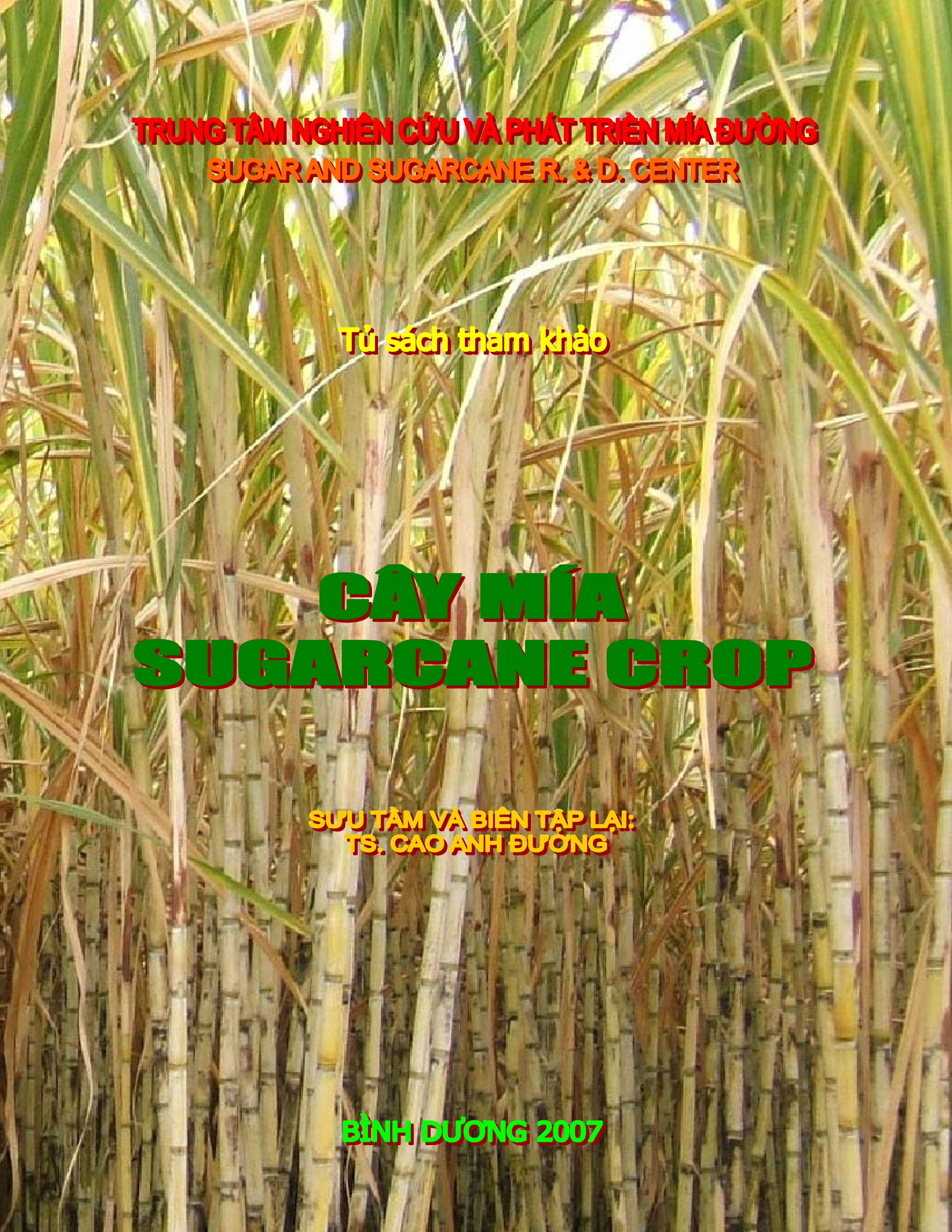


TRUNG TÂM NGHIÊN CỨU VÀ PHÁT TRIỂN MÍA ĐƯỜNG
SUGAR AND SUGARCANE R. & D. CENTER

Tủ sách tham khảo

CÂY MÍA
SUGARCANE CROP

SƯU TẦM VÀ BIÊN TẬP LẠI:
TS. CAO ANH ĐƯƠNG

BÌNH DƯƠNG 2007

Foreword

Numerous books and documents have been written and published about the sugarcane crop, documenting cultivation practices associated with its culture. A vast majority of these describing agronomic practices are adequate in written text, but are inadequate in directing the reader about field practical skills in growing sugarcane.

