance stage of cane leaf opening spray can cause injury to cane plant.
3. Germinated cane in two or three leaf stage is more susceptible to damage from chemical than is younger cane in its unfurled position.
4. Post-emergence application should always be directed so as to spray as little cane leaf area as possible. It is better to use flood jets nozzle in the inter rows.
5. Poorly grown cane suffering from diseases, nematode damage or nutrient deficiency is more susceptible to damage than is well-grown cane.
6. Some cane varieties are more susceptible to damage than others. For such varieties spray should be directed away from foliage or pre-emergence application should be practiced.
7. Hot, humid conditions increase the likely hood of damage to cane.

**Control of Noxious – Perennial Weeds**

**Nut grass (Cyperus rotundus)**

Young seedlings of nut grass are susceptible to 2, 4-D amine; early post emergence application at 2-3 leaf stage is effective. As the grass leaves get old, the effect is minimized. With one application at correct timing the weed leaves get pale and growth is checked. Second application at about one month interval will considerably damage the foliage and nuts. Some pockets may need third application to kill both its foliage and nuts in the upper soil layer. It will help to maintain weed free condition till the close in of cane canopy (Chang and Sze, 1963). The effect of 2,4-D is accelerated when used in combination with triazine compounds or diuron or delapon.
In 3 – 4 months old plant cane Actril DS @ 1.8 l ha\(^{-1}\) should be preferred to 2,4-D, while in ratoon cane Velpar K4 @ 4.5 kg ha\(^{-1}\) is better than Actril DS.

When cane has reached a height of 120 – 150 cm Round up @ 3 l ha\(^{-1}\) may be used at the pre-flowering stage of the weed (Mc Intyre). Shield should be used to avoid phytotoxicity to cane leaves.

**Bermuda grass (Cynodon dactylon)**

It is a perennial grass and is vegetatively propagated both by stolens and rhizomes. The plant is very hardy to completely kill by chemical treatment in cane crop. The aerial parts may be partly killed but the under ground portion escapes complete damage and re-grow to establish in the field. For plant crop the following mixture give best results (Anon, 1989).

Paraquat 2 kg (a.i ha\(^{-1}\)) + Dalapon 8 kg (a.i ha\(^{-1}\)) + 2, 4-D 2 kg (a.i ha\(^{-1}\))

Spray one month after planting keep the cane field clean for about 3 months. Localized patches of the grass can be effectively controlled by spot treatments. Dolapon can be substituted by asulam or metribuzine.

The plant is sensitive to chemical at the time of rhizome formation, so the chemical should be applied one month after planting. Use directed spray to avoid contact with cane leaves. Eradication of this grass in ratoon crop is difficult, specially the weed mass associated with stubbles.

**Johnson grass (Sorghum helepense)**

It is propagated by seed as well as through rhizomes. Young seedlings can be controlled by pre-emergence application of triazines and dalapon. Destruction of rhizomes should be the main target. Post emergence application of the following compounds one month after planting gives very effective control (Anon, 1989).

Asulox 2.5-3.5 pt/ acre + Dalapon 1.5-2.0 lbs/ acre + surfactant

Where broad leaves are also problem, one quarter of 2.4-D may be added in the above mixture. It is better to use directed spray. Spray may be repeated on selected spots. Spray should be avoided in advance stage of cane growth if temperature gets harsh.

**Vines**

Vines are climbing plants or creepers that entangle with cane growing stalks. They germinate later in the season when cane is in tillering stage. They climb up the plant covering cane stalks and leaves. In prolific form they entangle several rows of cane plants and wrap around stool. They pose serious problems during harvesting, both manual and mechanical. The vines commonly observed in Sindh province are morning glory (Ipomea spp), convolvulus (Ipomea spp), and passion vine (Passion spp).

When weeds are young can be effectively controlled by Tordon 101 @ 5 l ha\(^{-1}\) or Actril DS @ 1.8 l ha\(^{-1}\) or 2,4-D amine @ 2.5 l ha\(^{-1}\) + 2,4,5-T ester @2.5 l ha\(^{-1}\) (Mc Intyre).

Spray application of Gesapax Combi @ 2.5 kg ha\(^{-1}\) gave a fair control during full weed growth (Malik, 2006).
Dicot weeds

Annual dicot weeds are easy to control by herbicides. The 2,4-D show effective control by translocation through foliage. Combination of 2, 4-D with Triazine compounds and surfactant trigger weed control treatment. In normal case one application is enough. However, some weeds produce innumerous seeds in auxiliary branches at every successive growth. This seed accumulate on soil and develop heavy weed infestation on irrigation. Some weeds are also transported by irrigation water. Weeds like Trianthema (‘itsit’), Tribulus, and Haloan become troublesome if not completely eradicated. For such weeds herbicides having longer residual effect should be used. Therefore combination of 2, 4-D with Triazine and surfactants should be adopted. If need be second application should be made at infested spots.

A package of weed control programme

For complete weed control in cane field, control measures have to be adopted during intercrop cycles, land preparation and post planting phase of cane crop. During the cultivation operation weeds have to be rouged out. All measures should be taken for eradication of rhizomatous weeds in the field as well as on the bank of water channels. Rhizomes have to be dug and dried. Where it is not possible to mechanically destroy the rhizomes, chemical treatment may be applied.

Intercrop cycles: Terbacil @ 6-9 kg h^{-1} when incorporated in the soil gives excellent control of nut grass for 12-18 months. But the herbicide is highly persistent in soil and can prove toxic for subsequent crop growth (Walter and Burgis, 1968). The chemical can safely be applied on water channels. On fallow fields application of Bromacil @ 6.5 lbs a.i acre^{-1} gives very effective control of Bermuda grass. The combination of TCA (15 lbs) + Dalpon (5 lbs) is also effective against this weed.

Intermittent cultivation and spray of chemical give effective control for a long time (Peng, 1984). Round up 1-2 qts a.i + surfactant or Dowpon M 6-8 lbs a.i + surfactant also give effective control (Anon, 1989). By using Round up and Dowpon cane crop can be planted about a month after application.

For weed control on open spaces in cane fields and banks of water channels paraquat + dalopon + 2, 4-D may be sprayed for effective control of hardy weeds. Bromacil can also be used with 2, 4-D (Peng, 1984).

In the absence of proper soil moisture application of herbicide is not that effective. The herbicides have to be used as pre-emergence or post-emergence under optimum soil moisture conditions. Irrigation constraints require moisture conservation for which hoeing and inter row cultivation would be more feasible measure for weed control. Otherwise the herbicides have to be used as pre-emergence or post emergence treatment

Herbicides for post-planting phase.

The herbicides showing successful control of weeds in sugarcane by various workers are listed here under.

Pre-emergence
Gesapax combi (80 WP): 2.5 - 3.5 kg ha^{-1} (Malik et al, 1986; Shafi
Weeds and Their Control

Metribuzine 2 kg a.i ha\(^{-1}\)  (Kanwar, 1986; Khan, 1989)
Atrazine 1.0 kg a.i ha\(^{-1}\) + 2, 4-D (Na salt) 1.0 kg a.i ha\(^{-1}\)  (Kanwar, 1986)
Sencor 1.0 – 1.5 pt acre\(^{-1}\)  (for annual weeds and grasses)  (Annon, 1989)
Sencor 2.0 – 2.5 pt acre\(^{-1}\)  (for annual weeds and Johnson grass)  (Annon, 1989)
Karmax 1.5 lb acre\(^{-1}\), only for plant cane  (Annon, 1989)
Sinbar 0.5 lb acre\(^{-1}\), for annual weeds and grasses  (Annon, 1989)
Diuron @ 4 – 5 kg/ha  (for grasses)  (Mc Intyre, 1980)

**Post-emergence**

Gesapax combi 2-3 kg ha\(^{-1}\) +2,4-D 0.75 kg ha\(^{-1}\) + surfactant 0.2%  (Malik et al, 1986; Afghan, 1996)
Evik + 2, 4-D + surfactant  (Annon, 1989)
Dowpon + 2, 4-D + surfactant  (Annon, 1989)
Asulox 4.0 pt acre\(^{-1}\), for rhizomes of Johnson grass  (Annon, 1989)
Diuron 4-5 kg ha\(^{-1}\) + 2,4-D amine 3-5 l ha\(^{-1}\) (Mc Intyre, 1980)
Diuron 4-5 kg ha\(^{-1}\) + gramoxone 1.8 l ha\(^{-1}\) (Mc Intyre, 1980)
Diuron 2.5 kg ha\(^{-1}\) + Actril DS 1.8 l ha\(^{-1}\) (Mc Intyre, 1980)
Dalapon 3-5 lbs acre\(^{-1}\) + asulox 5-7 pt acre\(^{-1}\) + surfactant 0.2%  (Annon, 1989)

**Herbicides for use in inter cropping**

The crops grown as inter crop in inter-row spaces of sugarcane are wheat, mustard, potato and vegetables like peas, onion, garlic, cabbage, tomato as well as beans, mung, mash and ground nut. The herbicides such as atrazine, ametryne, metribuzine and asulox have residual effect and are not suitable for inter crop. Safe application of herbicides treatments are suggested as under (Hunsigi, 2001).

For legume crops like pulses, soyabean, ground nut, potato and oil seeds:

Linuron @ 1.5 kg ha\(^{-1}\) or alachlor @ 1.5 kg ha\(^{-1}\)

For pulses and oil seed:

Oxyfluorfen (Goal) @ 0.3 kg a.i. ha\(^{-1}\)

For ground nut and soyabean:

Amiben 0.7 kg ha\(^{-1}\)

**Follow up treatment**

In case of new emergence, weeds escape the first treatment, second application may be given. As per requirement spray application may be on spots. Besides the application of herbicides on cane rows the cane crop may be given hoeing or inter-row cultivation in inter-row spaces. It economizes the use of herbicides on cane rows only and also serves the purpose of hoeing and mulching for moisture conservation. One pre-emergence application of Gesapax combi followed by inter-row cultivation during tillering gives better crop stand and yield.
Practical Considerations for Effective Chemical Weed Control

Selection of herbicide: Herbicides are to be selected considering the types of weeds in cane fields and stage of crop and weed growth. The grasses, sedges and broad leaved weeds require different herbicides for their control in pre and post emergence stage of weed growth. Response of cane to herbicides differs before and after its germination. Cane in two and three leaf stage is susceptible to many herbicides, and cane varieties also show different reaction to herbicide application.

Soil moisture: For absorption of chemicals by roots of weeds, they must reach the root zone in the soil. Therefore the soil moisture is essential for the down movement of the chemicals. The pre-emergence application should therefore be made when there is sufficient moisture in the field, or before expected rainfall. However, post emergence foliar application should be avoided during or immediate before rainfall. A rain free period of 6-12 hours is enough to allow maximum absorption of chemicals by leaves.

Soil types: Increasing contents of organic matter and clay in the soil absorb the chemicals and reduce effectiveness of the herbicides. Therefore dosage rate for heavy organic soils are relatively higher for pre-emergence application than for light to medium soil types. For better action the soil should be well prepared to good tilth. Uneven coarse and clod soil does not give good results in pre-emergence application.

Spray equipment: For small land holding knapsack sprayers with continuous pumping system would give good results. The sprayers may be fitted with flat spray nozzles or even spray nozzles with tee jet tips or flood jet tips. These allow speedy work and make even distribution of spray liquids. Pumps are available to cover one or two rows of cane at a time. Special directed nozzles might be used for contact herbicides or non-selective herbicides.

For large holding tractor mounted boom sprays are used. They are fitted with flat spray nozzles well aligned according to cane rows. The spray drift should be avoided keeping the working pressure low to the range of 2-3 atm or 30-40 p. s. i. Mechanical or hydraulic jet agitation is necessary to uniformly mix the spray suspension.

Dose and concentration of herbicides: In herbicidal control of weeds great attention should be given to the recommended dose and formulation of the solution/ suspension. The chemical dose, more or less than the recommendation is likely to injure the crop, or get poor weed control, and thus wasting the chemical. It relates to the concentration of the solution with desired volume of water. The grower should have a thorough knowledge about the composition and physical properties of the herbicide. Calculation during preparation of spray liquid should be quite clear. The water to be used for making solution should be soft, as hard water may react with some herbicides to make precipitate that may affect the efficiency of the spray.

Spray volume: Speed and pressure of the pump, type of nozzle, its height above ground or nozzle spacing on a boom controls the amount of spray liquid on a given area. Usual spray volume ranges from 300 to 500 litres per hectare. In case of post emergence application, the weeds should be thoroughly covered with spray liquid. Heavy weed infestation with taller and denser population may require greater amount of spray liquid.

Uniform application: The chemical should be applied at a uniform speed and pressure,
keeping the nozzle at the even height above weeds. For correct output and distribution the spray equipment should be calibrated.

**Time of Spray:** Spray application should be preferred in the morning or late after noon to avoid high temperature and rapid drying of the solutes. Spray should be made during wind free environment. Delay in spray to May or June months when temperature get high is likely to cause phyto-toxicity in plants. Similarly spray application during cold months of December - January is not as effective as in mild season.

**Surfactants**

The application efficiency of foliar applied herbicides can be enhanced by adding some surfactant during preparation of the herbicide solution in water. They are in fact surface acting wetting agents, which include material as emulsifiers, detergents, and wetting agents. Surfactants have the following properties (Peng, 1984).

a) Increase solubility of the herbicide in water and increase retention on leaf surface.

b) Increase penetration of herbicides by increasing the area of contact between the droplets and leaf surface.

c) Increase penetration by eliminating the air film between droplets and leaf surface.

d) Increase direct entry through stomata by lowering the surface tension of the herbicide solution.

They main function is to ensure rapid penetration into treated plants. The surfactant thus offset the effect of rain occurring within a few hours of application, which could otherwise wash away the herbicide before its absorption by plant foliage.

Surfactants are usually added at a concentration of 0.01 to 0.5 percent of active ingredient of surfactant. Lower concentrations are used when the herbicides are of soluble types. In case the herbicides are not much soluble (e.g. diuron), high concentrates to the order of 0.5% are used. Since surfactants increase the application efficiency of herbicides, the dose of herbicide material can be reduced. The data in Table 10.04 show the economic efficiency of the surfactant used with herbicide "Gesapax Combi in cane crop. The data in Table-10.04 reveal that the lower dose of Gesapax combi at 2.5 kg ha⁻¹ gave significantly higher yield of cane with higher cost: benefit ration over the recommended dose of 3.5 kg ha⁻¹ (Table-10.04). Thus surfactant, besides increasing the efficiency considerably economizes the application rate of herbicide.

**Table 10.04. Role of surfactant in accelerating the effect of herbicides on sugarcane**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Tillers per plant</th>
<th>Millable canes ha⁻¹</th>
<th>Cane yield t ha⁻¹</th>
<th>% variation in yield</th>
<th>Cost benefit ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weedy check</td>
<td>0.79</td>
<td>111.64</td>
<td>73.08 d</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Use of herbicide Gesapax combi @ 3.5 Kg ha⁻¹</td>
<td>1.27</td>
<td>115.65</td>
<td>84.47 b</td>
<td>15.95</td>
<td>1:2.83</td>
</tr>
<tr>
<td>Gesapax combi @ 2.50 Kg ha⁻¹ +surfactant</td>
<td>1.49</td>
<td>122.20</td>
<td>90.06 a</td>
<td>23.23</td>
<td>1:6.81</td>
</tr>
<tr>
<td>Gesapax combi @ 3.75 Kg ha⁻¹ + surfactant</td>
<td>1.27</td>
<td>117.35</td>
<td>82.39 bc</td>
<td>12.73</td>
<td>1:3.10</td>
</tr>
</tbody>
</table>

Afzal et al, (1994)
Chemical vs mechanical control of weeds

Which method of weed control to adopt depends on irrigation frequency and planting method? In the case cane field after planting and irrigation is ploughed and planked to conserve moisture till germination, there is no fun to apply herbicides on dry soil surface. The cane field is either hoed or cultivated in inter-row spaces on completion of germination. In case the crop is planted in deep furrow and is to receive irrigation as and when required to accelerate germination, the field has to be sprayed with pre-emergence herbicide after about a week or two of planting. One application of herbicide would be enough or may require one follow up post emergence spray. But in repeated irrigation condition hoeing operation will need to be repeated and would prove much expensive compared to chemical treatment.

The chemical and mechanical methods of weed control have their own limitation and requirements. The studies conducted indicate that statistically both the methods were equally good for cane yield, but herbicidal treatment was more economical and gave higher cost benefit ratio than the mechanical control (Table-10.05).

If irrigation is not a constraint, full package of mechanical hoeing is a costly operation than chemical control. Nevertheless hoeing and cultivation in cane crop have their own benefits of loosening the soil for root and tiller development. All the treatments, with hoeing operations, show higher tillering than the application of herbicide alone. Maximum tillering and yield was recorded in the treatment of pre-emergence application of herbicide followed by inter-row cultivation during tillering stage in June. This treatment gave the highest cost benefit ratio.

Practically, herbicidal applications give better check on weed growth due to its residual effect for 8-10 weeks. The inter-row cultivation, after 8-10 weeks of herbicide application, helps in soil aeration, better tillering and plant development. The use of herbicide can further be economized by its spray on cane rows only, associated with cultivation in inter-row spaces.

Table-10.05 Economic comparison of herbicides with and without cultural operations in cane crop

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Tillers per plant</th>
<th>Millable canes t ha⁻¹</th>
<th>Cane yield t ha⁻¹</th>
<th>% variation in Yield</th>
<th>Cane benefit ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of weedicide (Gesapax combi 3.5 Kg ha⁻¹)</td>
<td>2.55</td>
<td>112.80</td>
<td>74.60</td>
<td>38.15</td>
<td>1:8.8</td>
</tr>
<tr>
<td>Two hand hoeing + one inter-row cultivation</td>
<td>3.27</td>
<td>104.42</td>
<td>71.08</td>
<td>31.63</td>
<td>1:3.6</td>
</tr>
<tr>
<td>Hand weeding in cane rows + herbicides in inter-row spaces</td>
<td>2.93</td>
<td>129.18</td>
<td>79.63</td>
<td>47.46</td>
<td>1:7.8</td>
</tr>
<tr>
<td>Herbicide on cane rows + cultivation in inter-row spaces</td>
<td>2.73</td>
<td>101.44</td>
<td>73.58</td>
<td>36.26</td>
<td>1:5.7</td>
</tr>
<tr>
<td>Only hoeing &amp; cultivation in inter-row spaces.</td>
<td>2.33</td>
<td>103.79</td>
<td>69.63</td>
<td>28.98</td>
<td>1:6.7</td>
</tr>
<tr>
<td>Use of herbicides on whole plot followed by inter-row cultivation in June</td>
<td>3.18</td>
<td>124.10</td>
<td>80.89</td>
<td>49.80</td>
<td>1:10.0</td>
</tr>
</tbody>
</table>

Malik et al, (1986)
Chapter-11

Cane Maturity and Harvesting

Cane after passing certain period of vegetative growth enters into reproductive phase of flowering and seed production or into stage of crop ripening and maturity. The period of vegetative growth may prolong for 18-24 months in long duration crop of tropical belts or 7-10 months in short cropping of sub-tropical regions. During the earlier phase of active crop growth the carbohydrates manufactured in leaves are primarily utilized in the growth of stem, leaves and roots and a little stored in storage tissues. With termination of growth phase and in the conditions favouring ripening and maturity, the whole physiological system of carbohydrate synthesis reverts by converting invert sugars to sucrose and its storage in inter-nodes. With advent in the maturity phase of the crop plant growth is restricted; water and nitrogen reserves in plant are depleted under declining temperature conditions.

In the process of stalk maturation each individual internode is changed from vegetative state to the state of food reserves. It is an ongoing process measured by progressive decrease in soluble solids (brix) within the successive internodes of the stalk. In the initial stages of cane stalk development the lower internodes would be more mature and a large percentage of soluble solids would be sucrose. The immature stalk with top internodes contain more of glucose and laevulose sugars that provide readily available energy to growing parts of the plant. With the advance in plant age and with lowering of temperature the sugar accumulation gradually continue in middle and upper portion of cane stalks. In fully mature cane the difference in sucrose contents of bottom and top portion of cane stalks minimizes. This is the time that gives maximum sugar at harvest though of course it is affected by a number of agro-climatic factors.

Cane harvesting period

As the cane ripens, cane harvesting proceeds with start of sugar mills crushing season. In principle, cane maturity is attained during cooler months of the year. In Northern hemisphere harvesting proceeds from October to March-April or may extend to July-August in tropics, while in Southern hemisphere harvesting season falls in June-October season. Nevertheless, cane-crushing season in tropical regions may cover 280 – 300 days, while in sub-tropical or temperate regions the crushing period is reduced to 90 – 180 days. In countries with severe frost spell the cane-crushing period may even be reduced to 75 – 80 days as observed in Louisiana. The cane harvesting periods of some of the countries are shown in Table-11.01.