To be viable and competitive, sugarcane growers face many challenges. These require significant economic and social restructuring and the adoption of new, complex and high-risk technologies. The main prerequisites for these decisions are the availability of high quality, timely and relevant information.

More than ever, sugarcane farmers, cane department officials of sugar factories, technicians, extension workers, students, consultants, bank officials, teachers and research scientists need to understand the whys and how's of modern sugarcane production with drip irrigation.

But recommendations given to farmers often do not answer questions such as growing method, drip system guidelines, how to increase the efficiency of water use and applied fertilizer through fertigation, how to lessen the chance of lodging etc. This is why there is a wide gap between the potential and actual productivities in most sugarcane growing regions of the world.

Producing this information was a challenge for Netafim ACS, Israel. The existing information system on drip irrigated sugarcane crop lacks adaptability to local conditions, completeness, quality, easy access and regular updating. Over the last 45 years Netafim has developed many crop growing manuals to address these deficiencies. This has culminated in this new series of growing guide on web pages.

Introduction

Sugarcane, Saccharum officinarum L., an old energy source for human beings and, more recently, a replacement of fossil fuel for motor vehicles, was first grown in South East Asia and Western India. Around 327 B.C. it was an important crop in the Indian sub-continent. It was introduced to Egypt around 647 A.D. and, about one century later, to Spain (755 A.D.).

Global Distribution of Sugarcane (Click to Enlarge)

Since then, the cultivation of sugarcane was extended to nearly all tropical and sub-tropical regions. Portuguese and Spaniards took it to the New World early in the XVI century. It was introduced to the United States of America (Louisiana) around 1741.

Botanically, sugarcane belongs to the Andropogonae tribe of the family Gramineae, order Glumiflorae, class Monocotyledoneae, subdivision Angiospermae, division Embryophita siphonogama. The subtribe is Sacharae and the genus, of course, Saccharum, derived from the Sanskrit "sarkara = white sugar", a reminder that the plant reached the Mediterranean region from India.

Sugarcane growing countries of the world are lying between the latitude 36.7° north and 31.0° south of the equator extending from tropical to subtropical zones. This map depicts the distribution of sugarcane in the world.

Worldwide sugarcane occupies an area of 20.42 million ha with a total production of 1333 million metric tons (FAO, 2003). Sugarcane area and productivity differ widely from country to country (Table 1). Brazil has the highest area (5.343 million ha), while Australia has the highest productivity (85.1 tons/ha). Out of 121 sugarcane producing countries, fifteen countries (Brazil, India, China, Thailand, Pakistan, Mexico, Cuba, Columbia, Australia, USA, Philippines, South Africa, Argentina, Myanmar, Bangladesh) 86% of area and 87.1% of production (Table 1). Out of the total white crystal sugar production, approximately 70% comes from sugarcane and 30% from sugar beet.

Sugarcane area and productivity differ widely from country to country (Table 1). Brazil has the highest area (5.343 million ha), while Australia has the highest productivity (85.1 tons/ha). Out of 90 sugarcane producing countries, fifteen countries (Brazil, India, China, Thailand, Pakistan, Mexico, Cuba, Columbia, Australia, USA, Philippines, South Africa, Argentina, Myanmar, Bangladesh) 86% of area and 87.1% of production (Table 1).

Table 1. Sugarcane In The world: Area, Production And Productivity

Country	Area (million ha)	Production (million tons)	Productivity (Tons/ha)
Brazil	5.343	386.2	72.3
India	4.608	289.6	62.8
China	1.328	92.3	65.5
Thailand	0.970	64.4	66.4
Pakistan	1.086	52.0	47.9
Mexico	0.639	45.1	70.6
Colombia	0.435	36.6	84.1
Australia	0.423	36.0	85.1
USA	0.404	31.3	77.5
Philippines	0.385	25.8	67.1
Indonesia	0.350	25.6	73.1
Cuba	0.654	22.9	35.0
South Africa	0.325	20.6	63.4
Argentina	0.295	19.2	65.2
Myanmar	0.165	7.5	45.4
Bangladesh	0.166	6.8	41.2
WORLD	20.42	1333.2	65.2

Sugarcane is a renewable, natural agricultural resource because it provides sugar, besides biofuel, fibre, fertilizer and myriad of by products/co-products with ecological sustainability.

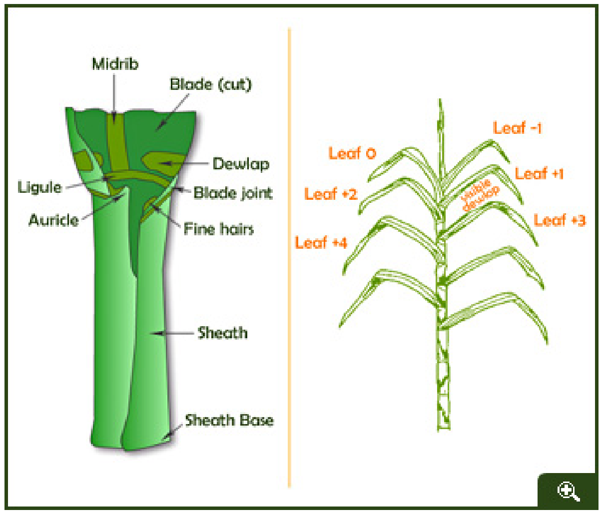
Sugarcane juice is used for making white sugar, brown sugar (Khandsari), Jaggery (Gur) and ethanol. The main byproducts of sugar industry are bagasse and molasses.

Molasses, the chief by-product, is the main raw material for alcohol and thus for alcohol-based industries. Excess bagasse is now being used as raw material in the paper industry. Besides, co-generation of power using bagasse as fuel is considered feasible in most sugar mills.

Growth morphology

Propagation

Stem cuttings or sections of the stalks called "setts" or seed pieces propagate sugarcane. Each sett contains one or more buds. The buds, located in the root band of the node, are embryonic shoots consisting of a miniature stalk with small leaves.



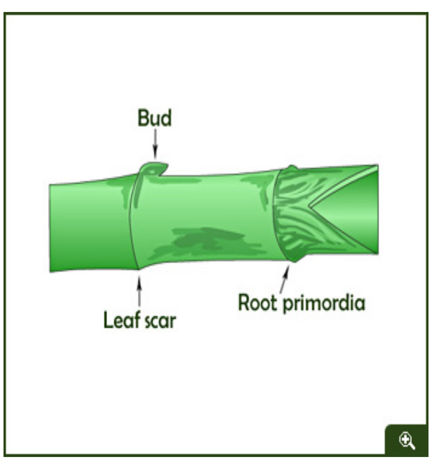
The outer small leaves are in the form of scales. The outermost bud scale has the form of a hood. Normally, one bud is present on each node and they alternate between one side of the stalk to the other.

Variations in size, shape and ther characteristics of the bud provide a means of distinguishing between varieties. Each sett also contains a circle of small dots above the node, which are the root primordia. Each primordium exhibits a dark center, which is a root cap, and a light colored "halo".

The bud sprouts under favourable conditions and gives rise to a primary stalk, whereas from the primordial the sett roots originate.

During nearly one month after germination, that is, sprouting of the buds, the young plant lives at the expense of the reserves present in the seed piece, and partially using water and nutrients provided for by the first roots.