In Indo-Pakistan sub-continent cane crushing season starts with onset of autumn and completes by the end of spring season. Length of crushing season depends on the volume of crop available for crushing. Thus the crushing season varies from year to year. Normally it ranges from November to April. It may be extended to May if cane plantation is large or crushing may be squeezed to November-March or even December-February season if cane plantation is somehow reduced.
Table 11.01 Cane crushing period in countries falling in North and South Hemisphere

<table>
<thead>
<tr>
<th>Country</th>
<th>Latitude</th>
<th>Harvesting period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mauritius</td>
<td>&quot;</td>
<td>May – Oct.</td>
</tr>
<tr>
<td>Argentina</td>
<td>&quot;</td>
<td>May – Oct.</td>
</tr>
<tr>
<td>Brazil</td>
<td>&quot;</td>
<td>May - Oct.</td>
</tr>
<tr>
<td>Philippine</td>
<td>Northern hemisphere</td>
<td>Oct. – May</td>
</tr>
<tr>
<td>Florida</td>
<td>&quot;</td>
<td>Oct. – Apr.</td>
</tr>
<tr>
<td>Louisiana</td>
<td>&quot;</td>
<td>Oct. – Jan. 1st week</td>
</tr>
<tr>
<td>Pakistan</td>
<td>&quot;</td>
<td>Nov. – April</td>
</tr>
<tr>
<td>India – Sub-tropical</td>
<td>&quot;</td>
<td>Nov. – Apr.</td>
</tr>
<tr>
<td>Tropical</td>
<td>&quot;</td>
<td>Nov. -August</td>
</tr>
</tbody>
</table>

Under Pakistan conditions cane ripening initiates around September; sugar accumulation is rapid up to December-January and gradually lowers by February onward. Except in late maturing varieties sugar is at peak stage during December - January and part of February. Thereafter sugar recovery declines and rate of decline is faster with rise in temperature. If cane is allowed to stand in the field after its maturity, sucrose gets decomposed with the formation of non-sucrose compounds and cellulose. Thus the over mature cane builds up higher fibre with reduced sucrose and increased invert sugars and other compounds. The harvesting should therefore be completed as the cane attains full maturity. There are a number of physical and chemical parameters that indicate the maturity stage of cane crop.

Factors affecting cane quality

Quality of a mature cane is affected by the following factors:

1. Cane variety.
2. Extraneous matter including trash, tops, stubble roots, weeds and soil particles.
3. Fibre in cane stalk.
4. Ratio of green tops and trash to cane.
5. Post harvest staling and delays before cane crushing.
7. Natural hazards: drought, frost, storms, cyclones, floods.
8. Disease and pest infestation.
9. Ambient environment conditions and infestation by microorganisms.
10. Moisture content of cane and juice percentage.
11. Physical damage to cane stalks during harvesting and haulage.
12. Soil type, salinity and water-logging, where the crop is grown.
Sugarcane quality in this context means the quality of cane as it arrives at the sugar factory. The harvesting practices, cane transport and cane delivery procedures are also included in the factors affecting sugarcane quality.

**Cane sampling**

For recording data un-biased collection of cane sample is of prime importance. Cane sample should represent whole mass of the crop the sample is taken from. Instead of selecting most healthy individual cane stalks, whole clump of cane stalks, including primary and secondary shoot stalks should be harvested and sent to the laboratory for analysis. At least three such clumps should be randomly selected from the field, harvested and mixed to make a composite sample for one test.

**Cane quality parameters**

Cane quality in the field, is assessed by Brix reading and in laboratory by complete juice analysis for Brix, Pol, Purity, invert sugars and acidity level.

True sucrose is now measured by chromatographic method and is recognized to be more accurate and less subject to distortion than analysis for Pol.

**Brix % juice**

The term Brix is the total dissolved sugars and salts that include sucrose, as well as reducing sugars the glucose and fructose. The Brix can be measured by hand refractometer or by a hydrometer calibrated with temperature, in the laboratory. Now computerized brixometers are often used. The ‘Brix’ reading taken by hand refractometer is slightly higher by about 0.5\(^0\) than the Brix recorded by the hydrometer.

Brix has direct relationship with sugar in cane. Mature cane indicates more of sucrose with lesser amount of reducing sugars and non-sugar dissolved solids. The Brix gives indication of maturity of cane stalk in the field. During ripening phase accumulation of sugar start in the bottom internodes and generally continue towards upper segments. In the early phase of crop maturity Brix is higher in bottom portion of stalk and lower in upper internodes. As maturity proceeds Top: Bottom ratio narrows. Crop is said to be mature with a ratio of 0.95 – 1.0. Brix is a good indicator of maturity during early periods of maturity. In over mature cane that has undergone inversion due to frost or staleness or very late harvesting period of April-June, Brix value is higher but with low value of Pol. Under such conditions Brix has no relationship with sugar contents in juice.

**Pol % juice**

It is the sugar % juice recorded after clarifying the juice sample and taking the Pol reading in a polerimeter or saccharimeter. Computerized ‘Sucromat’ are now being used in laboratories that record most précised reading of Pol. The Pol reading is in fact the angle of light waves that passes through the juice media. The light waves passing through sucrose solution rotate to a certain degree depending on sucrose concentration. This Pol reading is then matched with a Pol Table to get exact Pol in juice, at standard temperature, correlated with ambient temperature. In stale cane or frost affected cane, juice may give a false reading due to the dextro-rotatory compounds like dextran or and organic acids developed in juice.
Purity

It is simply the ratio between the Brix and Pol in juice

\[
Purity = \frac{Pol}{Brix}
\]

Higher purity in juice is due to higher Pol compared to Brix value. Purity is a better maturity index of cane. The juice with low purity contains more of non-sugar compounds. The quality of juice should not be valued on the basis of higher Brix; high purity is a good indicator of juice quality.

Non sugar: Pol ratio

The juice quality can best be judged by the non-sugar : Pol ratio as:

\[
\left( \frac{Brix - Pol}{Pol} \right) \times 100
\]

The lesser value of this ratio would indicate better quality juice. A cane juice sample with 20º Brix and 15º Pol would have 33.3 % non sugar Pol, while the other sample with 20º Brix and 17º Pol would have 17.6 % non sugar Pol ratio. The former sample has more of non sugars than the later; it would thus be producing lesser sugar and more of losses due to having more of non sugar compounds in juice.

N I R technique

In advance cane growing countries, true sucrose is now measured by highly sophisticated techniques, of which chromatography methods and NIR are often used in modern world. NIR – Near Infra Red Spectroscopy gives most accurate measure of sugars at any stage of cane processing in the laboratory or the processing plant.

NIR gives online analysis of factory prepared cane, cutter grinder prepared cane, final and intermediate bagasse, cane juice, raw and refined sugar, cane fibre, routine laboratory analysis for cane and sugar. The benefits of the system are:

- The technique is not subject to any distortion as is observed in conventional methods.
- Minimum or no sample preparation is required.
- Safe-no harsh chemical is required for the analysis.
- Multiple simultaneous analysis.
- Fast- online analysis for every 20 seconds.
- It is very precise and reliable.
- Can be applied directly during the milling process to analyse any requisite cane and juice component.
- The system can give more precise results for cane payment system.

Cane maturity indicators:

Crop maturity in the field can be indicated by some physical and morphological...
characters of cane and by recording Brix reading. Cane is not fully mature when Brix unit of upper internodes are much lower then the Brix of lower internodes. When this difference narrows to 1.0 unit or even less, cane is said to be mature. A number of physico-biochemical indicators of maturity have been reviewed by Solomon et al, (2000).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Indicator-signs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cane plant</strong></td>
<td></td>
</tr>
<tr>
<td>Foliage appearance</td>
<td>light green to pale yellow, drying and shedding of lower leaves.</td>
</tr>
<tr>
<td>Stalk growth</td>
<td>growth ceased</td>
</tr>
<tr>
<td>Sheath moisture</td>
<td>drop from 85 to 72 % or less</td>
</tr>
<tr>
<td>Nitrogen index in leaves</td>
<td>drop from 2 % to 1.25 % or less</td>
</tr>
<tr>
<td><strong>Cane juice quality</strong></td>
<td></td>
</tr>
<tr>
<td>Brix</td>
<td>higher than 18</td>
</tr>
<tr>
<td>Sucrose</td>
<td>higher than 16</td>
</tr>
<tr>
<td>Purity</td>
<td>higher than 85</td>
</tr>
<tr>
<td>Reducing sugars</td>
<td>level falls 0.4 to 0.2 % or even less</td>
</tr>
<tr>
<td>‘N’ in juice</td>
<td>around 200 ppm</td>
</tr>
<tr>
<td>‘P’ in juice</td>
<td>around 300 ppm</td>
</tr>
<tr>
<td>‘K’ in juice</td>
<td>around 1000 ppm</td>
</tr>
<tr>
<td>Brix – top: bottom ratio</td>
<td>&lt; 0.90 (immature)</td>
</tr>
<tr>
<td></td>
<td>0.95 – 1.0 (mature)</td>
</tr>
<tr>
<td></td>
<td>1.00 – 1.2 (over mature)</td>
</tr>
</tbody>
</table>

**Factors Affecting Maturity / Sugar Recovery**

**Weather**

The process of cane maturity is hastened by climatic factors, temperature, moisture and sunlight. In the absence of suitable ripening condition even the genetically high sugar varieties would not mature. Cool dry weather is considered the most effective factor inducing ripening in a full grown crop. A prolonged period of cool weather retard growth and improves sucrose in cane stalk even with ample supplies of nitrogen and soil moisture. Bright sunny days with temperature of 28°-30°C and low night temperature of 12°-14°C coupled with low relative humidity (50-55%), favour the ripening and accumulation of sucrose in storage tissue (Ali, 1996). Juice quality under minimum temperature range of about 7°-14°C tended to improve while in the range of 0 to 5°C sugar contents in juice tended to decrease (Panje et al 1964). Cold spell of lower than 5°C disrupts normal ripening in plant and increase reducing sugars and dextran. It has been established that with low night temperature, a wider difference in diurnal temperature condition induces better maturity in cane crop (Anonymous, 1970). With the termination of winter, weather gets warm and plant resume growth with rise in reducing sugars and a drop in sucrose contents.

Sunlight with intensity and duration is an important component of sugar synthesis and ripening process. The maturing process proceeds with lowering of temperature under
good sunny days. In rainy days and cloudy conditions the maturity curve often declines and resumes maturity with clear days under low temperature.

**Planting time**

Crop attaining longer growth period would establish a vigorous stand and more metabolites in cane stalks to synthesize sugar than a short season crop. It is why cane plantation in tropical regions has higher sugar recoveries than sub-tropical areas. In Pakistan, lower Sindh, where cane is planted in September depicts high levels of sugar recoveries than the Punjab, where cane is generally planted in spring season. Studies carried out on planting time at Sugarcane Research Institute, Faisalabad indicate that cane planted in autumn season has more or less 10% higher recoveries than the spring planting. And even in spring season, as the planting is delayed, there is a gradual drop in sugar recovery (Fasihi and Malik, 1989).

The planting time determines the age of crop, longer crop cycle avails of more solar energy to synthesis metabolites in plants for syntheses of carbohydrates. With longer crop age, the vigorous stand of cane stalks has more impact on the age. In this context early-developed shoots having vigorous stand would yield higher sugar than a slow growing crop. Therefore, the crop planted even earlier in the season should be nourished well with timely irrigation and fertilizer.

**Irrigation**

Adequate supplies of irrigation water are essential for uptake of nutrients by plant to promote the growth and development of cane, and metabolic activities in plant tissues followed by sugar synthesis and its accumulation. To have good sugar yields the crop has to be given adequate irrigation during grand period of growth (Sonu et al, 1979). During ripening phase sucrose accumulation is controlled through irrigation management. Water deficit hastens maturity by curtailing growth of plant. As the maturity approaches, the large top of 12-15 green leaves should be reduced to 6-8 green leave. Moisture in leaf tissues is a good indicator of ripening process. For inducing ripening sheath moisture should drop from 85 to 72% (Alexander, 1973; Chiranjivi Rao, 1987).

Moderate drought conditions during ripening period retard growth and accelerate the sucrose formation and its storage in internodes. Irrigation just before harvesting increases cane weight but brings marked reduction in sugar recovery. In studies at Faisalabad it was observed that restriction of irrigation 30 days prior to harvesting improved juice quality, while irrigation 5 days before harvesting lowered the sucrose 30 days (Table-11.02). However, harvesting cane just after irrigation gives considerable increase in yield and 30 days interval in irrigation shows marked reduction in yield. So as to harvest good sucrose yield it is now a recommended practice to withhold irrigation 20-30 days before harvesting.

In low temperature condition effect of irrigation can be soon mitigated but under moderate winters conditions frequent irrigation continues growth depressing the sugar accumulation.

Under sub-tropical conditions temperature is the key factor to induce ripening. Under tropical conditions, however, temperature has a lesser role to play; more emphasis is laid
on leaf moisture and nitrogen factors to induce forced ripening.

Table-11.02 Effect of pre-harvest irrigation on yield and quality of sugarcane at different periods of harvesting

<table>
<thead>
<tr>
<th>Time of harvesting</th>
<th>Irrigation days before harvest</th>
<th>Cane yield t ha(^{-1})</th>
<th>% variation over 5 days</th>
<th>CCS % cane</th>
<th>% variation over 5 days</th>
<th>% variation over 30 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 Nov.</td>
<td>5</td>
<td>58.27</td>
<td>11.61</td>
<td>10.95</td>
<td>- 1.37</td>
<td>1.35</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>51.50</td>
<td>13.14</td>
<td>11.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Jan.</td>
<td>5</td>
<td>62.46</td>
<td>8.87</td>
<td>11.75</td>
<td>- 0.94</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>56.92</td>
<td>9.73</td>
<td>11.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Mar.</td>
<td>5</td>
<td>51.06</td>
<td>15.60</td>
<td>12.47</td>
<td>- 5.53</td>
<td>5.24</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>43.09</td>
<td>18.50</td>
<td>13.16</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


If water and nitrogen are continually provided with suitable temperature and growing conditions, the plant may not fully mature regardless of its age. Cessation of growth by regulating the supply of water and nitrogen in cane plant would accelerate sugar accumulation.

In upper Sindh, Punjab and NWFP, irrigation is applied during winter just keep up the plant vigor so as to withstand frost and maintain a certain level of moisture in cane stalks. However, in lower Sindh condition the moderate temperature is somewhat high, irrigation causes continued growth and ripening is slow. In such areas special attention has to be paid to withhold irrigation to improve ripening and harvest good sugars.

Drought conditions during grand growth period have deleterious effect on sugar accumulation. Fibre contents are increased and storage tissues are badly affected. However, the magnitude of effect varies with the severity of drought stress and the cane varieties (Ali, 1996). If the deterioration has not progressed very far in the cane roots system or in its top, then the irrigation can help give rapid recovery to resume normal growth. If number of green leaves has been reduced to three or less and the roots system has lost its absorbing power, the recovery is slow and growth rate never reaches normal. These periods of low moisture supply are easily identified by the short internodes in the stalk.

Fertilizer

Fertilizers are concerned with respect to metabolic function of plant. They may promote active luxuriant growth when available in excess of the required level or deficiency may depress the growth. Good juice quality is attained under balance use of fertilizers including micronutrients. Nitrogen when applied in excess promotes vegetative growth, delays maturity, and has detrimental effect on juice quality. However needs of crop vary under different set of soil and climatic condition. Exact dose has to be worked out to harvest good sugar yields. To attain good early maturity, plant growth should be accelerated by earlier application of fertilizer. The fertilizers should be applied in the first three months of cane planting for spring plant; for autumn planting fertilizer application
should be completed by the month of April. Fertilizer application is sometimes delayed due to irrigation constrains, however to attain timely maturity in crop, nitrogen applied should be fully taken up by the crop two to three months before harvesting. A timely and judicious application of fertilizer is emphasized for optimum sugar synthesis and accumulation in cane stalk. A laboratory analysis indicates relationship of NPK in juice to cane quality. To achieve high sucrose contents cane juice should contain 200 ppm ‘N’, 300 ppm ‘P’ and 1000 ppm ‘K’ (Soloman, 2000). It was further reported that every increase in 10 ppm ‘N’ brought a 0.07 percent decrease in sugar recovery. Late application also adversely affects juice quality (Srivastava, 1994). N contents of leaves are the best indicator of juice quality. There is a negative correlation of leaf N with sucrose in juice. The 3-6 leaves N during growth stage is around 1.8-2.01, which is reduced to 1.2-1.3 % at maturity (Ali, 1996).

Phosphorus in cane has important role in clarification of cane juice during the process in the factory (Hogarth and Allosopp, 2000). After liming and heating, it ensures good flocculation of the precipitated non-sugar with a satisfactory rate of settling and clarified juice of minimum turbidity. Therefore, for better clarification of juice cane crop should not be ‘P’ deficient and its requirements should be met by ‘P’ fertilization.

Potassium has a significant role in improvement of juice quality (Hogarth and Allosopp, 2000). It has specific role with reference to balance use of ‘N’ in plant especially in later stage of crop growth. Soluble organic N is often higher in concentration in low potassium plants than in high potassium plants. Further that carbohydrate synthesis is reduced and metabolism is affected under condition of K shortage. Potassium keeps the nitrogen and moisture relation ship within their optimum level. The cane fields with critically low K levels result in high moisture, high reducing sugar, low sucrose and low purities with higher ton cane per ton sugar ratio.

**Soil type**

Organic rich soils conserve more moisture than organic deficient soils thus crop grown in the former case matures a little late. Crops grown in sandy and sandy loam soils mature relatively earlier due to lesser conservation of moisture than the crop grown in clay or clay loam soils which retain more water.

**Soil salinity**

Excess salts in soil result in poor moisture economy within the plant and poor juice quality. During ripening process, irrigation intervals are extended for dehydration of cane to induce maturity. In this practice cane plant face problems in saline soils. The excess salts increase the osmotic pressure and reduce the plants ability to obtain moisture from soil. Increased salts concentration in cane, with less moisture, cause problem in the milling process. The effect of sodium is more pronounced in lowering of sucrose in juice. Excess salts, particularly sodium also brings forced ripening in cane.

**Cane varieties**

Cane varieties have the inherent ability to give high or low sugar recoveries. Successive breeding efforts have made possible to develop varieties with 13-14% sugar recovery. The recurrent selection cycle in Louisiana gave a progressive improvement in sugar
recovery from 10.8% before 1949 to 14.1% in 1990 (Legendre, 1995). Progress in quality variety development is well marked in Australia, showing a sugar yield of 3.5 tonnes per hectare in early 1900 to 13.5 tonnes per hectare by the end of the century (Hogarth and Allsopp, 2000). In Pakistan as well variety development work has shown improvement in sugar recovery from 8.5% in Co 312 during 1930-40 to 11.5% in Th. 10 and 12.5% in CPF 237 during 2000-2005, period.

Cane maturity is a continuous process that starts with the termination of cane growth period; invert sugars i.e. glucose is transformed into sucrose which is then accumulated into storage tissues of cane stalks. Cane varieties, however, differ in their period of ripening. Cane varieties are characterized to mature in early, mid or late crushing season and may possess high or low recoveries. In early varieties the process of growth cessation and sugar accumulation starts earlier. Such varieties accumulate more sugar in a lesser period of growth, compared to mid or late season maturing varieties. However, sugar contents gradually increase with the advance in crushing season till a peak is reached. The growth behavior also varies with varieties. Some varieties show a progressive growth with gradual increase in sugar contents up till March (CV. BF 162), while others show their peak up till January and sugar contents decline thereafter (CV. BL 4), such varieties loose their cane weight in late harvesting. Since early maturing varieties culminate their growth in earlier period than late maturing varieties, are usually low yielders. Each variety has an optimum age of maturity. It is however established fact that early varieties maintain higher level of recoveries for longer duration in a maturity season than the late maturity varieties. Therefore, early varieties always harvest higher sugar yield per unit area. Cane varieties may be selected which are though early maturing but have very fast growth rate. The varieties BL 4, BF 162, SPSG 26 have fast growth habit, while L 116 and CP 43-33 have slow growth rate.

Mid season varieties like Tritron and CoL 54 do not contain good sugar content until the middle of the crushing season, say mid December under Pakistan conditions. These show progressive increase in sugar content with advance in crushing period.

Late maturing varieties attain good sugar contents late in the crushing season. They attain a short period of last 5-6 weeks of crushing period. These varieties have long growing season and are generally high yielder. In extended crushing season they yield higher sugar per hectare. The varieties L 118, Co 1148 and NIA 98 represent this group.

The periodic sugar recoveries of different varieties under cultivation in Punjab- Pakistan are shown in Table-11.03.

A cane crushing season may respond differently for different cane varieties. In a short crushing season, say 90-100 days, there is practically no scope of late varieties. However, in a late crushing season extending to over 150 days, some late maturity varieties would sustain high sugar yield in late season than early varieties.

To grow an early or late maturity varieties are of great economic consideration both for
growers and millers. Cane growers prefer to grow high yielding varieties, while miller's choice is to crush high sugar variety. The easiest approach to increase sugar production is to encourage early maturing varieties in harvesting programme. To cover the yield and recovery interaction, the criteria should be the sugar yield per unit area and time rather then the cane yield or the sugar contents only.

Table-11.03 Periodic sugar recoveries of some commercial varieties at Sugarcane Research Institute, Faisalabad

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>L 118</td>
<td></td>
<td></td>
<td>5.62</td>
<td>6.87</td>
<td>7.86</td>
<td>8.57</td>
<td>9.00</td>
<td>9.16</td>
<td>9.05</td>
<td>8.29</td>
</tr>
<tr>
<td>Co 1148</td>
<td></td>
<td></td>
<td>5.40</td>
<td>6.84</td>
<td>8.06</td>
<td>9.06</td>
<td>9.84</td>
<td>10.41</td>
<td>10.75</td>
<td>8.84</td>
</tr>
<tr>
<td>CoL 54</td>
<td></td>
<td></td>
<td>7.83</td>
<td>8.71</td>
<td>8.34</td>
<td>9.72</td>
<td>9.86</td>
<td>9.76</td>
<td>9.41</td>
<td>9.48</td>
</tr>
<tr>
<td>Triton</td>
<td></td>
<td></td>
<td>6.94</td>
<td>8.73</td>
<td>9.91</td>
<td>10.49</td>
<td>10.47</td>
<td>9.85</td>
<td>8.63</td>
<td>9.89</td>
</tr>
<tr>
<td>BF 129</td>
<td></td>
<td></td>
<td>6.51</td>
<td>8.06</td>
<td>9.27</td>
<td>10.14</td>
<td>10.67</td>
<td>10.87</td>
<td>10.95</td>
<td>9.80</td>
</tr>
<tr>
<td>BL 4</td>
<td></td>
<td></td>
<td>8.04</td>
<td>9.09</td>
<td>9.90</td>
<td>10.41</td>
<td>10.64</td>
<td>10.70</td>
<td>10.49</td>
<td>10.07</td>
</tr>
<tr>
<td>L 116</td>
<td></td>
<td></td>
<td>9.17</td>
<td>10.21</td>
<td>10.98</td>
<td>11.48</td>
<td>11.72</td>
<td>11.68</td>
<td>11.38</td>
<td>11.21</td>
</tr>
<tr>
<td>BF 162</td>
<td></td>
<td></td>
<td>7.32</td>
<td>8.56</td>
<td>9.75</td>
<td>10.26</td>
<td>10.74</td>
<td>10.96</td>
<td>10.94</td>
<td>10.05</td>
</tr>
<tr>
<td>SPSG 26</td>
<td></td>
<td></td>
<td>7.12</td>
<td>8.59</td>
<td>9.70</td>
<td>10.45</td>
<td>10.84</td>
<td>10.88</td>
<td>10.56</td>
<td>10.09</td>
</tr>
<tr>
<td>HSF 240</td>
<td></td>
<td></td>
<td>9.37</td>
<td>10.20</td>
<td>11.20</td>
<td>12.00</td>
<td>12.30</td>
<td>12.80</td>
<td>11.70</td>
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<tr>
<td>CPF 237</td>
<td></td>
<td></td>
<td>10.11</td>
<td>11.30</td>
<td>12.35</td>
<td>12.78</td>
<td>12.82</td>
<td>13.25</td>
<td>12.50</td>
<td></td>
</tr>
</tbody>
</table>

Age of crop

Long duration crop yields more cane weight and sugar recovery than a short seasoned crop. Generally cane crop in tropical belts give higher yields of cane and sugar than sub-tropical regions. And in sub-tropical regions, September- autumn planted crop is heavy yielder than a spring planted crop. And even in the same planting season early-planted crop would give higher yield and recovery than the late-planted crop. It is because the crop avails of more time to manufacture photo-synthates in cane leaves and store sugar. Higher cane yields of Maharashtra in Indian Punjab are due to long growing season. In Pakistan as well, lower Sindh region has higher yields than the upper Sindh, Punjab and NWFP provinces.

Experiments on planting season indicate that cane planted in autumn gave 0.5 to 0.8-unit higher sucrose than the crop planted in spring. The importance of autumn plating over spring crop with respect to sugar recovery and yields has been invariably been reported by a number of workers (Fasihi and Malik, 1989; Yadev, 1991).

Harvesting period also has its impact on cane and sugar yields. Under Punjab conditions, maximum yields are obtained when crop is harvested in January. The crop harvested in January or thereafter yields low sugar per acre. However, magnitude of yield reduction varies with cane varieties (Table-11.04).
Table 11.04 Effect of date of harvesting on the yield and quality of different cane varieties*

<table>
<thead>
<tr>
<th>Variety</th>
<th>Cane yield (tons ha⁻¹)</th>
<th>Variation over Jan. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoL 54</td>
<td>83.37</td>
<td>83.32</td>
</tr>
<tr>
<td>BL 4</td>
<td>79.53</td>
<td>86.20</td>
</tr>
<tr>
<td>L 116</td>
<td>76.24</td>
<td>80.95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variety</th>
<th>CCS % cane</th>
<th>Variation over Jan. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoL 54</td>
<td>8.95</td>
<td>11.82</td>
</tr>
<tr>
<td>BL 4</td>
<td>11.51</td>
<td>12.94</td>
</tr>
<tr>
<td>L 116</td>
<td>12.04</td>
<td>13.94</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variety</th>
<th>CCS (tons ha⁻¹)</th>
<th>Variation over Jan. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoL 54</td>
<td>7.46</td>
<td>9.85</td>
</tr>
<tr>
<td>BL 4</td>
<td>9.15</td>
<td>11.15</td>
</tr>
<tr>
<td>L 116</td>
<td>9.18</td>
<td>11.27</td>
</tr>
</tbody>
</table>

* Malik and Fasihi, 1989

Most early maturity varieties like L116 show lesser yield losses in earlier harvesting and the yield losses are the highest when harvesting is delayed till March and May. The effect of yield decline is more pronounced when measured in terms of sugar yield.

**Fertilizer**

Excessive amount of fertilizer tends to lower the juice quality. Ripening is delayed by excessive and late application of fertilizer. To accelerate early growth and to minimize the depressive effect of fertilizer, the fertilizer is to be applied within three months of planting for spring crop and before April to autumn season crop. All cultural and irrigation needs have to be met considering that the ‘N’ applied is fully taken up by the crop to almost two to three months before harvesting. At maturity a judicious level of N (200 ppm), P (300 ppm) and K (100 ppm) achieve high sugar content (Soloman et al, 2000).

**Flowering**

Induction of flowering offsets the growth of plant. Flowered cane stalks get thin and develop pith starting from upper inter-nodes and extending downward. Extent of pithiness varies with cane varieties and moisture condition. This results in more fiber contents and lesser juice and total sugar recovery. Flowered canes result in yield reduction compared to un-flowered cane. Arrowing has no immediate deleterious effect on sucrose content and purity of juice, the quality deterioration coincides with the shedding of flowers from the inflorescence. The arrowed canes mature earlier and show a superior juice quality, as compared to un-flowered cane, up to the middle of March, after which deterioration sets in (Kapoor, 1949).

**Ratooning**

A crop kept ratoon sprout much earlier than a plant crop. The early shoot formation of
ratoon increases the age of cane stalks by about one month. This helps promote more growth, longer period of photosynthetic activities and better sugar accumulations. Further the ratoon crop is exhausted of ‘N’ more than plant crop that tends to cessation of vegetative growth and termination of growth to maturity earlier in the season. Thus ratoon crop mature earlier with relatively higher sucrose contents than a plant crop.

**Water logging**

Some varieties may tolerate the effect of water logging and show a little better juice quality, but the effect is for short period. The crop is prone to the infestation of white fly and wilt disease. Long period of water stagnation results in poor juice quality with high level of invert sugar and gums.

**Lodging**

Lodging in well-grown cane mostly occurs in fertile soils receiving heavy ‘N’ fertilization following irrigation, or rainfall followed by high winds. Cane stalks may be up rooted, lay down flat or just bend. The cane stalks, may get dry in case of up rooting or buds sprout with growth of aerial roots in bent canes. Juice quality deteriorates with conversion of sucrose to invert sugars. The crop is subject to the attack of rats. A lodged crop shows severe reduction in sugars with loss in cane weight. The magnitude of loss depends on the lodging intensity and period of lodging. Lodging in earlier period shows more losses in yield and quality. The losses increase if the lodged crop remains in the field for longer period. To minimize the deleterious effect of lodging the crop should be harvested as soon as possible.

**Sugarcane pests**

Sugarcane pests cause severe loss in quality of cane juice. Sucking pests like pyrilla and whitefly suck cell sap from leaf tissues and lower the plant vitality. The secretion of pyrilla on leaf surface is covered by saprophytic black fungus, while white fly blacken the leaf surface with mucilage. These coatings on leaves hamper the photosynthetic activities, thus reducing the growth and sugar synthesis in plants. White web mites and red mites also have detrimental effect on plant growth and recovery due to sucking action of pests. The pests may cause one to two degrees drop in sucrose.

The borers make tunnels in internodes, which disrupt the conducting tissues and thus check plant growth. Borers directly damage the storage tissues, and also attract some pathogens, which cause severe reduction in juice quality. Top borers damage the growing parts of cane tops and directly check plant growth. Damage to terminal points induce sprouting of side shoots which with time convert the sucrose to invert sugars and thus reduce cane quality. Borer damage is more conspicuous.

**Sugarcane diseases**

A number of fungal, bacterial and rust diseases attack cane crop. Red rot, smut, and mosaic are serious diseases of India-Pakistan sub-continent. Pokkah boeing, rust, brown strip and ratoon stunting diseases are also invariably noticed in cane fields. These diseases affect growth and quality of cane. Red rot may even dry the cane stalks. The loss in quality varies with intensity of the disease infection.
Natural Hazard – Frost

Frost is a very injurious thermal factor to cane crop causing serious deleterious effect on yield and quality of cane. Frosts occur when the air temperature falls below freezing point. However, chilling injury to cane can occur even with a sudden fall of temperature below 5°C? At the freezing temperature water in the inter-cellular spaces is frozen, water from the cell is withdrawn that desiccates the plant tissues and increase the concentration of salts in cells. The excessive desiccation of cells and increased concentration of salts bring about coagulation and precipitation of cell colloids. Ice formation following freezing also cause mechanical injuries to cell walls bringing rapid injury to plant tissues.

Frost is a widely occurring problem in sub-tropical and temperate regions as well as in areas of high altitudes. Frost damages the crop during ripening stage. Early growth stage of autumn sown crop may also be damaged. Low temperature stress affects both yield and recovery and intensity of damage varies with intensity and duration of frost occurrence. Winter harvested crop leads to poor ratooning of stubble buds and consequent gaps. Frost effect on cane limits the availability of seed cane in some years. Frost damage to cane causes deterioration in juice quality and great bio-chemical changes followed by fermentation leading to marked reduction in sugar recovery.

Damage to crop depends on severity of frost, relative tolerance of cane varieties and conditions prevailing during and after frost occurrence. Young cane is more susceptible than mature cane. Early ripening higher sugar varieties suffer relatively lesser damage than low sugar varieties. Terminal growing point of cane is more severely affected than the lower portion. The effect may be noticed in different intensities in physical and chemical characters of plant by way of foliar damage, bud mortality and deterioration of juice quality (Singh and Rathan, 1998). Later, the leaves get dry affecting the severe loss in cane weight.
**Foliar damage:**
The effect of frost is categorized according to the intensity of frost occurrence.

1. In case of mild damage green leaves turn yellow; slightly more damage leads to browning and drying of spindle leaves.
2. Only the exposed parts are killed but rolled spindle remain green and apical meristem is saved.
3. Rolled spindle is killed while the apical meristem is saved.
4. More severe freezing kills the growing point leading to regrowth of side shoots, followed by rapid fall in sucrose contents.
5. The terminal portion of growing points decays and turns dark brown due to microbial infection. Length of decayed portion shows the extent of damage.
7. Extremely low temperature kills terminal as well as lateral buds.

**Bud mortality:** In its severe form frost has lethal effect on buds. Damaged buds turn brown, get soft to press and are incapable of germination. Bud mortality is higher in bottom and then middle portion of cane stalks and low in top section. It may be due to low sett moisture in the bottom followed by the middle and more moisture in top of the cane stalk.

Damage to buds of seed crop has a drastic effect on the germination of plant crop. Damage varies with the extent of frost and the frost tolerance in cane varieties. Buds of resistant varieties evade the shock of frost up to the freezing temperature of -3ºC, while susceptible varieties are worst hit. Under very severe frost conditions even the so called resistant varieties may not evade the effect of frosts. In case of ratoons, buds of subterranean buds lying close to soil surface are liable to be affected. Ratoon crop show very poor sprouting in year of severe frost spell.

**Juice quality deterioration:** Frost has a drastic effect on the chemical composition of cane juice. Following freeze injury dead cells become vulnerable to invasion by the bacterium, *Leuconostoc mesenteroides*. The bacterium utilizes sucrose and produces dextran (Irvine and Legendre, 1985). The bacterium entry into storage tissues is facilitated by dead lateral buds and freeze cracks. With the utilization of sucrose, fructose is also produced with lowered pH. The sucrose contents, purity and pH of cane juice are significantly decreased followed by increase in reducing sugars, electrical conductivity, titrable acidity and dextran-gum and mannitol.

Stress tolerant varieties had high level of anthocyanin in the juice. The increase in dextran content and acidity had deleterious effect on crystallization of sugar in the process (Singh and Kanwar, 1989, 1990, 1991).

Under dry weather conditions rate of deterioration is very low. But, under high relative humidity or rain accompanying warm weather following frost, damaged cane deteriorates rapidly, due to invasion of microbes.
Measures to Protect the Crop from Frost

**Radiation control:**

The crop may be protected from cold air currents by adopting several methods.

1. Crops of elongated stalks should be sown on the borders of the air currents. These prove barriers against cold air currents. Rows of Sarkanda give good protective covering to cane fields. Crops like Arhar, Dhancha, and Sunhemp planted around the cane fields may partially save from cold air currents.

2. Provide smoke screen by burning trash towards direction of wind current.

3. Flooding during frosty night raises the soil temperature to evade the effect of frost spell.

4. Green leaves have better thermal conductivity than dead leaves. The plants leaves killed by some herbicides like Paraquat reduce the heat conduction and save the cane stalks from frost spell (Singh and Rathan, 1998).

**Cane varieties:**

Some varieties possess considerable tolerance to frost.

1. Plant the varieties showing resistance to frost.

2. Cane varieties with dense leaf canopy evade the effect of frost better than the varieties with more leaf shedding.

3. The lodging resistant varieties should be cultivated. A lodged crop is severely hit by frost.

4. Early maturity varieties should be preferred. These should be harvested before the onset of frost.

**Cropping system:** In an autumn planted crop, inter cropping of suitable field crops and vegetables, can protect the newly planted cane from frost hazards.

**Irrigation:** Application of irrigation during frosty night’s can reduce the damaging effect of frost. Rain fall or irrigation increase the soil moisture with increase in soil temperature, thus the frost effect is minimized.

**Trash cover:** The stubbles of the cane harvested during October- November are liable to be damaged by frost, thus damaging the sub-teranion buds in under surface. This may give poor sprouts of ratoon. It can be saved by thick trash blanket on cane field soon after cane harvest.

**Dense plant population:** Weak and patchy stand of cane is more affected by frost than a heavy crop with dense cane stalk population.

**Removal of tops:** Upper parts of cane stalks are primarily affected by frost incident. Acidity and gums are more in top deteriorated cane portion. Topping of frozen cane low is desirable to increase quality of milled cane, to avoid processing problems.

**Soil:** Loamy soils are better than sandy loam or sandy soils. Heavy loam soils can retain
good amount of water, while sandy loam and sandy soils do not retain appreciable amount of water. Soil with lesser quantum of water loose heat energy soon, as such crop suffers more in sandy soils than the loamy soils. Organic matter in soils helps retain more moisture and also conserves energy and thus can help to withstand the ill effect of frost.

Potash in soil helps to balance the growth of plant. Potash keeps a check on unnecessary vegetative growth due to excessive N, and makes the plant hardy to withstand frost. The potash maintains turgidity of the plant, conserve moisture that helps in protection from frost.

**Dextran**

Dextran is polysaccharide, which is composed of long chain molecules compared to simple sugar unit homologous polymer of D-glucopyranose. They are usually formed by the action of enzyme dextran-sucrase on sucrose. They are gum soluble in water and are highly dextro-rotatory. The aqueous solution of dextran is viscous and appears as gummy substance. They cause great problems in processing and great loss in sugar recovery due to degradation of sucrose converting sugar into non-crystallizing reducing sugar. Physical problems are observed in the following procedure and processes.

**Pol analysis:** Dextran interferes with analytical tests for purity in process control. Dextran being highly dextro-rotatory inflates the direct polarization reading of cane juice samples. This results in an artificially high apparent purity in comparison with true purity, and therefore causes errors in purity figures.

**Clarification:** High dextran levels reduce the efficiency of clarification process. In severe cases of stale or soar cane the juice is often impossible to clarify and filter by normal methods. Presence of more dextran increases viscosity, which retards the settling time in the clarifier and prevents satisfactory removal of suspended matter. The clarified juice is cloudy and results in high mud volume. Filtration of the mud also becomes difficult. The process needs more of phosphitation and or sulphitation.

**Evaporation and crystallization:** The increased dextran levels reduce the factory capacity to handle the syrup and massecuite. Increased viscosity of syrups and massecuites decrease the rate of crystallization of sucrose. Crystal growth rate may be reduced to the extent of 50 % compared with fresh cane syrup.

**Factory capacity:** Increased dextran results in increased boiling and evaporation time and decreased crystallization rate. It may result in lowering the crushing capacity of a sugar mill to the extent of 50-70 %.

**Scale formation:** High level of dextran results in excessive scale formation on heating surface of heaters and evaporation and pans. This high scale combined with high viscosities results in increased boiling time and consequently less of sucrose by inversion and reduced capacities and more energy consumption.

**High massecuites and final molasses purity:** The fore discussed process leads to a reduction in the exhaustibility of low-grade massecuits in crystallization. Pumping and curing become difficult and inefficient resulting into higher losses of sugars in final molasses.
Measures to minimize the effect of dextran

There is no method of removal of dextran from cane juice in cane factories. So the following measures may be adopted to counter the ill effect of dextran.

- Cane varieties show different behavior to after harvest staling losses. The varieties, showing lower staling losses should be grown.
- There should be minimum delay between the cane harvest and milling of cane; cane procurement policy should be as efficient as possible.
- Dextran level should be frequently checked in the laboratory.
- Diseased cane show more dextran on staling, therefore cane should be kept free of disease and pests.

Post Harvest Staling Losses

Sugarcane, after harvest is very sensitive to environments. Due to bacterial action the cane juice undergoes chemical changes by inversion of stored sucrose to reducing sugars, dextran, gums and organic acids. These changes are rapid in warm weather and low in cold weather. Thus the cane harvested in autumn and spring is subject to rapid deterioration than the winter-harvested crop. The extent of damage depends on temperature, the period of cut to crush time and the cane varieties.

As the cane is harvested it starts drying and losing weight. The loss in cane weight varies with cane varieties, temperature, humidity, wind and method of storage.

Delay in delivering cane to a factory is a major cause of quality deterioration. Growers carry on harvesting; sometimes transport is not available and some time sugar mills are overloaded with its programme.

Piecemeal-slow harvesting by family labor may be useful for a cart load, but it takes days to complete a truck or trolley loads.

Breakdown in mills due to technical faults or shutdown due to cleaning imbalance the cane supply and volume of crushing.

Post harvest staling cause two types of losses

1. Losses in weight of cane
2. Losses in sugar recovery

Losses in weight of cane are due to evaporation and drying of cane after harvest, and loss in recovery is due to biochemical changes in cane juice.

Biochemical changes: Cane after harvest is subject to bacterial infection through cut ends and damaged portion of cane. Since physiological and biochemical control is upset in harvested cane, endogenous invertase get activated to convert the sucrose to invert sugars. Some other bacterium like leuconostoc enters the cane through cut ends and polysaccharides like dextran converts sucrose to other organic metabolites. The compounds formed due to biochemical and microbial changes are organic acids and ethanol.
These losses are governed by a number of factors.

1. Cane varieties
2. Crop condition: mature or immature
3. Weather conditions by way of temperature, humidity and wind
4. Harvesting period, autumn, winter, spring or summer; temperature is the main controlling factor
5. Harvesting method: hand cut or mechanically harvested
6. Nature of cane stalk: green cane or burnt cane, whole cane or chopped cane
7. Time lag between cut to crush
8. Cane storage time at the farm or in cane yard and the storage conditions; cane covered or kept un-covered
9. Crop stresses due to drought, salinity, pests and disease infection

**Cane variety:** Cane varieties show varying behavior to post harvest staling losses in different crushing months. The studies conducted at Faisalabad reveal that cane stalks of BF 129, CoL 54 and L 62-96 stored for eight days after harvest, during November, January and March, showed interesting results (Table-11.05).

**Table-11.05 Post harvest staling losses in cane weight and CCS % cane in three cane varieties**

<table>
<thead>
<tr>
<th>Harvesting period</th>
<th>Varieties</th>
<th>Percent loss in cane weight during storage, 1-8 days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Mid Nov</td>
<td>BF 129</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>CoL 54</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>L62-96</td>
<td>0.00</td>
</tr>
<tr>
<td>Mid Jan.</td>
<td>BF 129</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>CoL 54</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>L62-96</td>
<td>0.00</td>
</tr>
<tr>
<td>Mid Mar.</td>
<td>BF 129</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>CoL 54</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>L62-96</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Harvesting period</th>
<th>Varieties</th>
<th>CCS percent cane during storage, 1-8 days</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Mid Nov</td>
<td>BF 129</td>
<td>11.1</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td>CoL 54</td>
<td>10.5</td>
<td>10.3</td>
</tr>
<tr>
<td></td>
<td>L62-96</td>
<td>12.7</td>
<td>12.7</td>
</tr>
<tr>
<td>Mid Jan.</td>
<td>BF 129</td>
<td>12.6</td>
<td>12.6</td>
</tr>
<tr>
<td></td>
<td>CoL 54</td>
<td>11.4</td>
<td>11.9</td>
</tr>
<tr>
<td></td>
<td>L62-96</td>
<td>13.2</td>
<td>13.3</td>
</tr>
<tr>
<td>Mid Mar.</td>
<td>BF 129</td>
<td>13.5</td>
<td>13.4</td>
</tr>
<tr>
<td></td>
<td>CoL 54</td>
<td>13.3</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td>L62-96</td>
<td>14.2</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Fasihi and Malik (1989)
The data indicate that after harvest staling losses were the highest in CoL 54 compared to the other varieties in the test. The Losses were larger during warmer months of November and March than the winter month of January.

In India a sugar recovery loss of 5 to 25 kg per ton of cane and cane weight loss of 7.14 to 15 % in 72 hours staling is reported (Solomon, 2000). In studies at IISR, Lucknow the CCS % cane loss of 3.02 %, 25.9 %, 29.4 % and 70.5 % was reported in cane staling for 24, 48, 72 and 96 hours, respectively (Solomon, 2000).