The Leaf



The leaf of the sugarcane plant is divided into two parts: sheath and blade, separated by a blade joint. The sheath, as its name implies, completely sheaths the stalk, extending over at least one complete internode.

The leaves are usually attached alternately to the nodes, thus forming two ranks on opposite sides. The mature sugarcane plant has an average total upper leaf surface of about 0.5 square meter and the number of green leaves per stalk is around ten, depending on variety and growing conditions.

The blade joint is where two wedge shaped areas called "dewlaps" are found. The leaves are numbered by Kuijper's system, as quoted by Casagrande (1991). The first leaf from top to bottom of the stalk with clearly visible dewlap is designated as +1. Downwards they receive, in succession, the numbers +2, and +3. The "top visible dewlap" leaf (+3) is a diagnostic tissue that is frequently used in the evaluation of the nutritional status.

The Inflorescence

When a sugarcane plant has reached a relatively mature stage of development, its growing point may, under certain photoperiod and soil moisture conditions, change from the vegetative to reproductive stage.

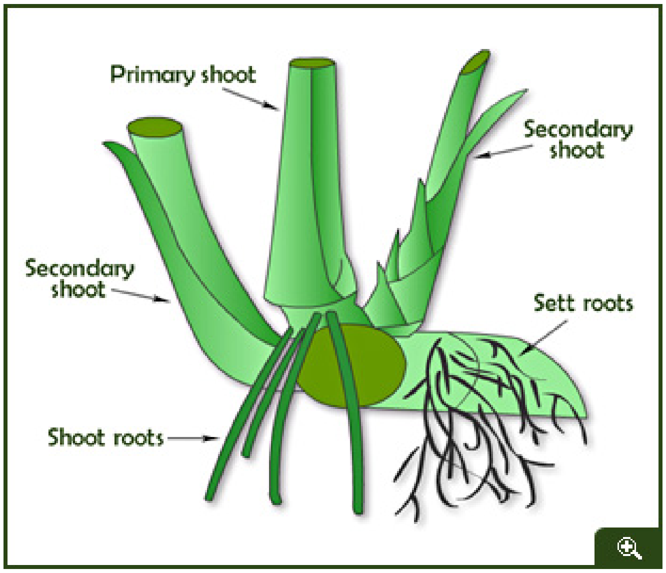
This means the growing point ceases forming leaf primordia and starts the production of an inflorescence. It is a short day plant. Its photoperiodic conditions can thus be attained largely in the tropics.

The inflorescence, or tassel, of sugarcane is an open-branched panicle .It is also known as arrow. Therefore flowering is also known as "arrowing". Each tassel consists of several thousand tiny flowers, each capable of producing one seed. The seeds are extremely small and weigh approximately 250 per gram or 113,500 per pound.

For commercial sugarcane production,inflorescence development is of little economic importance. Flowering is important for crossing and producing hybrid varieties.

Generally, a day length close to 12.5 hours and night temperatures between 20° to 25°c will induce floral initiation. Optimum growth conditions in the vegetative phase (fertile soil, abundant supply of nitrogen and moisture) restrict inflorescence while stress conditions induce formation of blossoms.

The Root System



In the commercial sugarcane crop, which is asexually propagated, development of the root system is initiated soon after planting a portion of stem (sett) with atleast one lateral bud.

The first roots formed are sett roots, which emerge from a band of root primordia above the leaf scar on the nodes of the sett.Sett roots can emerge within 24 hours of planting, although differences in the time required for root emergence occur among varieties. Sett roots are fine and highly branched roots, which sustain the growing plant in the first weeks after germination.

Shoot roots are second type of root, which emerge from the base of the new shoot 5-7 days after planting .The shoot roots are thicker and fleshier than sett roots and develop in to the main root system of the plant. Sett roots continue to grow for a period of 6-15 days after planting, mostly senescing and disappearing by 60-90 days as the shoot root system develops and takes over supply of water and nutrients to the growing shoot. By the age of 3 months, sett roots comprise less than 2% of root dry mass.