**Weather**: Data reproduced in Table-11.05 indicate higher loss of cane weight and juice quality during November and March months compared to January. It is due to the effect of higher temperature. At higher temperature the enzymes are more active to induce deterioration in cane juice. In case factories are in operation during April-May staling losses are further increased.

**Cane maturity**: Immature cane is more and rapidly prone to post harvest deterioration compared to mature cane. Since immature cane contains larger fraction of invert sugars; rapidly undergoes microbial changes leading to quality losses.

**Burnt cane**: Burnt cane undergoes rapid post harvest deterioration in juice quality than un-burnt cane due to the following reasons.

- a. Loss in moisture
- b. Increase in temperature rapidly hydrolyzes the sucrose to invert sugars.
- c. Dextran is produced which causes difficulties in filtration and crystallization process.

Manually harvested whole stalk undergoes less deterioration than the cane cut by chopper cane harvester.

Deterioration is much faster in burnt chopped cane than in burnt green chopped cane.

**Measures to avoid staling losses**

Develop awareness among growers and cane development staff on cause and effect of various quality losses in cane crop.

- Field storage of cane should be in small heaps with minimum ground contacts. It is better to place the heap on trash bed to avoid soil contact. It should be covered with trash to avoid moisture loss and to save from low temperature spell.
- Cane yard should be kept clean, maintaining good hygienic conditions through effective sanitation programmed to check growth of micro-organism.
- Cane department should be vigilant in issuing cane indents. The cane harvest and supply position should be in picture of the concerned cane officer. Some sugar mills have installed wireless, mobile system to keep in contact with its circle offices and the vehicles in the field.
- Cane harvesting should be as per schedule of cane supplies to sugar mills.
- Reducing time in cut to crush period can minimize staling losses. The sugar
mills management may take the following measures to control loss in quality.

- Efforts should be made for quick delivery of cane to sugar mills after harvesting and a little time to be allowed for waiting in cane yard. In Queensland, Sugar Industry allow just 16 hours time in cut to crush period and cane supplied late after harvesting are penalized (Hogarth and Allsopp, 2000).

**Forced Ripening of Cane**

**Use of chemicals in ripening:**

Optimum yield and maturity is obtained after a certain period of cane growth. In long duration crops of tropical belts cane naturally ripens with increasing age and modifying irrigation and fertilizer practices. Cane matures with exhausting of plant nitrogen and restricting irrigation to curtail active growth. In regions of short duration cropping, active growth is checked by low temperature conditions and the plant tends to maturity phase. In the absence of natural ripening conditions it is still possible to induce maturity by disrupting the physiological functions of plant. On completion of growth, maturity is the result of delicate balance between respiration and photosynthesis. Some chemical ripeners can be effectively used that can revert the photosynthetic system and induce the crop to maturity.

The mode of action of chemical ripeners is either through altered physiological functions or through morphological modification of cane plant. As the water and nutritional balance is altered, invertase activity is inhibited that reduce respiration in plants, decrease reducing sugars accelerating and increase sugar formation. Morphologically, leaf and stalk growth is restricted, flowering is minimized and fibre contents are reduced (Su et al, 1999; Shrivastava, 1994; Ali, 1979).

A wide range of physiologically active compounds have been used for inducing ripening. The ripeners 2, 4-D, Polaris, Ethrel, Embark and Asulum act by ripening immature cane and enhance the sucrose contents. The vegetative growth is restricted and the photosynthates are transferred into sucrose and non-sugars. The compounds of Fusillade, Glyphosate (Polado and Round up) improve the sucrose contents of mature stalk. These compounds have greater potential than the former ripeners, however, have to be used with caution as the over dose causes poor ratooning (Hunsigi, 2001; Denaldson and Staden, 2001). The best response of chemical ripeners is obtained in the start of the ripening period when sucrose contents just begin to rise. The ripeners are also effective when applied late in the harvesting season when sucrose in cane is on declining stage (Pan and Lee, 1974). In declining phase their role is to prevent deterioration in cane juice.

Response to ripeners is highly related to cane varieties. The early ripening varieties are reported to have shown better response in the early part of the crushing season (Kumar and Srivastava, 1993). The late maturing varieties were benefited more than the early ripening varieties (Ethirajan et al 1976, Bendigent and Hapes, 1994). Glyphosate applied 5-7 weeks prior to harvest improved sugar recovery by 10.9 % in CP 48-103, 7.1 % in L 62-96 and only 3.1 % in NC 310 (Legendre and Martin, 1977).

The chemical ripener “Polaris” was sprayed on cane variety BL 4 (early maturity), CoL 54, Triton and Co 564, (mid maturity) and L 118 (Late maturity). The chemical applied @
5 Kg/ha, during the first week of September and October, indicated that after 4 and 8 weeks of spray early maturing variety BL 4 showed little response to the ripener, while mid maturing and late maturing varieties showed 10 to 21% increases in CCS contents in different years (Table-11.06). Cane yield was not much affected.

Table-11.06 Effect of ‘Polaris’ on the quality of different cane varieties*

<table>
<thead>
<tr>
<th>Cane variety</th>
<th>4 weeks after spray</th>
<th>8 weeks after spray</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Treated</td>
</tr>
<tr>
<td>CoL 54</td>
<td>9.42</td>
<td>11.22</td>
</tr>
<tr>
<td>BL 4</td>
<td>10.77</td>
<td>10.83</td>
</tr>
<tr>
<td>L 118</td>
<td>7.38</td>
<td>8.97</td>
</tr>
<tr>
<td>Triton</td>
<td>9.38</td>
<td>9.59</td>
</tr>
<tr>
<td>Co 564</td>
<td>8.59</td>
<td>8.60</td>
</tr>
<tr>
<td><strong>Means</strong></td>
<td><strong>9.11</strong></td>
<td><strong>10.08</strong></td>
</tr>
</tbody>
</table>


This may prove a good tool to ripen some low sugar and late maturity varieties, which are otherwise high yielder’s. The advent of forced ripening chemicals have opened new vista of enhancing sugar yields. Different ripeners are in use on commercial scale in a number of countries (Table-11.07).

Table-11.07 some sugarcane ripeners used over globe

<table>
<thead>
<tr>
<th>Ripener</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polaris (4.5 kg/ha)</td>
<td>Brazil, Guyana, India, Taiwan,</td>
</tr>
<tr>
<td></td>
<td>Mauritius, Louisiana, S. Africa</td>
</tr>
<tr>
<td>Elhrel (1.0 – 1.5 kg/ha)</td>
<td>S. Africa, India, Taiwan</td>
</tr>
<tr>
<td>Glyphosate(0.25-1.0kg/ha)</td>
<td>S. Africa, Taiwan, India, Jamaica,</td>
</tr>
<tr>
<td>Roundup/Polado (0.7-1.0 kg/ha)</td>
<td>USA, Mauritius, Taiwan,</td>
</tr>
<tr>
<td>Embrak (2.3 L/ha)</td>
<td>Taiwan</td>
</tr>
<tr>
<td>Fusilade super (1215g. a.i./ha)</td>
<td>USA, Mauritius</td>
</tr>
<tr>
<td>Cycocel (4 kg a.i./ha)</td>
<td>India</td>
</tr>
</tbody>
</table>

Source: (Soloman et al, 2000).

In many areas, early start of crushing season gives low sugar recoveries, which have poor impact on sugar yields. Rains, at the start of the crushing season or prolonged period of relatively moderate temperatures, delay maturity in cane. These conditions show favourable response to the use of chemical ripeners. However, the effect of the ripeners should be studied before hand.

- Their response to specific varieties.
- They should retard apical growth without interfering the biosynthesis of sucrose.
• Should not have depressing effect on the following ratoon crop.
• Yield of cane is not affected.

In large cane belts the chemical is applied through aerial spray. But in small holdings and small pockets there may be operational difficulties due to higher size of crop. Studies have yet to be ascertained on the commercial use of suitable ripeners through irrigation water.

At the time when crop has reached the stage near to maturity, ground spray (except aerial spray) is not well manageable. So the sugarcane ripening chemicals, Dinitrosocifrol (10 kg/ha) and Triacontanol (1.0 kg a.i./ha) were applied along with irrigation water during the first week of October. The observations recorded 60 days after treatment show 0.2 to 1.0 unit increases in Pol % cane. The effect was noticed till 120 days after treatment. The maximum response was noticed in upper one third portions of cane stalks. Cane varieties showed varying response to the chemical (Solomon and Shahi, 2001).

Cane and sugar yields are low due to some physio-biochemical action that impedes growth of plants. To minimize these constraints agro-chemical manipulation techniques were used at different stages of sugarcane growth. Ethephon (2-Chloroethyl phosphoric acid) was found to promote seed cane sprouting, improve tillering and mill-able cane formation, and help in initiation and formation of ratoon shoots / tillers of winter-harvested cane (Solomon et al, 2001). The following observations were recorded:

**Germination:** A 12 months old crop was completely drenched with ethephon @ 1000 mg per liter, and crop was harvested one week after treatment. Germination showed 13 – 17 % improvement in seed cane sprouting.

**Tillering and biomass production:** Ethephon @ 500 – 1000 mg / liter applied to the crop 60 – 70 days after planting as post emergence showed 12 -16 % improvement in tillering and biomass production.

**Sprouting of winter initiated ratoon growth:** Ethephon @ 1000 mg / liter + 2 % urea was applied as foliar spray at the standing crop 7 – 10 days before its scheduled winter harvest. Spray in Dec-Jan not only improves juice quality but also has stimulatory effect on bud sprouting and growth of stubble buds during winter.

Aerial spray of Ethephon (2 l/ha), 6 – 10 weeks prior to harvest consistently increased sucrose contents in juice 0.5 to 1.0 unit with no adverse effect on stalk density, height and cane yield of succeeding ratoon crop.

### Cane Procurement Programme

Cane Procurement Programme has the key role in optimizing quality harvest in the field and regulating milling operations to the highest efficiency. The cane department should be vigilant before hand regarding the required cane transport system and labour for handling cane in the yard. Maintenance of roads and culverts should be watched and the roads should be kept in perfect order.

The most important feature to run the program on successful lines is laid out as under.
Survey
Correct survey is the first step to collect concrete information on the volume of crop and its quality in the area. The available data help regulate the mills crushing during crop harvest season. The Cane staffs survey the specified area around sugar mills zone record information on:

1. Cultivated area under cane crop with reference to area under plant, ratoon and autumn cane
2. Information on diseases and pests infestation
3. Crop condition and expected yield
4. Ownership or tenant area
5. Distance from sugar mills
   - Cane variety
   - Communication and transport facility available in the area

Cane crushing dates
The crushing period of sugar mill in a particular region/province is notified by the cane Commissioner. Before declaring the crushing programme, crop maturity should be given due consideration. Crop maturity is generally affected by cane variety and weather condition. Sometimes excessive rains or late rainfall condition delay the maturity of the crop. Pre-harvest maturity survey may be conducted to ascertain the harvesting period. A general crop view with juice Brix, hand reflectometer reading of various spots may give indication of maturity trends. In this context Top: Bottom ratio may give a useful indication of maturity. To harvest maximum sugar per hectare it is advisable to start crushing when the crop is mature near to peak sugar recovery of cane.

Purchase centers
Direct purchase at mill gate is always preferred. Depending upon distance from sugar mills and cane supply position, purchase centers are established at certain locations. This is especially so where cane fields are not directly linked with main roads and that sugar mill is at far off distance. Cane is brought to purchase centers by bullock carts, camel back or small trolleys. Temporary weigh bridges are installed at the centers.

Considerable weight loss in cane is observed at the centre and in transit, at the expense of sugar mills. So as to same weight loss, extra cost on raw material and additional transport, it is always desired to eliminate purchase centers. Purchase centers some time induct neighboring mills in the area, which instigate to increase cane price. The best approach is to purchase cane direct at the mill gate.

Weigh bridge
The modern weigh bridges are computerized and print out the gross and tare weight of cane load. They may weigh as much as 10 to 60 tons or more load. Their accuracy has to be maintained under the Cane Act.

Transport arrangement
For smooth running of a sugar factory, a good transport mechanism plays a major role. Cane transport may be in the form of trucks, trolleys or rail tracks. The transport may be
hired from companies or growers have their own arrangement. However the cane Department make contract with the transport companies much before the harvesting season. Transport arrangement should be assured before commencement of crushing season. The present day mills capacities demand round the clock arrangement of transport. For efficient working of the transport system local arrangements should be made for repaid replacement of machinery parts at the mills site.

**Loading and unloading labors**

As for the transport, arrangements have to be assured for provision of labor for loading cane in the field or purchase centre and unloading cane at the cane carrier. Labor contracts have to be made well ahead of sugar mills operation.

**Cane yard**

Cane transport is parked in cane yard. The yard should be well spaced to accommodate different mode of transport in well organized manner. There should be separate arrangements for parking waiting and token transport. Good hygienic conditions should be observed for keeping the cane yard clean of trash and cane stalks.

**Cane indenting**

Cane is purchased from cane growers at the mill gate or at purchase centers. Cane indent is cane supply permit issued to growers for supply of specified quantities of cane on specified date. A calculated number of indents are issued to supply cane for regular crushing of sugar mills considering its crushing capacity within 24 hours. Indents are issued two or three days in advance of the date of cane supply by growers.

This is a very important activity of cane department that needs consistent vigilance with respect to crop maturity, date of indent, mills operation during the period and weather condition. Total crop produce surveyed is uniformly divided into expected mills crushing days to work out each day requirement. After having issued the indents the following precautions have to be taken.

- Time validity of indents should be adhered to strictly. The supply dates of the indents not availed of should not be changed and must be cancelled.
- There should be close liaison between cane and technical department for actual crushing requirements for each day. The indents should be issued showing vigilance and sense on mills working, growers demand for permits and actual harvesting operation.
- There should be complete check on arrival of excess cane without indents.
- The indents should enter complete information of grower and his variety. All the information on indents should be placed on computer daily.
- The assessments of daily crushing requirement and daily arrivals should always be carefully evaluated. Cane arrival must coincide with any breakdown or mills stoppages. There should be communication net work to check and with hold the supply of cane in case of sudden mills stoppages. If need be emergent indent
must reach the growers and circle offices within minimum possible time.

- Round the clock communication mechanism between cane office and the circle offices is a key to the successful program of cane supplies to the mills. The walky talky arrangement in offices and mobile vehicles triggers to regulate the cane supply position.

- Indenting policy may be reviewed considering the loading or unloading position of cane.

**Main barrier in effective procurement program**

**Cane payments**

For smooth production and supplies of cane to the factory, the growers have to be assured of a reasonable price of his produce after supplies to sugar mills. Based on demand and supply of cane confidence of grower is sometimes shaken by uncertain cane procurements and cane payment polices of sugar mills.

1. Cane payments should be made at regular interval, but some times payments are delayed for months.
2. Undue competition in cane price for cane procurement. It happens when cane is in short supply competition results in un-realistic escalation of cane price.
3. Sudden role back of cane price is again uncertain blow to cane growers.
4. In years of over production, millers suppress the interest of growers.
5. Payment of transport subsidy on cane brought from far off distance.
6. Prompt payment of cane brought from long distance and detains the cane payment near to sugar mills.
7. Illegal deduction of cane weight.
8. Induction of middle men / brokers for cane supplies to sugar factories.

**Involvement of brokers/ middle men**

Some sugar mills take it easy to have in confidence a few parties for cane supplies to keep the sugar mills running. The induction of brokers jeopardizes ethics of cane procurement. Growers though get cash returns per ton of cane supplies, but have more confidence on broker for their timely payments, than on sugar mills.

- Brokers tempt the millers to increase cane price in competition with neighboring mills.
- They are least concerned with cane quality with respect to cane variety, staleness of cane presence of trash.
- They break the friendly ties and interaction of growers.
- The brokers system of cane supplies in a sugar mill and cane development services can not work side by side.
- They purchase cane from growers much before the crushing season at much
lower prices and later sell it at their own terms. During slump years they exploit both growers and millers interests to upset their economy.

- Brokers are the main cause of cane price competition in a cane zone.

Sugar mills stoppages

Sudden mechanical electrical problems in milling operation resulting into break down of cane crushing disturb the cane procurement program. It takes time to make up the ranger period of break down. Persistent problems leading to intermittent mills closure is a serious blow to regulate the cane supplies to cane carrier.

Cane harvesting schedule

For a sugar factory to achieve maximum average sugar recovery in a crushing season, the harvesting schedule should be such as to crush early maturity varieties early in the season and late maturity varieties late in the crushing season. The late varieties if harvested earlier would have a detrimental effect on the overall recovery of the factory. The varieties BL 4 and BF 162 are considered early maturing varieties and show the higher recoveries in October- November with progressive rise till late in the season. These have average seasonal recoveries of 11.31 % and 11.89 5 %, respectively. The variety Triton to start with its crushing give recoveries of 6.91-9.21 %, though it may reach to a peak of 11.94 % but the seasonal average is 10.781 %. The late maturity variety Co 1148 start it's crushing with 5.6 % and the peak of 10.48 % would be obtained in March with average seasonal recovery of only 8.84%.

In a short crushing season of 100-120 days, good average recoveries can be maintained by maximum reliance on 60-70 % crushing of early maturing varieties, with crushing 30-40 % of mid season varieties. If cane quality is the main consideration, late maturity varieties may prove liability on the grower and sugar industry. In longer crushing season, however, late maturing varieties may be accommodated to the extent of 20-30 percent.

However, there are some other aspects as well under consideration. In order to harvest maximum sugar per unit area and time, the cane harvesting should proceed according to maturity survey of cane crop. It helps achieve consistently high sugar recoveries throughout the crushing season of sugar mills.

1. Any delay in harvest of a mature crop results in deterioration of sucrose contents, increase in fiber and loss in cane weight.
3. Delay in harvesting of a lodged cane, diseased and pests infected cane further enhance the rate of quality deterioration.

Cane varieties:

Peak recoveries can be obtained by systematic harvesting of cane varieties according to their maturity period. The varieties in general have the following features.
Early maturing varieties generally lose their sugar yield potential when harvesting is delayed till late season. While late varieties give low yield and recovery if harvested in early period of crushing.

A sugar mill having maximum area under early maturity varieties would recover maximum sugar in a season.

A ratoon crop is ready for harvesting 3-4 weeks earlier than a plant crop.

The autumn planted cane, crushed in early season, recovers 0.5-0.8 degree more sugar than spring planted cane.

Control on Sugar Recovery Losses

Sugarcane is the raw material for manufacture of sugar in a factory. Efforts have to be made to extract maximum sugar available in cane. Still a considerable amount of sugar is lost during various stages of cane handling from field to factory and then during milling and processing operations. These losses include.

1. Poor harvest: harvesting immature cane, cane left in the field with debris and the portion un-cut with stubbles.
2. Cane staling in field and in cane yard before crushing.
3. Cane crushing with trash and tops.
4. Un-hygienic conditions in the factory leading to losses due to microbiological action.
5. Crop damage due to lodging, frost, pests and diseases.
6. Inefficient milling and processing operations in the factory.

The fore mentioned losses could be controlled by taking appropriate measures.

Harvesting mature cane

Crop should be harvested when it is fully mature. The harvesting programme should consider the planting time, time of keeping ratoon, and the variety- early, mid or late maturing.

1. The water logged and lodged crop should be considered first for harvesting.
2. The late shoots and side should be removed before hand.
3. The flowered cane should be harvested earlier.
4. The burnt cane should be harvested and supplied to the factory within 24 hours of the fire out break.
5. Dry leaves/trash to be removed from standing crop before harvesting.

Toping of cane

Cutting tops before harvesting is a normal process. Top internodes are immature and especially so in early period of cane harvest. This section of cane contains large
concentration of non-sugars, reducing sugars and ash. It is rich in nitrogenous matter and high acid invertase activity. If crushed with mature cane it affects clarification and reduces sugar recovery. Tops should be removed while harvesting. Cane should be de-topped to avoid quite immature internodes.

In years of fodder scarcity growers de-top cane to meet fodder requirements of livestock much before mill harvesting. By this practice lateral buds below top portion tend to sprout. Sucrose is gradually converted to glucose to feed the growing side shoots, as such sugar recovery of these stalks decline. Drop in recovery is more in moderate winters compared to the lowest temperature months.

Supply of clean and healthy cane
Crushing clean and healthy cane attains better recoveries. Growers should be educated to abstain from the supply of diseased, dried, up rooted and burnt cane. Clean cane incentive schemes sometimes produce excellent results to attract the growers for supply of fresh and clean cane.

Control of extraneous matter
Extraneous matter
Any material, other than clean cane, mixed with harvested cane stalks, would be termed extraneous matter. It could be green leaves or dried trash; tops, roots, water shoots or dirt. Up rooted dried cane stalks, dried cane due to severe disease infection or pest infestation would also be termed as extraneous matter. Crushing cane with extraneous matter has detrimental effect on sugar recovery. Their presence results in:

- Reduction in cane weight actually crushed, as the extraneous matter increases weight without giving any sugar.
- Increased fibre and poor extraction.
- High losses of sugar in bagasse.
- Increased turbidity in juice.
- Poor clarification and low quality sugar.
- Higher losses in final molasses.
- Trash delivered with cane to the factory, practically reduces cane weight.
- Trash reduces grinding capacity of mills rollers affecting efficiency with more power consumption.
- Trash absorbs juice affecting juice extraction.

Supply of fresh cane
Good sugar recoveries are attained with minimum cut to crush time. Cane should be crushed within 24 hrs of harvesting. In some countries penalties are imposed on cane brought to the factory 16 hrs after harvesting. Under Pakistan conditions, time lag between two to seven days is usual depending upon cane production conditions in a
season. Large production seasons cause delay in crushing while in slump years problems may not be that serious.

**Sugarcane Trash**

Sugarcane trash is the dry and green foliage of cane plant left in the field after cane harvest. Trash amounts to 5-20 % of cane weight. The quantity varies with crop growth and vigor, cane varieties and the harvesting method. Cane harvested manually leaves a trash residue of only 5-7 %, as tops are mostly used as fodder for livestock.

Cane harvested mechanically have different pattern of trash disposal:

1. The trash is either burnt before harvest, while the crop is standing in the field, or
2. Crop is harvested and burnt while the cane stalks are lying in the ground or
3. Crop is harvested green with billet chopper harvesters.

The latest method of harvesting is now getting popular and leaves trash 10-20 % of cane weight.

In the case of mechanized harvesting, main system to get rid of trash in the past has been to:

1. Burn the trash on standing crop of cane in field.
2. Harvesting crop with whole stalk harvester and burn the trash in laying position of cane stalk in field.
3. Cane harvesting with billet chopper harvester, where in trash is blown away and settles in cane field as GCTB.

In manual harvesting, cane is manually cleaned of the trash; still some trash is left on stalks. In areas of labor scarcity a little care is taken to de-trash the cane. Nevertheless presence of trash creates problems in various operations. It is, however, emphasized that cane carried to sugar mills should contain minimum trash. The physical damage caused during milling and losses that may occur during processing are:

**Trash damage to milling operations**

- Trash increases the fibre, ash and soluble impurities in juice.
- Increased bulk of cane shredded material make mill feeding difficult and utilized more power.
- Trash absorbs considerable volume of juice and decrease juice extraction during mill crushing.
- Added impurities and suspended material make clarification difficult with reduced boiler efficiency.
- Dirt carried with trash cause deterioration of milling equipment by way of increasing plant maintenance cost, reduces extraction and milling capacity.

It has been assessed that 1.0 % trash in cane brought to the factory cause decrease in extraction by 1.5 %, with 16 % reduction in grinding rate, one degree drop in juice purity
and 0.75 degree reduction in sugar recovery (Kent et al, 2003). The extraneous matter has great deleterious effect on milling and processing operations. Impact of crushing clean and dirty cane in a factory can be observed from the Table-11.08

**Table-11.08 Effect of extraneous matter in milling and clarification**

<table>
<thead>
<tr>
<th>Composition:</th>
<th>Dirty cane</th>
<th>Clean cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roots %</td>
<td>20.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Tops %</td>
<td>6.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Leaves %</td>
<td>8.3</td>
<td>0.6</td>
</tr>
<tr>
<td>Residue</td>
<td>1.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Bin weight (t)</td>
<td>7.32</td>
<td>8.64</td>
</tr>
</tbody>
</table>

**Factory operation:**

<table>
<thead>
<tr>
<th></th>
<th>Dirty cane</th>
<th>Clean cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushing rate (t)</td>
<td>306</td>
<td>351</td>
</tr>
<tr>
<td>Fiber rate</td>
<td>46.7</td>
<td>54.7</td>
</tr>
<tr>
<td>CCS %</td>
<td>12.77</td>
<td>13.96</td>
</tr>
<tr>
<td>Water % bagase</td>
<td>49.53</td>
<td>47.31</td>
</tr>
</tbody>
</table>

**Liquor production:**

<table>
<thead>
<tr>
<th></th>
<th>Dirty cane</th>
<th>Clean cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purity</td>
<td>89.9</td>
<td>91.5</td>
</tr>
<tr>
<td>Reducing sugars</td>
<td>4.0</td>
<td>3.56</td>
</tr>
<tr>
<td>Ash</td>
<td>2.68</td>
<td>2.17</td>
</tr>
<tr>
<td>Colour</td>
<td>154</td>
<td>118</td>
</tr>
</tbody>
</table>


Studies conducted at Shakrganj Mills indicate that addition of 5 % tops to the clean cane reduced juice extraction from 69.39 to 68.31 % and reduced sugar recovery from 8.85 to 8.32 %. Addition of 5 % trash reduced juice extraction from 69.39 to 64.49 % and sugar recovery from 8.85 to 7.99 %. It was concluded that every 1 % increase in extraneous matter in cane decrease the sugar recovery by 0.12 % (Samee et al, 1996). The losses are two fold, extra payment of cane on additional weight of extraneous matter and considerable reduction in recovery.

![Cane being supplied to a sugar mill; (A): cane full of trash, (B): cane some what clean](image-url)
Utilization of Cane Trash

Cane trash can be utilized either by composting or direct incorporation in the field. It can also be used for production of energy through burning in sugar mills boilers.

Composting of sugarcane trash

Trash can be composted in one-meter deep pit of 9m x 5m dimension. Trash is placed in alternate layers of trash and press mud, applied with slurry of cow dung and urea fertilizer. It is covered with a layer of earth. At 8 to 10 days interval the whole mass is stirred, moistened with water. It takes 4-5 months to decompose the matter in nutrient rich manure. To accelerate the degradation, some microbial culture can be added in initial preparation of the trash layers. The compost would be ready in about 45 days (Sundra, 2000).

Trash can also be composted by keeping in heap of 3m x 2m x 1m dimension. Trash is moistened with water and mixed by cow dung slurry (5 part dung + 1 part water), sufficient to cover the trash. The whole mass sprayed with urea (8 kg) + SSP (10 kg) per tonne of trash. Four to five layers of trash and slurry fertilizer mixture should finally be covered with soil + dung layer. The mass has to be turned over after 15 days. It takes 3-4 months to decompose into compost (Sundra, 2000).

Pre-harvest burning

In some countries cane is burnt immediately before manual or mechanical harvesting. The objective is to avoid the labour for cleaning cane. Care is exercised that time interval between burning and crushing cane must not exceed 20 hours. It has also to be taken care of that burning is not in windward direction; rather it is in calm environment. Carelessness in supervision is liable to spread fire causing vast damage. Nevertheless, burning is not a desired practice. It may cause great losses to the sugar industry. Any delay in harvesting and haulage of cane to the factory is liable to deterioration of juice quality.

- Sucrose is converted to glucose and fructose by hydrolysis
- Recovery of sucrose is reduced and the quantity of molasses is considerably increased.
- Burning of cane, in fact, is burning of sucrose.
- In delayed harvesting the dextran contents increase that hamper the milling efficiency.
- Excess of molasses in tanks imbalance the milling and boiling process which also reduce efficiency.

Now, with change of harvesting machinery the burning practice is being abandoned. Besides the controlled burning, fire may spread in adjacent fields or fire may break out in other fields due to negligence or irresponsible activity of passers by persons. Such fire may cause tremendous loss to the growers as well as industry. Such a large quantity of burnt cane cannot be managed for timely harvesting. If supplied and crushed is a burden on milling and processing section causing severe manufacturing losses. Cane crop when
mature should be kept in close watch. Dry trash especially when temperatures are high during March-May can take up light with simple mach striking.

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Sugarcane Harvesting

Cane is harvested when ready for crushing and processing in an industry. The harvesting operations can be performed by manual labour or mechanical harvesters. Harvesting system varies from region to region depending on labor availability, labor cost, weather conditions, equipment in use and the technical advances.

Manual harvesting

It is the conventional method of cutting cane with simple hand tools like cane cutter knife, axe, toka, or any other tool used in the region. The cane stalks are manually cut by hand tools, cleaned of all the trash and tied into bundles with trash or straw formed ropes. So as to avoid trash, nylon thread is used to tie the bundles in some countries. The cane bundles are manually loaded on trucks, tractor drawn trolleys, bullock carts or camel
back. The system may provide quite clean cane free of trash.

Manual harvesting is labor intensive and the cane growers, with times, feel problems of shortage of labour. Labour wages are getting high and harvesting charges are adding to high production cost. Usual harvesting standard is one half to one ton per man day depending upon crop condition. Harvesting proceeds slowly and sometimes it takes days to complete cane supply assignments. In small holding grower’s own family or locally available labour can serve the purpose. During fodder scarcity period labour even harvest the crop in lieu of tops. But it takes more time in harvesting. In large plantation special labour is hired for whole season, which settles at the farm and manage harvesting and loading regularly as per supply permits.

Mechanized harvesting

In the 20th country the mechanized harvesting has undergone vast changes in designs and development of harvesters. Mechanization was initiated in Hawaii and later Australia, USA (Louisiana and Florida) and Puerto Rico have been the center of research in this direction. Whole stalk ‘Soldier’ harvesters were developed in Louisiana and the chopper harvesters in Australia. The modification done from time to time have finally contributed to significant increase in harvesting efficiency, delivered cane quality and reduction in operational cost as well as sugar losses.

Economics has played its part to purchase and maintain expensive machinery based on its out put per hectare of its operations. To minimize sugar yield losses from mechanized operations prime consideration are given to field layout, cane planting method, crop growth, lodging, harvester design, cane loading and working efficiency.

Harvesters have to be purchased considering:

1. The operating cost in the field.
2. Harvesting capacity and capability to complete the job within desired crushing season.
3 Field layout and row planting design.
4 Availability and capability of operations.
5 Availability of repair and replacements facilities in the vicinity.
6 Availability of adequate transport and haulage equipment.

Improved field layout designs improve machinery performance by improving time lost by up to 30%. Saving in wear and tear and fuel consumption are added advantages. Wider row spacing accommodates infield transport track width and assists in controlling traffic paths. Before harvesting operations, trash may be partially removed by burning the cane.

In this way machines have fast harvesting rates, but burning trash has been a big issue in environmental pollution control. As such green cane harvesters were introduced. Green cane harvesting has much advantage over the deleterious effects of burning. Latest device is to spray desiccants 3-4 weeks prior to harvesting. Self trimming cane varieties show better performance during harvesting and cleaning operations.

Mechanical harvesting has the potential to reduce harvest – to – crush delays. In the past, harvesters had the problems of higher cane losses and poor quality of cane being delivered to sugar mills. These have now been significant improvements in harvester's designs in respect of its easy maintenance, better feeding mechanism and extractor fan speed setting leading to lesser delivery of trash to sugar factory and lesser losses. New machines have considerably higher harvesting rates, lower fuel consumption and better time saving. The harvesters now being used in various regions are mentioned as under.

**Whole stalk harvesters**

These are the two row harvesters. Cane stalks are gathered together, topped, cut at the base with a rotary blade, drawn into machines butts, cleaned and placed across the adjacent row in regular heaps. These heaps piled on side rows are loaded with grab loader equipped with mechanized lifter. The extraneous matter is removed either by burning the trash from standing crop before harvest or by burning the cane stalk in piles before the cane stalks are loaded and carried to the sugar mills. This harvester can easily harvest erect standing crop, while a heavy yielder and a lodged crop cannot be handled easily.

Cane can be loaded by grab loader and shifted to sugar mills. The other mode of loading is continuous loader, wherein Cane stalks are picked by a convey type elevator. At the top of elevator the cane is cut into billets by a series of circular saws in a manner of cut-chop material. The chopped cane is then delivered into wagon transport.

The whole stalk harvesters were introduced during 1944 and covered the sugar industry till sixties, thereafter were gradually replaced by chopper harvesters.

**Chopper harvesters**

Development work on chopper cane harvesters initiated during 1956, which soon got established due to their ability to handle lodged cane crop. The cut and load operations are eliminated as the extra loading trip are required with whole stalk harvesters. Chopper harvesters are the combine harvesters with two spirals in front to pickup the cane. It has the top cutter to cut the tops and base cutter to harvest the cane stalks, which are
regulated to the height of the cane. A rotating two bladed chopper knife cuts the stalks into billets, approximately 25-40 cm long, taken up to a shout with blower on it; trash and dirt is removed by an air blast. The partially clean billets are forced through a tunnel passage into a tractor drawn tipper bin (6-8 tons capacity), traveling by the side of the harvesters. This tipper bin when filled is then taken to pads where the 24 tonnes containers are stationed to be picked up by a tractor, which tips the container directly into mill carrier or mill yard.

Different models of chopper harvesters have been introduced. The Claas IH, Austoft 7000 of Australia, CH 3500 of Cameco (USA), and A 7000 of Brazil are the common model in use. Day to day modifications in machine has now reduced the losses in cane. The latest model of Austoft 7000 and CH 3500 has improved the cane cleaning performance of the machine. John Deer and Massey Ferguson have also developed its harvesters and are fetching market. Depending on crop condition cane harvesting capacity of modern green cane chopper harvesters is 40-60 tonnes/hour.

Burning cane prior to harvesting was a standard practice till 1980. Later the system was gradually replaced by green cane harvesters. Since green cane harvesting poses problems in very high yielding, severely lodged entangled crop, such crop is burnt before harvest. Capacity in green cane harvesters ranges from 50-80% of that in burnt cane.

**Cane and sugar losses during harvesting**

Mechanized harvesting brings about great advantages by way of time saving and cost reduction. The advantage of chopper harvester is in its ability to cut cane into billets, clean and transport sugarcane as an integrated operation. Besides time saving, mechanical harvesting cost was reported to be US $ 1.65 per tonne cane compared with US $ 2.12 in case of manual harvesting (Vachaparampil, 1999). The extraneous matter and soil processed increase the cost of transport, cost of maintenance of milling equipment, and reduces milling efficiencies and extraction of sugar (Anon, 1988; de Beer, 1980).
mechanical system if not properly managed can cause considerable losses in field as well as in factory due to subsequent deterioration of poorly harvested cane. Usual losses are the uncut cane pieces left on stubbles, cane cut sticks scattered in the field during harvesting, poor de-trashing and large percentage of tops and trash going to cane carrier, roots, dirt and mud stuck to base cut billets. During harvesting, billets are also damaged by striking knives. These damaged billets are subject to bacterial infection and deterioration if stacked long in cane yard. Cane stalks or cane pieces left in the field account for yield losses while dirt, tops and leaves mixed in harvested cane account for the extraneous matter that exert deleterious effect on juice quality and mills processing operations. A study in Brazil revealed that by delivering poor quality cane losses are more than the saving from mechanization. It was estimated that every 1 % increase in extraneous matter caused a reduction of 1.3 % to 1.4 % theoretical recoverable (TRS) contents of cane (Anon, 1888).

The direct damage of harvesters to cane fields is in the form of soil compaction that causes considerable yield losses. Now modified planting system of dual row planting has reduced the impact of compaction. The losses occurring in cane fields reported by Ueno and Izumi (1999) are reproduced in the table below.

Trash contents of chopper harvested cane are reported to be 2 – 15 %, while losses of cane left in the field are to the range of 0 to 10 percent. (de Beer, et, al, 1992).

<table>
<thead>
<tr>
<th>Cane Losses due to mechanical harvesting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Where Cane yield:</td>
</tr>
<tr>
<td>Trash rate :</td>
</tr>
<tr>
<td>Cane loss by extraction</td>
</tr>
<tr>
<td>Loss by un-cut cane</td>
</tr>
<tr>
<td>Loss by billet drop</td>
</tr>
<tr>
<td>Total loss</td>
</tr>
<tr>
<td>Loss ratio loss /yield</td>
</tr>
<tr>
<td>75 t/ha</td>
</tr>
<tr>
<td>10.5 %</td>
</tr>
<tr>
<td>7.7 t/ha</td>
</tr>
<tr>
<td>1.6 t/ha</td>
</tr>
<tr>
<td>0.7 t/ha</td>
</tr>
<tr>
<td>9.9 t/ha</td>
</tr>
<tr>
<td>14.4 %</td>
</tr>
</tbody>
</table>

The effect of side leaves (trash), tops, water shoots and soil was studied on the yield of cane and sugar from hand harvested and mechanically harvested crop (Richard et Al, 2001). The data of hand harvested cane indicated that increase in cane trash and tops caused a significant increase in cane weight. The trash accounted for a 10.6 % decrease in sugar t/ha of cane, compared with the clean cane treatment, while combined effect of trash and tops accounted for 18.5 % decrease in sugar contents. It shows a 3.6 % reduction in sugar per tonne of gross cane for each percent increase in fibre contents (Table-11.09).

The data for machine harvested crop indicate that for each 1 % increase in trash, there was a 0.08 % increase in fibre % cane, 1.4 tonne gain in weight and 0.85 kg loss in sugar per gross tonne of cane. For every one percent increase in fibre there was 4.8 kg reduction in sugar per tonne of gross cane.

Table-11.09 Effect of extraneous matter on cane & sugar yield in hand harvested
### Working efficiency in the field

A number of factors control the working efficiency of the harvesters in the field during operation.

**Crop size and growth condition:** The growth and size of crop affect the pour rate of the harvester. Both poor growth and vigorous crop affect the working efficiency. A lodged crop is not only a barrier in even harvesting of the crop, increase losses with respect cane left in the field and increased rate of suckers, tops, trash and dirt.

**Cane variety:** Erect growing and easy trashing varieties are preferred for efficient harvesting operations.

**Water:** Wet weather impedes harvesting efficiency.

**Weeds:** Excessive weeds especially vines and weeds having spiral growth are entangled with cane mass and create problems during harvesting.

**Cane pests:** Pests like grubs, rats weaken the root system and easily uproot plants.

**Row spacing:** Inter-row spaces of cane should be compatible with the wheel track of harvesters that the field haulage of machinery should allow easy movement of the system avoiding stool damage. An inter-row space of 1.5 to 1.8 meter has been the usual row distance used for machinery operation in the cane fields. It is now advocated that wider row space cause compaction of soil. Dual row planting at 1.3 : 0.50 : 1.3 m is the latest device for efficient accommodation of harvesters in Australia.

**Field layouts:** Layout of cane field in large blocks, with minimum number of irrigation and drainage ditches, increase the working efficiency of harvesters. Plot length should be large enough to reduce time lost in turning. A minimum field length of 300 – 500 ft is required and still longer fields are preferred.

**Soil management:** There should be harmony in soil and water management that the machinery used has the least compaction.

**Irrigation system:** The irrigation should be so managed as to allow proper drying at harvesting and suitable drainage to avoid marshy conditions.

**Harvester’s machine adjustment:** Position of top cutting device and extractor fan speed

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### Table: Cane Maturity and Harvesting

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Extraneous matter %</th>
<th>Cane t ha$^{-1}$</th>
<th>Sugar tons cane (kg)</th>
<th>Sugar t ha$^{-1}$</th>
<th>Fiber % cane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean cane</td>
<td>0.00</td>
<td>100.19</td>
<td>132.61</td>
<td>13.33</td>
<td>11.04</td>
</tr>
<tr>
<td>Cane + trash</td>
<td>9.07</td>
<td>108.80</td>
<td>118.59</td>
<td>12.97</td>
<td>14.30</td>
</tr>
<tr>
<td>Cane + trash + tops</td>
<td>19.41</td>
<td>123.44</td>
<td>108.09</td>
<td>13.40</td>
<td>14.67</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>2.77</td>
<td>4.99</td>
<td>5.76</td>
<td>NS</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Richard et al., 2001
has to be judiciously adjusted to reduce the loss of cane and extraneous matter to a minimum.

**Regular maintenance:** Working efficiency of the machine with respect to daily operating time, quantum of cane harvested and minimizing losses, can be improved by its regular maintenance. Workshop and technical know how should be available to keep the machine in good working condition. Expertise of operator should be given first preference.

**Varieties for mechanical harvesting of cane**

The increase in area under cane associated with expansion in sugar industry has brought about problems in non-availability of desired labour for timely harvesting of cane. To avoid post harvest staling losses and for prompt supply of cane to sugar factories, mechanized harvesting of cane has now become a common practice in most of the cane growing countries. Mechanized harvesting system demands specially bred cane varieties. Soft, staggered and lodged cane, with heavy trash does not suit the harvesting machinery. The variety must withstand the strain on stubbles during movement of harvesting machinery in the field, so as to have better ratoon sprouting.

**High yielding varieties:** Good cane and sugar yield per unit area harvested increase the working efficiency of machinery. Working cost of the machinery increases by its operation on low yielding fields.

**Varieties tolerant to lodging:** Suitable agronomic and crop management techniques may be adopted to reduce degree of lodging. A balance in stubble growth and yield may be maintained to have an erect crop of cane. The stage has to be adjudged beyond which the crop lodges, it may be 100 t/ha for a variety, or 150 t/ha for the other. Quite a few may withstand little more than 150 t/ha.

**Cane: Trash Ratio:** Heavy trash may have problems in harvesting operations and post harvesting care of the ratoon crop. Heavy trash blanket can reduce the stand and early growth of the following ratoon crop. Torres et al (1998). The performance of harvesters is reported to be better where cane: trash ratio is less than 30% (Torres et al, 1998).

**Brittleness:** Brittle stalks while pose problems in the harvesting process a lot of cane is lost through the extractor fan. Stalks break easily even before entering the throat of the harvesters. Pieces of brittle cane left behind in the field are reported to the tune of 20 t/ha (Torres et al, 1998).

**Self Stripping:** A self-stripping variety with low ratio of trash to cane and with thick stalk diameter (>35 mm) is preferred both for manual and mechanical harvesters. The self stripping varieties bring increase in harvesting efficiency.

**Uniform cane height:** Though the topper of the harvester can be adjusted according to plant height, a uniform stalk height facilitates topping efficiency of mechanical harvester. For the purpose, a variety with profuse early tillering and uniform growth may be selected.