Sett roots initially have an elongation rate of a few mm/day, reaching 20 mm/day within a few days of germination under favourable conditions. Shoot roots grow more rapidly, with maximum rates of elongation of up to 80 mm/day observed, though only for short periods. Mean growth rates for shoot roots over 10 days were 40 mm/day in sandy soils and 28 mm/day in heavy clay.

Mean rates of root penetration, or the rate of descent of the root system, of 20-30 mm/day were also reported. Root penetration in another trial was 20 mm/day down to a depth of 1.6 m for rainfed crops, but slowed in irrigated crops to 17 mm/day in the first 1.0 m and 6 mm/day between 1.0 and 1.6 m.

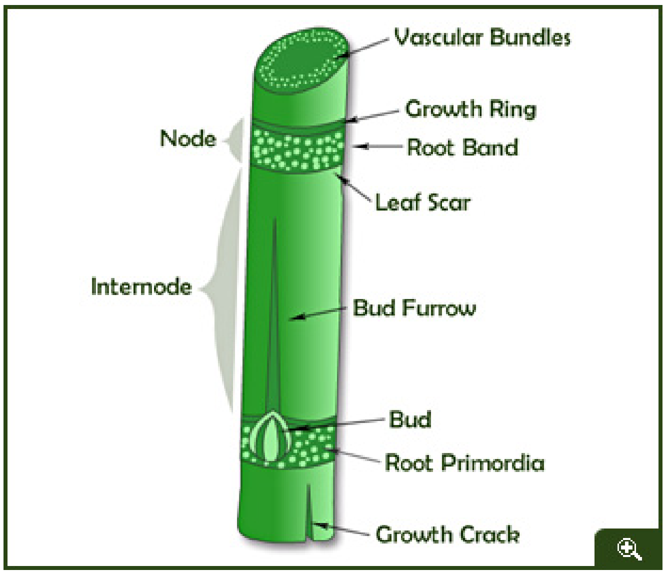
Genotypic variation in sugarcane root systems is well documented and those producing many tillers normally produce many roots because each new tiller is a source of shoot roots. Likewise cultivars with more horizontal (weak gravitropic) root penetration are more resistant to lodging than those with strongly gravitropic root system.

A longitudinal section of a root tip consists mainly of four parts: the root cap, the growing point, the region of elongation, and the region of root hairs. The root cap protects the tender tissues of the growing point as the root pushes through the soil. The growing point consists mainly of an apical meristem, where cell division takes place.

In the region of elongation, the cells increase in size and diameter until they reach their ultimate size. The region of root hairs is characterized by epidermal cells forming outgrowths (hairs), which dramatically increases the root-absorbing surface.

Stalk

Stalk is also known as "millable cane". It develops from the bud of seed-cane. When seed-cane is planted, each bud may form a primary shoot.



From this shoot, secondary shoots called "tillers" may form from the underground buds on the primary shoot. In turn, additional tillers may form from the underground secondary shoot buds. The stalk consists of segments called joints.

Each joint is made up of a node and an internode. The node is where the leaf attaches to the stalk and where the buds and root primordia are found. A leaf scar can be found at the node when the leaf drops off the plant. The length and diameter of the joints vary widely with different varieties and growing conditions. The colors of the stalk seen at the internodes depend on the cane variety and environmental conditions.

For example, exposure of the internodes to the sun may result in a complete change of color. The same variety grown in different climates may exhibit different colors. All colors of the stalk derive from two basic pigments: the red color of anthocynin and the green of chlorophyll.

The ratio of the concentration of these two pigments produce colors from green to purple-red to red to almost black. Yellow stalks indicate a relative lack of these pigments. The surface of the internode, with the exception of the growth ring, is more or less covered by wax. The amount of wax is variety dependent.

The top of the stalk is relatively low in sucrose and therefore is of little value to the mill. The top 1/3 contains, however, many buds and a good supply of nutrients, which makes it valuable as seed cane for planting.

A cross section of an internode shows, from the outside to the center, the following tissues: epidermis, cortex or rind, and ground tissue with embedded vascular bundles. The cells of the rind are thick-walled and lignified. These cells help strengthen the stalk. More toward the center, the ground tissue contains the vascular bundles with the xylem and phloem.

Xylem tissue conducts water and its dissolved minerals upward from the roots, and phloem conductive tissue transports plant- manufactured nutrients and products, for the most part, downward toward the roots.

Two types of cracks are sometimes found on the surface of the stalk; harmless, small corky cracks, which are restricted to the epidermis, and growth cracks which may be deep and run the whole length of the internode.

Growth cracks are harmful since they allow increased water loss and expose the stalk to disease organisms and insects. Growth cracks are dependent on variety and growing conditions.

Crop growth phases

Germination and Establishment Phase

- The germination phase is from planting to the completion of germination of buds.
- Under field conditions germination starts from 7 to 10 days and usually lasts for about 30-35 days.
- In sugarcane, germination denotes activation and subsequent sprouting of the vegetative bud.
- The germination of bud is influenced by the external as well as internal factors.
- The external factors are the soil moisture, soil temperature and aeration.
- The internal factors are the bud health, sett moisture, sett reducing sugar content and sett nutrient status.
- Optimum temperature for sprouting is around 28^o-30^oc .Base temperature for germination is about 12^o. Warm, moist soil ensures rapid germination.
- Germination results in an increased respiration and hence good soil aeration are important.
- Therefore open structured porous soils facilitate better germination.
- Under field conditions, about 60 per cent germination can be considered safe for raising a satisfactory crop.

Tillering Phase

- Tillering starts from around 40 days after planting and may last up to 120 days.
- Tillering is a physiological process of repeated under ground branching from compact nodal joints of the primary shoot.
- Tillering provides the crop with appropriate number of stalks required for a good yield.
- Various factors viz., variety, light, temperature, irrigation (soil moisture) and fertilizer practices influence tillering

- Light is the most important external factor influencing tillering. Adequate light reaching the base of the sugarcane plant during the tillering period is of paramount importance.
- Temperature around 30^{o}c is considered optimum for tillering. Temperature below 20^{o} retards tillering.
- Early formed tillers give rise to thicker and heavier stalks. Late formed tillers either die or remain short or immature.

- Maximum tiller population reaches around 90-120 days after planting. By about 150-180 days, atleast 50 per cent of the shoots die and a stable population is established.
- Cultivation practices such as spacing, time of fertigation, water availability and weed control influence tillering.
- Though 6-8 tillers are produced from a bud, ultimately only 1.5 to 2 tillers per bud remains to form canes.
- Ratoon crop gives much higher and early tillering than a plant crop.
- Encouraging good tillering is important to build adequate population.

Grand Growth Phase

- Grand growth phase starts from 120 days after planting and lasts up to 270 days in a 12-month crop. During the early period of this phase tiller stabilization takes place. Out of the total tillers produced only 40-50% survive by 150 days to form millable cane.

- Most important phase of the crop wherein the actual cane formation and elongation and thus yield build up takes place.
- Leaf production is frequent and rapid during this phase with LAI reaching around 6-7.
- Under favourable conditions stalks grow rapidly almost 4-5 internodes per month.
- Drip irrigation, fertigation and warm, humid and sunny climatic conditions favour better cane elongation. Moisture stress reduces internodal length. A temperature around 30^{o}c with a humidity of around 80% is most conducive for good growth.