It may however be understood that besides development of cane varieties, proper crop and field management practices have to be adopted to save the crop from lodging. The engineering device with respect to type of harvesters and harvesting technique play part
Mechanical v/s hand cut cane

Cane productivity and investment costs must be linked with profits. Labour cost in harvesting operation and working efficiency have in the past tempted the industry to introduce mechanized harvesting system in industrial countries. The present day labor crisis call for the attention of planners to the use of appropriate farm machinery in various sectors. However, economics have to be worked out to purchase and maintain expensive machinery per hectare of its operations. Facilities for repair and replacements and skill of labour for man day performance and benefit cost per hectare have to be judged in comparison with manual harvesting and loading charges. Quality losses from mechanized operations with respect to efficiency need to be considered in given cane plantations and working environments. So long as labour is plentiful, introduction of machinery may invite un-employment restlessness. Thus one has to be cautious to take the decision on social issues as to adopt complete mechanization or partial mechanization in cane culture.

Economic benefits

The working of the harvester should be economically viable in a given crop and field conditions, operating efficiency, quantity of cane harvested and transported and maintenance and operating cost. It should consider the field conditions in field transport, vehicle availability, distance and time taken for haulage of cane to sugar mills. All the working units should be in tact with working facilities to cross all the barriers and hindrances. The best harvesting system would be one that reduces the working cost of machinery and equipment by management, utilization and best efficiencies.

Loading and Transport

There are different modes of loading and transport for carrying cane from field to factory. Cane is manually loaded on trucks or tractor drawn trolleys with different loading capacity. Trucks may carry cane load of 10-16 tonnes while trolleys may have the capacity of 6 to 30 tonnes. The erect cane stalks are bundled in full length and loaded as such. If lodged, the stalks are cut into two or three pieces to make bundles for convenient loading. In some areas labour is quite specialized to make small sized bundles of erect or lodged cane for convenient loading on the truck/trolley.

In the field near to the factory cane is loaded on bullock cart or even on camel back for supply to sugar mills. Bullock cart may load one to two tonnes weight of cane while camel can hardly carry on its harness 2.5 to 3 quintal cane.

For the cane fields much away from sugar mills and having purchasing centers, growers send their cane to purchasing center through cartloads, camel and even donkeys. Sugar mills may have their own truck / trolleys system for carriage of cane from purchase center to the sugar factory.

Under mechanized harvesting system, cane loading and transport is also mechanized and well organized. For example cane transport system in the Queensland Sugar Industry is a combination of in field transport delivery cane to mill bins at local siding, and narrow gauge rail network for delivery of bins to the mill by locomotives. Twenty six mills
operate their own railway system over some 3500 km of track. About 90% of the cane is delivered to the mill by locomotives. The most common size for rail bins is 6 tonnes. Now 8-12 tonnes bins are also being introduced. Some mills have full road transport delivery system; others have combined system of road and rail transport. In road transport 24 tonnes container lifts cane from farms pads to sugar mills. Most mill transport system tip directly into the mill carrier and some mills trans-load cane into the rail system to allow cane storage prior to crushing. Bins have tippers system to off load cane in the field bins or field bins into cane carrier. At the cane carrier mostly one bin is off loaded into carrier through a chout. The tipper system is very efficient that unload cane between 30 seconds to one minute.

In some countries truck or trolleys load is made to stay around cane carrier and the manual labour throw the cane bundles into the carrier. The use of tippers is also getting common for off-loading cane into the cane carrier. In some mills the cane is off loaded around carrier and grab type mechanism pick the cane bundles and drops in the carrier mechanically.

The cut to crush time is of great economic consideration in sugar industry. Any delay in cane transport to sugar mill can cause significant losses in sugar due to staleness in cane. In manual harvesting this is the usual problem faced during over production or shortage of labour. In such cases cut to crush time may be as long as one to several days. But in mechanized harvesting the problem has been solved by systematic mechanized transport system, as delivery and pickup of bins are designed to minimize cut to crush delays. The cane procurement programme is organized to ensure that the time between cut to crush does not exceed 16 hours, beyond which the cane supplier is liable to penalty.

**Cane Marketing**

The cane brought for crushing in sugar factories is regulated by a set system of cane procurement. The cane procurement programme for the purpose of crushing varies broadly from region to region and from factory to factory. It may be categorized as under:

**Sugar mills plantation**

Sugar mills have their own land, either as ownership or acquired on lease. The sugar mills have their own staff to run the farms for growing cane and other crops in rotations. They manage cane supplies to factories is managed as per requirements.

**Cooperative farming**

It is the private farming, but cane growers join hand as cooperative societies to grow and supply cane under well organized system. A cooperative society organizes their input requirements for equipment, seed, fertilizer and plant protection. Cane supplies to mills are not individual deal. The cooperative body itself deals with mills affair and to arrange the programme of cane harvesting as per requirements of sugar mills. The grower's lot for cane harvesting and cane supplies to factories is selected by the societies.

In some countries sugar factories are owned by cooperative organization; all the business of farming and factories is run by the cooperative units. India, Mauritius and Sudan may be quoted as example. In Queensland and Louisiana, growers join hands to manage their harvesting collectively under a well set programme. The sugar mills, to meet its crushing
requirements have not to deal with individual, but body of the cooperative farm units. In this case sugar mills have to deal with only a few dozen or hundred of the cane supply units.

**Individual farming**

Growers manage their farm at their own will and cropping programme. Sugar mills have to deal with individual growers for cane procurement. Number of growers varies with farm size. In the region having small land holding, sugar mills have to tackle with thousands of farmers, but in case of big holdings and cane growing states the number of supply units may be reduced to a few hundreds only.

Cane supplies to sugar mills are controlled by set legislation by Government. In India some areas are reserved for a particular sugar factory. The growers falling in this zone are bound to supply their cane only to a particular factory. In this zoning system sugar mills have the opportunity to organize cane development programme for cane yield maximization and propagation of quality varieties. The system is sometimes misused during the years of over production, as growers can't dispose off their produce to any other mills and have to wait for late in the crushing season.

**Factors Affecting Cane Price**

In countries like India and Pakistan, where cane is paid on the basis of cane weight, irrespective of its quality, cane price is vulnerable to some natural as well as induced factors.

**Cane yield**

Cane yield has the pivotal role in influencing the price of cane. Higher cane yields would tend to increase gross income per hectare. Cane yield must exceed the cost of production of sugarcane. As for instance if a cane yield of 80 t ha$^{-1}$ balances the cost of production at Rs 100 per quintal, the grower with yield of only 40 tons would demand Rs. 200 per quantal to balance his economy. So it is the yield of cane that satisfies the growers for a fixed price of cane.

The agronomic factors being constant cane yields are greatly affected by seasonal changes in weather, the periodic rains, and natural calamities like drought, frost and floods. Timely rainfall and availability of irrigation water is the most crucial factor affecting yields of cane. Severe infestation of diseases and pests may cause severe damage to cane crop.

**Cane area**

Cane area influences the overall total production of cane. Higher cane prices of the preceding year crop tend to increase area under cane. Low cane prices, delayed payment of cane or other disputes on cane supplies / procurement may tend to decrease area under cane. It has been often observed that in vigorous crop year millers exploit the interest of growers by making less payment or deducting weight of cane on one reason or the other. On the other hand during low cane production years growers would demand high price of cane.
Price of gur and khandarsi

Manufacture of Gur and Khandarsi has acquired the position of an alternate industry in India and Pakistan. Higher price of Gur and Shakar tend to divert cane to the cottage industry. In NWFP province of Pakistan, almost 20 to 40 % cane is utilized in cottage industry for the production of Gur and Khandarsi. To avert this cut throat competition, cane price is increased. In Punjab as well, tendency to Gur manufacture is more during slump years of cane production, which tends to increase price of cane.

Price of alternate crops

Cotton, rice and maize are seriously competing crop of sugarcane in Kharif season. Sugarcane is a long duration crop covering the ground for 12 to 18 months in Pakistan. While cotton and rice have crop season of 6 months and maize 4 months. To promote the growing of sugarcane should have an edge on income from its competing crop plus the income from an additional Rabi crop in rotation with Kharif crop. In some regions Banana and vegetables earn more cash return than sugarcane. Comparative higher cash return from sugarcane gives impetus to growers to plant cane crop. The adverse situation may lead to divert sugarcane area to other remunerative crops. In countries making cane payment based on sugar price, the same principle applies. In years of less sugar price, growers alter their cropping programme and switch on the cane area to other crop fetching higher cash returns like banana, pineapple, cotton, maize, vegetables.

In sugar mill zones, sugar mills make survey of cane area before the start of crushing season. Cane growers make cane supply contracts with the sugar mills in that particular zone. Cane supplies/ procurement and cane payments are regulated under set rules of Cane Act.

Transport charges

In cane marketing, distance for cane purchase is of great economic significance. Sugar mills on the approval of cane commissioner fix the cane transport charges for specific distance from sugar mills. Cane purchased from far off distance increase the cost of cane which in turn increase the production cost of sugar. During years of short production of cane, millers tend to purchase cane from far flung areas which increase transport cost. In case the area falls in other mills jurisdiction or other mills plunge into the same area for cane purchase, it tends to creat competition in cane purchase. This situation increases the price of cane. Growers are benefited but mills economy may be shattered. The millers may speculate while purchasing cane, considering the future sugar prices in the country and in the world market.

Cane trash

Supply of cane with trash to sugar mills look simple thing but is of great economic significance to millers. While the trash has detrimental effect on the sugar mills recoveries, the millers have to pay additional cost on the weight of trash brought with cane. The quantum of trash that could be 1 to 20 percent or even more in extreme cases, is going to increase the cost of cane proportionate to the amount of trash present.

In Pakistan, cane supplies by individual growers to sugar mills were previously organized under zoning system. A minimum price of cane was fixed by Government and all the
sugar procured by factories was purchased by Government at a fixed price. The Government used to dispose off sugar to consumers on weekly rations. During 1984, cane zones were abolished, and growers are now free to supply cane to the factories at their own discretions. Sugar mills are free to dispose off sugar without any control on price. Nevertheless, minimum price of cane is fixed by the Government. The system of decontrol on cane and sugar marketing still prevails, but with a minimum fixed price of cane.

Cane Payment System

Sugar industries in various countries have adopted different systems of cane payments.

Minimum fixed price of cane.

In indo-Pak sub-continent a minimum price of cane is fixed by the government at a base sugar recovery level. In Pakistan, base sugar recovery level is 8.5 % for Punjab and NWFP provinces and 8.7 % for Sindh. However, an incentive is given to growers on an enhanced sugar mills recovery. In case the sugar mills average recovery exceeds the base recovery, the sugar mill is liable to pay quality premium in proportion to the sugar recovery it exceeds.

The premium is payable to all the growers supplying cane to the respective sugar mill, irrespective of their cane quality. The growers supplying high quality cane or cane of poor juice quality are equally benefited.

Incentives on cane varieties

In some countries, as in China, cane price is fixed for the season, but an additional price incentive is allowed on better quality varieties. This is in fact an incentive to promote the growing of quality varieties. As otherwise, quality of cane is liable to be affected by agronomic factors, fertilizers and irrigation application, diseases, pests and natural hazards.

Payment based on sugar recovery of individual consignment

In all the advance cane growing countries, payment is made on an individual consignment of cane supplied to sugar mills, based on its sugar contents, linked to market price of sugar. This is the system that values the cane for its quality. The system is in vogue in countries, USA, S. Africa, Mauritius, Philippine, Australia and others. The system has helped improve sugar recovery of the sugar industries of the the respective countries.

In this system cane consignment of each grower or group of growers is analysed for sugar recovery. For cane analysis, generally two methods are in use:

Cane juice is collected from the first roller of the mill tendem and is termed as the “first expressed juice and the data for Brix, Pol and Purity is based on this juice analysis. In Australia cane carrier is so designed that cane lot of only one grower or group of growers is received and crushed. Cane supply programme is so organized that a cane lot of one consignment may include five to twenty or more sugarcane bins at a time. So the sampling of first expressed juice of an individual consignment poses no problem.
In the other system “Core Sampler” is used for taking representative samples of cane from the cane load supplied to the sugar mill. The laboratory meant for cane sugar analysis is controlled by a control board representing government, growers and the sugar mill. It is un-biased analysis accepted by all the parties. Duplicate sample is taken, one for the immediate analysis and the other is kept in reserve for latr testing on any challenge or appeal. The sugar recovery for the early, mid and late season crushing is adjusted with a set formula.

The trolley / truck load of cane is quantified containing the weight of sugar as per laboratory analysis. The sugar worked out is distributed between the growers and miller on pre-determined share, which could be 75 : 25; 70 : 30; 68 : 32, as the case may be. Growers are paid for their share according to the sugar price worked out by the concerned Board.

The prevailing cane payment system in Australia is briefly given as under (Malk, 2005).

Sugarcane is an important cash and sugar crop that earns major share of foreign exchange for the country. Australia is one of the world's lowest cost sugar producer and second largest raw sugar exporter. Cane is grown within average yield of 87 TCH and raw sugar is produced at the CCS level of 14.5%. The recovery level at which Australia stands is mainly due to the linkage of cane payment to the sugar contents in cane.

The number of growers in each sugar factory is considerably less in different cane growing districts, which on an average ranges from 17 to 280 growers per sugar factory. Usually five to seven growers of adjoining areas are grouped for supply of cane to a sugar mills; and, even some growers themselves are the owners of sugar factories. As such it is quite easy to organize the growers for making pre-sowing contracts and to manage the harvesting programme based on individual grower's cane analysis for sugar contents.

Cane growers make pre-sowing contract with sugar mills, they like to supply. Cane supply quota for that grower is fixed for the particular season. He is bound by sugar mills to grow the varieties recommended by the sugar mills and keep the crop free of pests and diseases.

Cane is supplied to sugar mill, and as per individual grower's sugar recovery, the share of his sugar which is 68 % against 32 % for sugar mills, is credited to his account.

Marketing of total sugar produced by the sugar mill is directly controlled by Queensland Sugar Limited (QSL). Queensland Sugar Limited (QSL) is the single desk marketing organization that has the monopoly in sugar trade. Queensland has retained vested ownership of raw sugar and marketing functions.

The company is run by a Board of Directors including 4 members representing growers, 4 from sugar mills and 4 independent members including the chairman.

Queensland Sugar Limited operates on following principles:

- Operates on not – for – profit base
- Pool sales revenues, deduct sales and marketing cost and pay net returns back to sugar mills.
• Borrow in order to make advance payment to sugar industry.

As per decision on the market price (including export price), value of his cane is transferred to sugar mills, which pass on the amount to account of the growers. Queensland makes such 8 to 12 progressive payments to mill owners, in a season. Final 'pool price' payments are made in July each year, after the previous season's sugar has been sold and delivered.

Refiners purchase raw sugar from QSL for sale both domestically and for export, without QSL involvement.

A Ministerial Direction given to QSL by the Minister for Primary Industries and Fisheries ensures that raw sugar purchased by domestic users is bought at export parity price.
Chapter-12

Sugar Manufacture

Sugarcane Stalk

Sugarcane stalk is constituted by nodes and internodes. The nodal portion has the growing parts the bud, the root forming dots and the growth ring. The nodal part contains invert sugars and a little sucrose, to be utilized by growing tissues of buds, roots and the growth ring. The internode has surface layer of hard tissues, termed rind; used as protective layer to the inner tissues. The inner cells are the conductive tissues, the xylem and phloem bundles and the soft cells the cortex which is store house of sugar. Sugar is synthesized in cane leaves and is then stored in cane stalk. Cane stalk is thus the store house of sugar and is of main concern to the sugar industry. Cane stalk is also valued for its fibre – bagasse used as the main energy source for sugar manufacture.

Sugar Synthesis in Cane Plant

The fresh weight of cane plant is composed of 99% of the elements oxygen, hydrogen and carbon. Of this 99%, almost 75 % is water and the balance is made up of dry matter that includes sugars, fibre and organic compounds forming plant parts during various growth phases. (Dillewijn, 1952). The dry matter substances are synthesized in complex intricate processes of photosynthesis, phospherelation, sugar and starch synthesis and sugar translocation and storage. These processes are associated with respiration and energy release.

Photosynthesis: In this process, sugarcane makes use of solar (radiation) energy to convert carbon dioxide (absorbed from atmosphere) and water (absorbed from soil) into carbohydrate and oxygen. The process takes place in leaf blades in the presence of chlorophyll and light. Chemically six molecules each of carbon dioxide and water diffuse to form simple sugar molecules, releasing energy. Formation of simple sugar is represented by an equation;

\[
\text{Chlorophyll} \quad 6\text{C}_2\text{O}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \\
\text{Sun light}
\]

Carbon dioxide is absorbed by the plant; over its green aerial surface chiefly the leaves, in the presence of light. It passes into the intercellular spaces through stomata and diffuses into the parenchymatous cells, the mesophyll cells of leaves. It should be noticed that it passes through the cell walls not as a gas but as a solutions and is dissolved in the cell sap which permeates the walls of the cells. In the interior of these cells the chemical processes take place under the influence of chlorophyll and light. The water (H\text{2}O) absorbed by the roots and the carbon dioxide (CO\text{2}) built up into carbohydrates. The first compound formed is formic aldehyde (CH\text{2}O) and oxygen is given off. In the process from aldehyde, soluble carbohydrates of the nature of the sugar are formed.

Sugar belongs to the chemical group known as carbohydrates. The process by which carbon dioxide is incorporated in the plant in the form of carbohydrates is referred to as
carbon assimilation. Since this only takes place in the presence of light it is called photosynthesis. And, when this process is reversed, energy is liberated:

\[ \text{C}_6 \text{H}_{12} \text{O}_6 + 6 \text{O}_2 = 6 \text{CO}_2 + 6 \text{H}_2 \text{O} + \text{energy} \]

This process is called respiration and occurs in all living tissues and is of particular importance in the growing region. The assimilates which are not utilized in the production of energy, are incorporated in the plant, in the form of dry matter and constitute a reservoir of potential energy.

Enzymes play important role in the conversion of one kind of carbohydrates into others; they accelerate the rate of conversions:


There are two phases for the manufacture of sucrose in the plant. In the first phase simple sugars, glucose and fructose are formed only in the presence of day light under the photosynthetic action. During the second phase simple sugars are converted into sucrose and polysaccharides. This process requires neither chlorophyll nor light; In contrast to photosynthesis the second phase is synthesized in the dark.

\[ \text{Simple sugars} + \text{Sucrose} \]

Translocation of sugars

The sugars produced in the leaves move to all other parts of the plant, where it is partly utilized in respiration and in the building up of plant body. The remainder is stored in the stem in the form of sucrose. Translocation takes place in the phloem tissues and proceeds day and night. Both sucrose and simple sugar are translocated in the sugarcane plant and one of the dominant factors for translocation is the moisture contents. Since the rate of sugar formation during day time exceeds the transportation capacity of phloem, parts of the sugar have to be stored during day time in the leaf blades in the form of starch and other insoluble polysaccharides.

Sugarcane with its high fiber and carbohydrate contents constitutes an important source of energy. This carbohydrate is initially utilized in development of various cellular organs of plants; leaves, roots and cane stalk with conducting and storage tissues. As the plant growth is complete, plant uses solar energy for synthesis of sugars and their storage in plant tissues. During its long growth period of 9-16 months a good amount of solar energy is converted into sugars and cellulose. With cane stalk formation, sugar accumulation starts in the lower portion; with advance in cane growth sugar storage progressively increase towards upper portion of cane stalk till cane gets fully mature. Within the cane stalk, internodes are richer in sugar while nodes have more of non-sugars with higher fibre contents. Cane stalks with short internodes will have high fibre and low sugar, the tops and leaves contain very low sugar but are quite rich in salts.

Sugar remain stored in cane stalks during winter or till the crop is harvested from the field. If allowed to stand in the field after its maturity phase, sugarcane starts
Sugar Manufacture

deteriorating; sucrose decomposes with the formation of non-sucrose compounds and cellulose. Thus over mature cane has high fibre and reduced sugar contents.

As the cane is brought in a factory sugar is extracted through various milling, clarification, boiling and crystallization process. Other organic constituents produced in a factory are residue, in the form of fibre, filter press cake and molasses. They are utilized as value added by-products, while cellulose biomass is directly utilized for generating power energy in the factory. Physical and chemical composition of sugarcane is given as under.

**Composition of sugarcane**

Sugarcane plant at its full age constitutes 65-70 % mill-able cane, 15-20 % green tops, 5-7 % dry leaves (Trash), 5-7 % stubbles and 5-8 % roots mass. The variation in plant constitution is observed with plant age, crop maturity and climatic changes. Each plant part has its cultural, industrial or commercial importance in one way or the other. The main basis of crop importance is the mill-able portion of cane stalk. The mill-able segment of cane plant is composed of 75-80% water, 12-15% fibre 10-15 % sucrose and other invert sugars and 2-3% mineral salts and organic compounds.

![Composition of Sugarcane Diagram]

Different plant constituents dealt in a sugar factory are described as under.

**Sugar**

Sugars are the carbohydrates chemically formed by carbon, hydrogen and oxygen elements. First step in plant is synthesis of simple sugars like glucose or dextrose and fructose or laevulose. These are the monosaccharide each having chemical formula of C₆
H$_{12}$O$_6$. These contain six carbon atoms and are called hexoses. Sucrose a disaccharide is a condensation product of glucose and fructose/levulose with empirical formula: $C_{12}H_{22}O_{11}$.

\[
6C_6H_12O_6 + 6H_2O = C_{12}H_{22}O_{11} + 6O_2
\]

\[
C_6H_{12}O_6 + C_6H_{12}O_6 = C_{12}H_{22}O_{11} + H_2O.
\]

Under conditions of low pH with the reaction of some acids or under the influence of certain enzymes like invertase, sucrose is hydrolysed into two mono-saccharides viz glucose and levulose

\[
C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6
\]

**Nomenclature of carbohydrates**

The main three groups of carbohydrates are distinguished as under:

- **Monosaccharide**: $C_6H_{12}O_6$ dextrose/glucose
- $C_6H_{12}O_6$ levulose/fructose
- **Disaccharide**: $C_{12}H_{22}O_{11}$ sucrose/mltose/lactose
- **Polysaccharide**: Cellulose, starch, fibre

The physical and chemical properties of sucrose are:

- Molecular weight: 342.3
- Density of 26% solution at 20º C: 1.108
- Melting point: 188º C
- Saturated solution contains 67.1% sucrose by weight at 20 ºC.

The carbohydrate compounds containing five carbon atoms are termed as pentose sugar like arabinose and xylose.

**Sweetness value**

Relative sweetness values assigned to different types of sugars, with reference to sucrose reported by Mead and Chen (1977) are reproduced as under. Sugarcane also contains several polysaccharides like gums, starch cellulose, dextran which is produced by condensation of monosaccharide.

<table>
<thead>
<tr>
<th></th>
<th>Sweetness Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>1.0</td>
</tr>
<tr>
<td>Maltose</td>
<td>0.4</td>
</tr>
<tr>
<td>Fructose</td>
<td>1.1</td>
</tr>
<tr>
<td>Lactose</td>
<td>0.4</td>
</tr>
<tr>
<td>Glucose</td>
<td>0.7</td>
</tr>
<tr>
<td>Galactose</td>
<td>0.6</td>
</tr>
<tr>
<td>Xylose</td>
<td>0.7</td>
</tr>
<tr>
<td>-</td>
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</tr>
</tbody>
</table>

**Fibre**

This is water insoluble portion of sugarcane and is composed of 40% cellulose, 30% hemi-cellulose and 15 – 20% pectin. The cellulose is composed of chain of glucose
molecules held together closely with varying degree of polymerization. The complex fibrous structure of plant is bound together by lignin, pectin and hemi-celluloses.

In milling process fibre has an important role to play in the extraction of juice, in loss of pol and overall sugar extraction and power consumption, during sugar manufacturing processes. Some sugar is lost in bagasse in the form of juice not properly extracted. Higher is the fibre, higher is the loss in sugar.

Fibre may be low in earlier season of crushing, and increase with advance in plant maturity, in late season it may reach to 16 % or even more. Under drought spell or very late harvesting, fibre may be as high as 17 – 18 %. In Australian sugar industry 12.5 % fibre is taken as standard for assessment of 94 nt sugar.

Moisture loss in bagasse is of great economic significance. It is the juice extraction that determines the moisture loss. This too is regulated by the fiber and the crushing of cane

Fiber quality depends on cane varieties, lodged or erect cane, drought, infestation of pests and disease infection. Besides the amount of fibre in cane, the foresaid plant features would also regulate the crushing rate in milling. Hard cane and cane with short internodes would require more energy in crushing cane at lesser rate.

Fibre quality is also equally important. Cane varieties having long fibre particles, than short and brittle fibre, would give better fibre structure during shredding process. Long, hard and tough fibre extracts better juice than soft and brittle fibre. Cane varieties with spongy pith have less extraction than the varieties having solid pith which is full of juice.

Hard nodes pass through fibrizer; as such require heavy pressure for its breaking during milling process. For power economy the cane structure should be such as to give good fibrous material during initial preparation.

**Gums**

They are composed of six different monosaccharides and are soluble in water. They are removed in clarification process, however, may persist to some extent till the final stage of molasses and sugar.

**Dextran**

It is the polymer compound of glucose molecules and is the product formed by microbiological infection of damaged cells of the plant by the action of bacteria leuconostac mesenteroides. Dextran has a molecular weight of 15,000 to 20,000 and is gummy colloidal substance. Dextran is mostly formed in frozen cane or post harvest stale cane. Dextran present in cane juice creates difficulties in crystallization contributing to high loss of sugar in manufacture process.

1. Dextran affects the polarization of the juice resulting in false sugar contents and false juice purities.
2. The sucrose is biologically converted into dextran and levulose.
3. It produces the low grade massecuities.
4. Dextran reduces the growth of crystals and promotes the promotion of false
grain formation.

5. The low grade massecuities create centrifuging problems resulting in higher purity molasses.

6. The large dextran molecules increase the viscosity of syrup massecuities and molasses.

7. It makes molasses exhaustion very difficult.

8. Factory capacity and sugar yield are lowered.


Organic acid

Cane juice is acidic in nature with pH of 5.5 – 6.0. The acotinic acid is the major constituent of various acids. The deteriorated cane after harvest also generates acetic acid and lactic acid. A number of amino acids, glutamic acid, and alanine are also present in cane juice. These acids are not affected by clarification and accumulate in final molasses.

Colour Forming Pigments and Compounds

Colour in the juice is due to natural pigments like chlorophyll, anthocyanin, sacchararetin and tannins and the organic compounds like polyphenols and flavonoides. Coloring matter has an adverse effect on crystallization process.

Chlorophyll. It is insoluble in water but soluble in alcohol. It is in colloidal form and exists in suspension of cane juice. It is removed in clarification process and does not affect the color of sugar.

Anthocyanin. It gives purple color to cane rind. It is soluble in water and cane juice. Purple color is changed to dark green coloration by addition of lime. Excess of lime is added to eliminate color in defecation process; sulphitation process can not bleach the color.

Sacchararetin. This pigment is in cane fibre. Bagasse particles get yellow color and should be properly filtered. It may be extracted by the action of lime on fibre.

Tannins. These pigments are present in vegetative cells of tops and leaves. It is green in nature but get darker when reacts with iron salts of cane juice.

Chemical decomposition of cane juice. During juice treatments it comes in contact with iron juice heaters, evaporators and pans; tends to increase color due to absorption of iron salts, especially in acid medium because of possible reaction with polyphenols. These reactions influence color of sugar. Care is to be taken to bleach the color through sulphitation and phosphitation process.

Inorganic compounds

Some cations of silica, iron, aluminum, calcium, magnesium, potassium and sodium, anions of phosphates, sulphates and chlorides are absorbed by cane plant during period of cane growth. These salts extracted along with juice are not fully removed in clarification process. The potassium and chlorides are not removed and persist to accumulate in
molasses. Most of the salts are concentrated in juices from immature cane tops. The mineral matter and mainly the potassium, which constitute over 60% of the total ash, are mainly responsible for retention of sucrose in the final molasses. High concentration of salts in juice results in high loss of sugar in molasses.

**Lipids**

The rind of cane stalk is coated with waxy lipids. This fatty lipids and wax are extracted during milling and are then eliminated in the filter press cake during clarification process. The crude wax content of dry filter cake varies from 8 to 12%.

**Colouring agents**

Cane juice and the sugar produced in the factory may have light or darker colour. This may be due to some colouring pigments in cane and production of compounds as a result of chemical reaction during the milling and boiling processes. The compounds are formed by the oxidation of plant pigment called flavonoids and phenolic acids. These may include polymers from reducing sugars under alkaline reaction. Color may also be developed by caramelization of sucrose at high temperatures.

Cane varieties vary in their color forming pigments; presence of top and trash contribute more colours than cane stalk.

The most damaging colourants of sugar are formed by the reaction of amino-nitrogen and reducing sugars. It happens when crop is grown in heavy fertile soil or added with heavy 'N' doses of nitrogen.

The factory may also generate colour through high temperature and alkaline reaction. Care has to be taken during clarification process and maintenance of equipment during pan boiling.

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**Sugar Manufacture Process**

**Milling**

**Cane preparation**

The cane is received and unloaded into the cane carrier, mechanically through grabs, tippers or using manual labour. From cane carrier sugarcane is slowly conveyed to milling process through a belt convayer. The milling process occurs in two steps, breaking a hard structure of cane and grinding the cane. Cane juice is held in cells which has protective fibrous covering. For better extraction the juice cells have to be broken and ruptured. For breaking the cane it is fed into revolving knives, hammer mill shredder, unigraders or fibriser or combination of these processes. The fibriser consists of heavy duty cane cutting knives that break cane sticks to longitudinally small shreds. The fibriser opens up 90% of the juice cells which facilitates extraction of sugar from the fibre in subsequent processing.

**Milling**

For grinding and milling, a uniform bed of crushed cane is pushed to multiple sets of
three roller mills. The rollers are so arranged in triangular set as to squeeze the cane mass twice under pressure. Four to six sets of such mills make up a crushing tandem. Sugar mills may have one or two tandems according to their crushing capacity. Some sugar mills have pressure feeder device wherein cane is compressed to the mill through a chute under pressure. It helps enhance crushing capacity as well as extraction.

In first mill almost 68 – 70 % of cane juice is extracted. To extract the remaining juice, residue of the cane is passed from one mill to the other mills of the tandem. To accelerate extraction from the shredded cells, some water is added on to the passing residue in a roller set of 4th or 5th mill. This water which is more or less 200-250 % of the amount of fibre (worked out in due course) is called imbibitions water. The amount of imbibition water with juice and the steam requirement are to be efficiently and economically controlled. Hot water temperature of 60º - 80ºC is considered optimum for extracting most of the juice from cells than the use of cold water. The water temperature higher than this dissolves waxes and is not desirable. The juice extracted from the last mill is pumped and applied back to the previous mill and transferred from mill to mill towards the first two mills. It is only from the first and second mills that the mixed juice is pumped out, strained to remove large particles, weighed and sent for boiling and clarification.

After complete juice extraction, the sugarcane residue called 'bagasse' contains more or less 50 % moisture and the crushing process extracts 92 – 97 % of the sucrose present in the cane sent to the mill.

Bagasse from the final mill is conveyed out partly to the boiler and the rest to store in a yard. It is used for fuel in boilers for producing high pressure steam for driving turbines for the mills, shredders and power generation. The exhaust steam is used for heating and juice evaporation.

The ash is collected and sent out as waste material. It may be blended with filter cake for use as organic manure in cane fields.

From view points of milling operation amount of fibre in cane is of great economic significance. High fibre cane varieties with high sucrose may be usefull as more energy bagasse is saved. But extraneous matter in cane in the form of trash, tops, roots and mud particles are extra drain on cane milling. The extraneous matter reduces extraction as well as crushing rate. High dirt cause wear to shredders and rollers; milling efficiency is reduced with increased maintenance cost.

Clarity

The juice obtained through crushing cane contain many impurities including fibrous material, soil particles, suspended colloidal matter, dissolved organic substances such as pigments (chlorophyll, anthocyanin, polyphenols), wax, gums, albumins, proteins, pectin’s, starch, glucose, fructose, minerals and amino acids. These have to be removed as far as possible.

The pH of the juice is basically acidic in nature which has to be raised to neutral level. Juice is heated to about 75ºC and is limed with calcium hydro oxide Ca (OH)² @ 0.06 to 0.10 % of cane weight. If needed, additional phosphorus may be added as super phosphate. It is further heated to 102 - 105ºC. The objective is:
Sugar Manufacture

a. To kill the bacteria to avoid possible infection and remove air.
b. To prevent inversion of sucrose which otherwise takes place in acidic medium.
c. To coagulate the impurities with suspended particles to form precipitate.

The heated juice is brought to clarifier where all the impurities and also calcium phosphate, formed by milk of lime and naturally occurring phosphates in cane juice, coagulate to form flocks and are precipitated as mud.

Juice is then made to pass through clarifier where the impurities are precipitated and settled down taking with it dirt, fibre particles and other organic substances. Settling time should be the minimum to avoid charring of the juice. To enhance settling rate some flocculants are added.

The clarified juice in upper portion of the clarifier is drawn out and sent to the evaporators. Precipitate that settles in the bottom of the clarifier is called “mud” and is drained out.

The presence of soil particles, juice from deteriorated cane or stale cane has detrimental effect on clarification process. Poor clarification lowers sugar quality and has adverse effect on crystallization process and finally increases sugar losses.

Filtration

For extracting juice from mud, it is passed through rotary vacuum filters. To further recover the sucrose from the mud, it is mixed with bagacillo to make it porous. It is pushed to rotary drum vacuum filters. Hot water is sprayed on rotary filters that helps remove maximum sugar from the mud. The filtered solute is sucked and returned to clarifier, whereas the hard layer of residue is gently scraped and is called filter cake or simply filter cake. The juice from the Vacuum Filter is sent to defecation for processing.

Fresh cake contains 75 – 80 % moisture and 0.5 % sugar. If quantity of mud is more, sugar will be lost from the process. Lesser juice impurity would produce lesser quantity of mud and low sugar losses.

Evaporation

Evaporation is performed in two stages, initially in evaporators to concentrate juice, then in vacuum pan to crystallize sugar. The clarified juices are passed through heat exchange to preheat the juice and sent to evaporation station. Evaporation station consists of a series of about 5 evaporates called multiple effect evaporation. Steam from power house is used to heat the first evaporator, the vapour from the first evaporator is used to heat the second evaporator, and this heat transfer process continues to the last evaporator.

Pre-requisit of evaporators is to be efficiently and economically controlled.

Clear juice is pre- heated to a temperature around 107-110ºC and is passed to the evaporator. In the second vessel it is heated at little low temperature but under high pressure with vapors developed in the first vessel and than is passed on to the third vessel. At this point juice temperature is reduced to about 85ºC but vapor pressure is almost 660 mm. In the last vessel temperature would be about 65ºC, vapor pressure 760 mm and syrup density reaches 60-65º Brix and 85% purity just below the saturation point.
The final outgoing product is called syrup. Chemist at the spot control the heat transfer, the steam pressure, the vacuum developed and the Brix of incoming juice and finally the syrup. During boiling operations, salts and other substance foul the heating surface of tubes and are to be frequently cleaned out with chemicals or mechanically.

**Pan boiling**

The syrup from evaporators passes through crystallization stage together with seed. The crystallization process is carried out in vacuum pan, which may be batch or continuous in operation. The contents are boiled under vacuum at about 60ºC. During boiling as the magma concentrates, C sugar (seed) is added to initiate crystallization of sugar. Crystals in mother liquor grow to achieve requisite size. The boiling action continues with the formation of crystals in mother liquor. As the crystal size is achieved new syrup is added. This is a critical stage and has to be carefully monitored.

This process produces sugar crystals and concentrated syrup called molasses, and whole mass is termed as massecuit. Whole operation is completed in three stages of syrup boiling system producing A, B and the 'C' sugars. The 'A' and 'B' sugar constitutes raw sugar while C sugar is recovered in the lowest purity boiling and is typically used as the starting crystals (seed for A and B sugar boiling).

The process of crystallization may be hampered by impurities in juice especially dextran. Efficiency of pan boiling process is affected by level of impurities and the sugar in the syrup. High level of impurities imbalance the production of A and B massecuite with special reference to time frame for boiling. The technologists have to set the pan boiling system based on cane crushing capacity, and considering the purity level of cane juice.

**Crystallization**

Vacuum pan boiler is equipped with a steam heated calandria (tubes for syrup flow) and a condenser to maintain vacuum. Syrup is charged into the evaporator to about one third of its capacity. Syrup at this stage is viscous mixture of fine sugar crystal and syrup, called as massecuit. It is super saturated to form crystals, and is then seeded with additional powdery sugar crystals to start the crystallization process. As the water is evaporated more syrup is added. The process of crystals growth to a desired size is carefully watched. When the pan gets full to the desired crystal size and mother liquor (90- 94º Brix), the massecuite is discharged into crystallizer. In the crystallizer the temperature is kept low to allow crystallization.

**Separation of sugar**

As the crystallization is complete, the massecuite is subjected to the centrifugals for separation of sugar from molasses. The centrifugal speed is at about of 1600-2100 RPM. The sugar is screen while the molasses is drained out. To clear the sugar from adhering molasses it is slightly sprayed with water at 85ºC. The sugar crystals should preferably be uniform in structure. The centrifugals now in use are fully automatic, having charging, washing, spinning, de-loading and restarting steps. They have the capacities of 500 to 1000 kg of massecuite per charge with 15-20 cycles per hour.

It is 'A' grade sugar and A-heavy molasses. In order to get possible maximum sugar from the syrup, series of graded massecuits A, B and C are gradually boiled to achieve
maximum crystal contents at appropriate stage. For refine centrifugal the recommended speed is 1200 RPM.

**Refined sugar**

Most of world sugar is marketed as raw sugar. The countries like Cuba, Brazil, Mauritius, Thailand, Australia, mostly produce and market raw sugar. The raw sugar is refined to make it free of all impurities according to the taste and standards of consumers. A number of processes are involved in refineries.

**Refinery Process**

**Carbonation of raw liquor**

Carbonation process is carried out by adding milk of lime (calcium hydroxide), Ca (OH₂) to the liquor and bubbling carbon dioxide through gas coils, which reacts with the lime to form fine crystalline particles of calcium carbonate. To obtain stable flocks, the pH and temperature of reaction are carefully controlled in the range of first stage 9.2 – 9.4 and in second stage 8.2 – 8.4.

**Phosphitation of carbonated liquor**

5 % diluted phosphoric acid added in the carbonated liquor to stable the non sugar precipitates (Tri calcium carbonate and Tri calcium phosphate) and reduce the pH level 7.2 to 7.4. Separation of flocks is carried out by filtration the liquor through pressure filters.

**Filtration of carbonated liquor**

Carbonated liquor passed through pressure filters for the separation of Tri calcium carbonate, Tri calcium phosphates and obtains clear liquor maintaining the pH value 7.2 to 7.4.

**Sulphitation of clear liquor**

Sulphitation of clear liquor takes place in sulphitor liquor column where SO₂ gas sucked by vacuum creation. Gas acts as bleaching agent to remove the colouring matter and produces shining and transparent liquor, before filtering the liquor pH maintained at 6.4 to 6.6.

**‘Talo’ clarification process**

Raw liquor in the 1st step is treated in reaction tank No.1 with decolorizer and travel to reaction tank No.2 treated with lime sucrerate and dozing of phosphoric acid carried out to produce the flocks of calcium phosphate and pH maintaining up to 7.2. In the second step treated liquor travel to aeration bottle where Talo flock dozing is carried out to aggregate the non sugar flocks and compressed air injected for the floatation of the flocks to upward in the clarifier. Fine liquor of pH 6.4 to 6.6 produced, passed through deep bed filter, to retain the carry over in the liquor and produce the good quality liquor for the final product.
SIMPLIFIED PROCESS FLOW DIAGRAM FOR SUGAR MANUFACTURING IN A CANE SUGAR FACTORY
**Filtration of sulphated liquor**

Sulphated liquor passed through pressure filters for the separation of ferrous sulphate precipitates and obtains fine liquor, maintaining the pH value 6.4 to 6.6.

**Production of refine massecuite -1**

R-1, refined massecuite produced in the vacuum pan under vacuum boiling condition liquor and the seed taken in pan is boiled to produce the refine massecuite by means of vapors from vapors cell, maintaining the desired Brix 88 to 89º.

**Production of refine massecuite -2**

R-2, refined massecuite produced in the vacuum pan under vacuum boiling condition run off-1, seed (cut seed obtained from other pan) taken in pan is boiled to produce the refine massecuite-2, by means of vapors from vapors cell maintaining the desired Brix 89 to 90º.

**Production of refine massecuite -3**

R-3 refined massecuite produced in the vacuum pan under vacuum boiling condition run off-2, seed (cut seed obtained from other pan) taken in pan is boiled to produce the refine massecuite-3, by mean of vapours from vapour cell maintaining the desired Brix 90 to 91º.

**Centrifuging (purging of refine massecuite)**

Refine massecuite charged in TSK centrifugal machines for the separation of sugar crystal and from run off by means of spray hot water of 90ºC through spray nozzles. Sugar crystals separated in the form of refine sugar and molasses in the form of run off.

**Sugar drying and bagging**

Sugar when discharged from centrifugal may have moisture of 2 % and temperature of 70-75ºC. The sugar is subjected to a bucket elevator on a conveyer. Hot air is blown as a counter current, where the sugar is completely dried. The sugar must give white luster and transparency. The sugar is then passed through a continuously shaking sieve. The crystals having larger size are separated for re-melt processing. Fine grain is used as seed in the refine pan, bold and medium grain is bagged, weighed and sent to godown for storage and marketing.

**Sugar Recovery Assessment**

Sugar recovery is the main parameter for the assessment of cane quality. It is the kilogram of sugar recovered from 100 kg of cane crushed. Actual recovery of sugar is the quantity of sugar bagged from the certain weight of cane crushed during a certain period says a day, week, month or a season. Since cane passes from long chain of milling, and juice processing operations to bagging sugar, it takes long time to work out the actual sugar recovery of cane crushed in a factory. Nevertheless, a number of rapid laboratory tests and techniques are in use to determine the sugar recover of cane crushed in a laboratory crusher or sugar mill roller. At present the cane quality is assessed by either of the following methods.
a) Simple analytical methods for Brix, Pol, Purity.

b) The Pakistan sugar industry has adopted the formula linked to S J M. However, actual recovery is worked out on the bases of sugar bagged per quantum of cane crushed in the factory.

c) NIR technique: Latest technique that gives exact sugar recovery at any stage of cane milling and processing.

d) Different countries have developed their own formula for recovery assessment.

e) Some research institutions have followed the Australian formula of CCS.

Cane quality is the inherent character of a variety; however it is, to some degree, affected by a number of factors in the field and factory. Sugar recovery in the field is affected by soil conditions, irrigation and fertilizer inputs and timing, planting time, method of planting, harvesting time and methods, disease infection and pest’s infestation and presence of tops and trash on cane, and post harvest staling due to delay between cut to crush time. The sugar recoveries can be restored by amelioration of these factors. Climatic factors and natural hazards like drought, frost, floods, cyclones have detrimental effect on sugar recovery and extent of losses depend on the degree of intensity. The inefficiency in milling and processing operations in sugar factories increase losses and thereby reduce recoveries.