Ripening and Maturation Phase

- Ripening and maturation phase in a twelve-month crop lasts for about three months starting from 270-360 days.
- Sugar synthesis and rapid accumulation of sugar takes place during this phase and vegetative growth is reduced.
- As ripening advances, simple sugars (monosaccharide viz., fructose and glucose) are converted into cane sugar (sucrose, a disaccharide).
- Cane ripening proceeds from bottom to the top and hence bottom portion contains more sugars than the top portions.
- Ample sunshine, clear skies cool nights and warm days (i.e., more diurnal variation in temperature) and dry weather are highly conducive for ripening.

Practical Implications

- Better understanding of what is going on in the plant
- This understanding aids in efficient water and nutrient management
- Control of vegetative growth and manipulation of sugar production to some extent is possible
- Knowledge of phenological growth phases is essential for maximizing cane yields and sugar recovery

Climate

Sugarcane is grown in the world from alatitude 36.7° N and 31.0° S, from sea level to 1000m of altitude or little more. It is considered as essentially a tropical plant. It is a long duration crop and thus it encounters all the seasons' viz., rainy, winter and summer during its life cycle.

Principal climatic components that control cane growth, yield and quality are temperature, light and moisture availability. The plant thrives best in tropical hot sunny areas. The "ideal" climate for production of maximum sugar from sugarcane is characterized as:

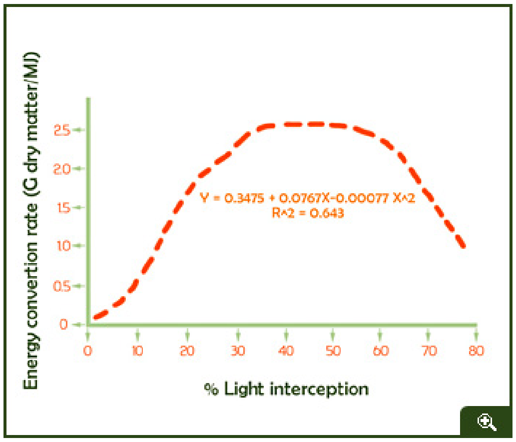
- A long, warm growing season with a high incidence of solar radiation and adequate moisture (rainfall) - the plant uses from 148 to 300g of water to produce 1.0g of dry substance.
- A fairly dry, sunny and cool, but frost free season for ripening and harvesting - moisture percentage drops steadily throughout the life of the sugarcane plant, from 83% in very young cane to 71% in mature cane, meanwhile sucrose grows from less than 10 to more than 45% of the dry weight.
- Freedom from typhoons and hurricanes

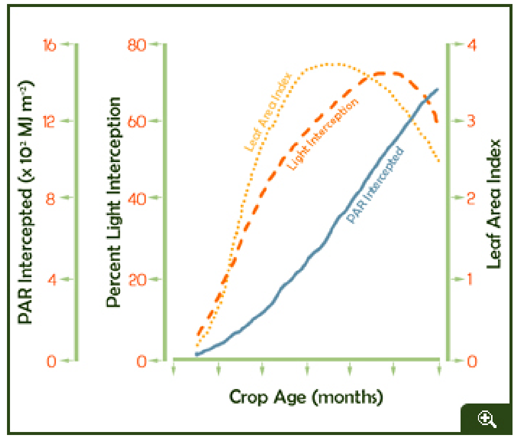
Rainfall: A total rainfall between 1100 and 1500 mm is adequate provided the distribution is right, abundant in the months of vegetative growth followed by a dry period for ripening. During the active growth period rainfall encourages rapid cane growth, cane elongation and internode formation. But during ripening period high rainfall is not desirable because it leads to poor juice quality, encourages vegetative growth, formation of water shoots and increase in the tissue moisture. It also hampers harvesting and transport operations. This seems to be the case in regions of South America, South East Asia and some parts of Southern India.