It is an agreed principle that sugar is manufactured in cane and not in the factory. The sugar factory simply extracts sugar from the cane delivered. However, the amount of sugar recovered depends to a great deal on the quality of cane and milling and processing efficiency of sugar factories. The main components of cane include:

Sugar Cane:

1- cane juice: Sucrose contents
   : Water
   : Impurities,
   Expressed in molasses and filter press cake

2 - Fibre (Bagasse)

In a sugar factory, sucrose has to be separated from various components of cane, in different milling and processing operations. Nevertheless, not all the sucrose in cane is recovered, some is lost in bagasse with fibre during juice extraction and some is lost in molasses and filter cake during boiling and clarification process. The implications observed during these processes are-

1 Composition of juice depends upon the quality of cane.

2 The efficiency of the extraction process and the changes occurring under the conditions of extraction-caused by microbiological action, chemical changes like inversion and solubilization of solid material.

3 Chemical and physical nature of fibre and soluble impurities would affect the
factory operations.

4 Presence of trash increase the fibre content and hence the loss of sugar in bagasse.

5 Stale cane, diseased or otherwise damaged cane usually contain solutes due to which juice purity is lowered, which in turn lowers the recovery of sugar from cane juice.

Based on these parameters empirical formulae have been developed to assess the recovery of sugar in cane.

1. Pakistan Society of Sugar Technology (PSST) Formula:

The method has been described as an official method of PSST (1990)

Sugar recovery = SJM x Mill Extraction x Java ratio x Pol % crusher juice x Boiling House Recovery

2. Louisiana Sugar Industry Formula

The Louisiana Sugar Industry has drawn a formula based on the bagasse / fiber and juice extraction through hydraulic press (Legendre, 1992). Cane sample is collected by means of a Core Punch Sampler.

Data required

- Bagasse % cane
- Moisture % Bagasse
- Extracted juice Brix (First expressed juice Brix)
- Extracted juice Pol (First expressed juice Pol)

Assuming that the extracted juice and the residual juice have the same composition, the fibre % bagasse is given by:

Fibre % bagasse = 100 – (moisture % bagasse) / (1 – extracted juice brix/100)

Fibre % cane (F) = (fibre % bagasse) x (bagasse % cane)/100

Absolute juice % cane = 100 – fibre % cane

Brix % cane (B) = (absolute juice % cane) x (brix % juice)/100

Pol % cane (P) = (juice % cane) x (pol % juice)/100

The above expressions allow the Brix, Pol and Fibre % cane to be calculated.

The theoretical sugar yield in laboratory of 96 Pol sugar per gross tonne of cane is reduced to

(2000 x pol % cane)/100 x Extraction/100 x Retention/100 x 1/0.96

The retention is obtained using the Winter-Carp formula and multiplying by the boiling house efficiency (BHE)
Retention = [1.4 – (40/ extracted juice purity)] x BHE

The Winter-Carp formula is based on standard molasses purity of 28.56º indicating the factor '40'.

The extraction is obtained assuming a constant reduced extraction with an absolute juice % fibre of 56.67.

Pol extraction = 100 – 56.67 (fibre % cane) / (100 – fibre % cane)

Substituting the reduced extraction expression developed above for the Pol extraction, the Winter-Carp formula for the boiling house retention, and assuming a boiling house efficiency of 96, the theoretical recoverable sugar (TRS) yield expression reduces to:

TRS, Lbs. 96º sugar/gross tonne cane = (0.28P – 0.08B) (100 – 56.67F/100 – F)

Liquidation factor = (actual factory sugar production)/Total TRS calculated for all cane.

CRS = TRS x Liquidation factor

The sugar recovery worked out by a formula may not be exactly recovered in a process. A sugar factory may have some losses, which may not be detected by a formula and are termed undetermined losses. Such losses can be covered by applying liquidation factor (LF).

For correct estimation of sugar recovery, the average LF value of the period may be taken as the base. The application of LF in sugar recovery assessment is the usual feature in world sugar industry (Legender, 1992).

In the next step, the sugar recoveries assessed by fore-mentioned formulae are balanced with the actual sugar recoveries of the respective sugar mills and the ratio difference indicated as Liquidation Factor (LF). The Liquidation Factor is to be applied in the end of the crushing season.

3. The Australian Sugar Industry Formula-CCS

In Australia, sugar recovery is worked out by a formula termed as CCS (commercial cane sugar) (Anon, 2005). Since Maximum juice is extracted in the first roller the formula is based on the cane analysis data of Brix and Pol of first expressed juice and fibre percent cane. The formula is used to calculate Brix and Pol percent cane.

It is assumed that:

- For 100 parts of soluble solids (Brix) in the first roller juice, there are approximately 97 parts in the whole juice.
- For every 100 parts of Pol in the first roller juice, there are approximately 95 parts in the whole juice of cane.

Therefore, multiplying the Brix or Pol in first expressed juice by 0.97 or 0.95 gives an estimate of the Brix / Pol in the total juice cane.
The next step is to determine the fiber percentage in cane. If fiber is 15 percent the Brix or Pol in cane would be:

\[
\text{Brix in cane: } (\text{Brix in juice } \times 0.97) \times 0.85 \\
\text{Pol in cane: } (\text{Pol in juice } \times 0.95) \times 0.85
\]

For calculation of CCS, it is assumed that 25% of the impurities in cane are recovered in clarification process and the remaining 75% are in molasses. For every 60 parts impurities going to the molasses 40 parts of sugar are also removed. As a result, high impurities in cane reduce the potential for raw sugar production. The prescribed standard efficiency is such that for every pound of soluble impurities in cane on half pound of sucrose is lost in the process.

\[
\text{Impurities in cane = Brix in cane – Pol in cane} \\
\text{CCS = Pol in cane – \frac{1}{3} (impurities in cane x 40/60)} \\
\text{CCS = Pol in cane -1/2 impurities in cane}
\]

All the foresaid assumptions are reduced to the following formula

\[
\text{CCS: } \frac{3}{2} P \times \left[100 - \frac{(F+5)}{100}\right] - \frac{1}{2} B \times \left[100 - \frac{(F+3)}{100}\right]
\]

The formula determines a sugar of 94 NT (net titre)

## 4. Mauritius Sugar Industry Formula

In Mauritius, the available Pol in cane is adjusted with standard extraction and purity of the juice.

\[
\text{Sucrose % cane = Absolute juice % cane x sucrose % Abs J / 100} \\
\text{Absolute juice % cane = 100 - Fibre % cane} \\
\text{Sucrose % Absolute Juice = Brix Absolute Juice x Purity Absolute Juice} \\
\text{These data are derived from the juice collected from hydraulic press.} \\
\text{Commercial sugar % cane (98.5 Pol) = Sucrose % cane x overall recovery / 98.5} \\
\text{Overall recovery = (Mill Ext. x boiling house recovery) / 100} \\
\text{Boiling house recovery (BHR) = S (J-M) / J (S-M)} \\
\text{S = sugar purity} \\
\text{J = purity of mixed juice} \\
\text{M = purity of final molasses}
\]
5. Formula Suggested by Mathur (1990) in India
Quite a simple formula is reported from India, which determines the available sugar in cane by the equation

\[
\text{Available sugar} = [S-(B-S) \times 0.40] \times F,
\]

Where

- \( B \) = Brix % first expressed juice
- \( S \) = Pol % first expressed juice
- \( F \) = Fibre factor

- The ‘F’ is available juice calculated on the basis of fibre contents as
  - “F = 100 - 1.6 \times \text{Fibre}”;
  - It is assumed that one unit of dry fibre carries with it 0.4 unit juice and 0.2 unit of brix free water. Thus, one unit of fibre in cane would be equal to 1.6 ‘F’.
  - The constant factor ‘0.40’ is derived from the standard molasses purity of 28.56, based on the formula: \( M / (1 - M) \) (Molasses purity / 1 - Molasses purity).

6. Formula suggested by Malik (2005), in Pakistan
To make the formula applicable to the conditions of Pakistan Sugar Industry, the constant factor ‘0.40’ and the factor ‘F’ may be substituted by the following equation:

\[
\text{Available sugar} = [S-(B-S) \times 0.50] \times F,
\]

Where

- \( B \) = Brix % first expressed juice
- \( S \) = Pol % first expressed juice
- \( F \) = Fibre factor

Where 0.5 is based on the average molasses purity of 33.5 %, as achieved in Pakistan and

\[
F = 100 - 1.7 \times \text{Fibre}, \text{ based on 43 % undiluted juice lost in bagasse % fibre and 27 % brix free water.}
\]

The individual mill may work out its recovery by changing the molasses purity factor of 0.5, based on actual molasses purity of the day or the period, using the formulae:

\[
M / (1 - M).
\]

Core Sampler
This is a mechanical device to take a representative sample of cane from truck or trolley load for analysis in a laboratory. The specification of the core sampler used in Louisiana Sugar Industry is as follows (Legendre, 1992).

The corer is a hollow tube with saw teeth on the end. It speedily drills with motor power and penetrates the full depth of the cane mass in the whole stalk delivery vehicle. It is fitted overhead near the weigh scale.

There are basically two sizes of core tubes in use, an 8 inch diameter tube with extracts
about 25 pounds (11.3 kg) of cane and a 6 inch diameter tube that extracts about 15 pounds (6.8 kg) of cane. The core tube enters the cane mass in from the top at an angle of about 45 degrees and corers almost average length of the cane delivery load. A single corer can handle approximately 250 samples in 12 hours.

Sample processing

The sample is prepared to fine shreds through a Jeffco grinder. A sub-sample of 1000 g of the prepared cane is pressed in a hydraulic press. The hydraulic press consists of a cylinder having a diameter of 6 inches. The sides or bottom of the cylinders is perforated. The press is operated at a pressure of 3500 lbs per inch² (2460 kg / cm²) on the sample. The pressing cycle is for 2 minutes time. The press separates the cane sample into juice and residue (bagasse), both of which are analyzed, the former for brix and pol and the latter only for moisture (by drying). The Brix, Pol and fibre is calculated on the assumption that the small quantity of juice remaining in the residue has the same composition as that of the juice extracted. The coefficient of variation for brix % cane, Pol % cane, and fibrr % cane has been reported as 0.81, 0.91% and 2.17%, respectively (Birkett, 1988). The following data are required for predicting sugar yield:
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Residue (bagasse) weight% cane obtained by weighing</td>
</tr>
<tr>
<td>2</td>
<td>Moisture% residue (bagasse) obtained by weighing</td>
</tr>
<tr>
<td>3</td>
<td>Extracted juice brix determined by refractometer</td>
</tr>
<tr>
<td>4</td>
<td>Extracted juice Pol determined by Polarimeter</td>
</tr>
<tr>
<td>5</td>
<td>Sediment volume % juice obtained by centrifuging</td>
</tr>
</tbody>
</table>

\[
\text{Fibre}\% \text{ residue} = \frac{(100 - \text{moisture}\% \text{ residue})}{(1 - \text{extracted juice brix})/100}
\]

\[
\text{Fibre}\% \text{ Cane} = F = (\text{Fibre}\% \text{ residue}) \times (\text{Total residue}\% \text{ cane})/100
\]

\[
\text{Absolute juice}\% \text{ cane} = 100 - \text{Fiber}\% \text{ cane}
\]

\[
\text{Brix}\% \text{ cane} \ B = (\text{juice}\% \text{ cane}) \times (\text{Brix}\% \text{ Juice})/100
\]

\[
\text{Pol}\% \text{ cane} = P = (\text{Juice}\% \text{ cane}) \times (\text{Pol}\% \text{ juice})/100
\]

The sugar recovery is worked out by applying the formula adopted in respective country, using the forementioned parameters.
Chapter-13

Gur and Khandari Sugar Manufacture

The manufacture of gur and khandari sugar is an indigenous cottage industry of Pakistan and India. During 1950, almost ninety percent of cane was utilized for gur, shakkar and khandari sugar manufacture in Pakistan. With the advent of sugar industry, cottage industry gradually vanished; during 2006 - 07, hardly 16 % of cane was consumed in cottage industry and some 74 % crushed in sugar mills for white sugar production. Besides fast development of sugar industry, the cottage industry still dominates in NWFP of Pakistan with over 40 % cane crushed for gur manufacture in this province. In India as well 15 % of cane is utilized for gur & khandarsi sugar manufacture.

The main operations involved in gur and open pan sugar manufacture are:

a. Cane crushing for juice extraction
b. Purification and clarification of juice
c. Concentration of juice to form solid form of gur or concentration to form ‘Rab’
d. Production of gur or shakkar
e. Production of sugar in centrifugal machine

Boiling of the juice is the most important process and needs care, skill and experience. Several factors affect the quality of gur and rab but the most important points to remember are:

(a) The cane to be crushed and the juice boiled as soon after cutting as possible; a delay of even one day has very adverse effects on the results.

(b) The cane should be healthy and fully mature; crops that are diseased, lodged or attacked by rats cannot give good quality rab.

(c) The variety of cane having high sucrose contents produces good quality gur and white crystalline sugar.

(d) Pans and other utensils required should be scrupulously cleaned and washed before starting the operation. The juice while being put into the pans should be filtered through a coarse cloth.

(e) Gur produced from good quality cane has longer shelf life while gur of immature and poor quality cane has short shelf life and looses its structure, luster and color in storage.
Gur Manufacture

Cane crushing

Three main operations are involved in gur manufacture:

- Cane crushing for juice extraction
- Purification and clarification of juice and
- Concentration of juice to solid form of gur or shakkar.

For extraction of juice, cane is generally crushed in three rollers crusher. Rollers are so set in triangular form that cane is pressed twice. They are driven either by bullocks or by mechanical means.

Bullock driven crusher

This is vertical three rollers crusher (Fig----). The manufacturing companies have different roller sizes, but generally the size ranges between 7" to 12" in diameter and height. The crushing capacity ranges from 5 to 6 maunds per hour with juice extraction from 55 to 60 percent.

Power crusher

Three rollers are placed in vertical or horizontal position and are driven by mechanical power. These could be run by electric motors (5 to 25 HP) or tractor driven pulley (Fig. -- ----). The crushing capacity varies with roller size, which generally ranges between 15 to 50 maunds cane per hours. The juice extraction varies from 60 to 65 %.

Juice Extraction

The extraction of juice depends upon the cane variety, cane quality, design and setting of the crusher and the feeding of the cane stalks into the cane crusher. Roller size, setting, types of grooves and uniform working influence the extraction. Since cane is fed
manually, feeding should be optimum as per requirement of crusher and should be uniform.

**Juice Composition**

Sugarcane contains about 85% juice and 12.5 to 17.5% fibre. The juice is composed of 70 to 75% water, 11 to 14% sugars (sucrose, glucose, and laevulose), 0.4% proteins and other nitrogen substances, 0.5% mineral matter and 0.6% fats and waxes. The juice contains all the soluble solids with suspended fibre and colloidal matter. The juice compositions depend on cane variety, type of soil, quality and time of fertilizer application and the time of irrigation. High sugar varieties grown in salt free soils in sweet water zone produce very good quality gur. The cane grown in saline soils have sourish taste.

**Clarification of Juice**

Soon after extraction, juice is to be boiled in open pan. If left for sometime, sucrose is liable to inversion and fermentation due to microbial changes in juice. However, while pouring juice into the pan, the fibrous suspended particles are sieved through muslin cloth placed on gunny bag sheets. The boiling action checks the microbial changes and coagulates all the colloidal material and nitrogenous substances along with un-dissolved colloidal suspended particles. All the substances coagulate and appear in the form of scum rising on the juice surface. At this moment, the fire under the pan is reduced so as to collect the scum from the surface and filtered through gunny bags placed in a bucket on the pan. Frequent sieving clear of the juice from impurities gathered in the scum.

After the main mass of scum is removed, some flocculants are added in the juice to further coagulate the remaining colloidal mass and other unwanted substances in the juice. The flocculants generally used are.

i) Addition of vegetable albumins which coagulate on boiling and entangle all suspended impurities.

ii) Addition of electrolytes

In vegetable material extracts of Deola, Bhindi or Sukhlai are used as flocculants. They are added as the temperature has risen to boiling point. The thick layer of scum cracks on the surface and is sieved by perforated strainer and is thrown in strainer basket. The extract is repeatedly added and cracking scum layer is collected, until the time juice gets clear of all the impurities. The scum collects better when boiling action is stopped by checking fire. Brisk boiling may be lowered by sprinkling a little water.

The juice is basically acidic in reaction; it should be changed to neutral state to avoid conversion. When a fairly clear juice has been obtained, some chemical flocculent (alkaline in nature) is added. At this moment, firing is to be checked to avoid brisk boiling of juice. It will also coagulate and flocculate the unwanted substances in juice that would scum out for collection by ladle. When no more scum appears on the juice surface, clarification process may be considered complete.
Clarificants Used in the Process

**Organic clarificants**

These include the bark and roots section of abuminous plants like Deola (Hibiscus ficulneus), Bhindi-Lady finger (H. esculentus), Sukhlai (cadia culcunia), falsa (Grewia asiatica) bark.

Five kg each of Bhindi, Sukhlai, Deola or Falsa bark are soaked over night in 50 liter of water. Before using, plant material is rubbed in water until mucilaginous liquid having thick consistency is produced. Two Kg of this bark infusion is added to 120 liters of juice at its boiling stage, as the scom is about to crack.

**Chemical Clarificants**

The chemicals that can be used for final clarification are sodium bicarbonate, lime water, Sajji and Alum. These chemicals help in solidification of gur and give good results in case of the cane badly lodged, disease and pest infested and other inferior quality cane. However, excess use of chemical give dark colors to the gur and also spoil taste, nevertheless, sodium bicarbonate is mostly used. The chemicals are often used after clarification with organic clarificants. The addition of their flocculants liberates impurities, neutralize acidity and bleach the organic coloring matter. Excess application darkens the color of gur at later stage in storage, however, helps in formation of large sugar crystals. usually solutions of one pound of soda ash and 1.5 ounce of sodium sulphite is prepared, of which ¾ kg is used for each lot of 120 kg juice.

**Concentration of Juice for ‘Gur’ and “Shakkar”**

After clarification the juice is boiled vigorously to evaporate its water and concentrate it into a thick semi-solid mass which on cooling solidifies into gur. The exact point at which the boiling is stopped and the pan is "struck" is judged by the size of bubbles on the surface and from the sound produced by their bursting. Constant stirring with a 'T' shaped stirrer is done that the beating may be uniform and charring does not take place. The mass begins to leave off the surface of the pan, as it is stirred when the "striking" point is near. The consistency at which the pan is struck for gur is found to correspond to a temperature of 115º C to 117º C.

The semi-solid mass from the pan is transferred on to a large circular pan, called “Gand”, which may be made of wood or iron. The mass is stirred constantly for some time by means of small spade like stirrer and then allowed to cool into a soft solid product. Thereafter, when the mass is solidified small balls of gur are made. The gur may also be molded into rectangular blocks from the mass when it is still soft.

For Shakkar production, the striking point of the boiling mass is little over the ‘gur’ state. As it is applied in wooden pan “Gand”, it soon tends to solidity. It is then rubbed briskly by hand to give it powdery form of “Skakkar”.
Concentration of juice for rab

The juice after being thus clarified is further boiled till the syrup attains the final consistency of rab. During this process it has a tendency to boil over and this is avoided by sprinkling very small quantity of castor seed emulsion (prepared by crushing 1 kg of castor seed in 10 litters of water). On the boiling mass the boiling should be rapid and brisk but care should be taken to minimize charring and caramelisation.

Rab is generally struck between 110º C and 111º C but this point varies with different canes; canes rich in sucrose are struck at lower temperatures and vice versa.

The final product (rab) should be poured in an earthen vessel (Daura) and cooled slowly to about 70ºC by ladling. It is then finally stored in canisters, earthen mattered or any kind of containers. It is, however very desirable that the rab produced each day should be stored separately.

![Cane Juice after boiling, clarification and concentration, solidified to make small pieces of “Gur”](image)

The rab after pouring should be left undisturbed in a cool dry place from 7 to 10 days to complete crystallization and then should be put through the centrifugal machine which separates the sugar crystals from the molasses. These crystals are dried and prepared for the market. This entails grinding with a wooden roller or rubbing with feet. Molasses are once again boiled and converted into second rab of gur.

Aeration

The act of ladling the hot syrup before potting has a two-fold purpose, viz., aeration and uniform cooling. It greatly increases the recovery of sugar to the extent of rom 5 to 6 per cent more than from unaerated rab.

Second rab

The molasses as they come out of the centrifugal machine are re-boiled till they attain the required consistency, struck at 112º C and are then cooled, aerated, potted and stored as
in case of first rab. The second rab, however, requires more aeration and takes 2 to 4 weeks to form crystals. The boiling of molasses unlike that of juice is to be slow. Molasses are slightly acidic and should be neutralized by the addition of one kg of supper saturated solution of lime in water to one maund of molasses.

**Gur from molasses**

Molasses can be boiled into gur which is valued at a figure slightly below that of the ordinary gur made from the cane juice. The manufacture of the gur from molasses is paying so long as the market rates of gur are high. This Gur is prepared practically in the same manner as second rab except that the molasses are heated to a higher temperature and thicker consistency.

The furnace used for boiling juice / syrup is known as the Auxiliary bel. It has 4 pans and is constructed to burn wood as fuel. The Jullundur special or the Doaba four pan furnace can also serve the purpose. The actual centrifuging is a simple and all that requires to be done is to wash the rab which is being centrifuged with a syringe of hot water when about 3/4 th of the molasses have purged out. More washing in the cage whitens the crystals but reduces their size, and consequently the recovery. The only points to remember are that the basket should always be washed thoroughly before use and that the charge of rab should be put in while the machine is stationery.

The criterion for selection should be that the machine should be easy to work and should be fitted with a black steel perforated cage lined with No. 8 steel gauge and No. 70 copper twill or copper perforated lining.
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