Temperature: Growth is closely related to temperature. Optimum temperature for sprouting (germination) of stem cuttings is 32° to 38°c. It slows down below 25°, reaches plateau between 30°-34°, is reduced above 35° and practically stops when the temperature is above 38°.Temperatures above 38° reduce the rate of photosynthesis and increase respiration. For ripening, however, relatively low temperatures in the range of 12° to 14° are desirable, since this has a noticeable influence on the reduction of vegetative growth rate and enrichment of sucrose in the cane. At higher temperatures reversion of sucrose into fructose and glucose may occur besides enhancement of photorespiration thus leading to less accumulation of sugars. Severe cold weather inhibits bud sprouting in ratoon crop and arrests cane growth. Temperatures lower than 0°C induces freezing of less protected parts such as young leaves and lateral buds. The damage depends upon the length of the cold period. Smut initiation and spread is high at ambient temperatures of 25° -30°. Similarly the spread of red not disease is high at higher temperatures (37°-400°) when all other conditions are similar. Rust incidence is high when the minimum temperatures are drastically reduced. Shoot-fly incidence is high in summer when the air temperatures are very high. Also higher shoot fly incidence was observed when the difference between maximum (day) and minimum (night) temperature are low.

Relative humidity: High humidity (80-85%) favours rapid cane elongation during grand growth period. A moderate value of 45-65% coupled with limited water supply is favourable during the ripening phase.

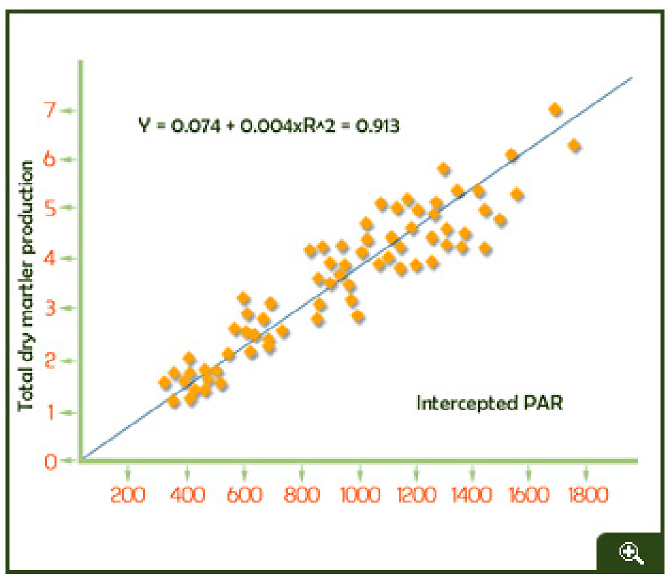
Sunlight:





Sugarcane is a sun loving plant. It grows well in areas receiving solar energy from 18 - 36 MJ/m^2. Being a C_4 plant, sugarcane is capable of high photosynthetic rates and the process shows a high saturation range with regards to light. Tillering is affected by intensity and duration of sunshine. High light intensity and long duration promote tillering while cloudy and short days affect it adversely. Stalk growth increases when daylight is within the range of 10 - 14 hours. Increase in leaf area index is rapid during 3rd to 5th month, coinciding the formative phase of the crop and attained its peak values during early grand growth phase (Ramanujam and Venkataramana, 1999).

Optimum climatic requirements: Mean total radiation received in 12 months of growth has been estimated to be around 6350 MJ/m^2. About 60% of this radiation was intercepted by the canopy during formative and grand growth periods. The total dry matter production showed linear relationship with the intercepted PAR and the test of correlation yielded R_2 value of 0.913 (Ramanujam and Venkataramana, 1999). However, the energy conversion rate in terms of dry matter production per unit of intercepted radiation showed a quadratic response with percent light interception indicating that the rate of energy conversion increased linearly up to 50% light interception and beyond this level, the rate of photosynthetic conversion of solar radiation gets reduced (Ramanujam and Venkataramana, 1999). In sugarcane crop canopy the upper 6 leaves intercept



70% of the radiation and the photosynthetic rate of the lower leaves decreased due to mutual shading. Therefore, for effective utilization of radiant energy a LAI of 3.0 - 3.5 is considered optimum. Areas having short growing period benefit from closer spacing to intercept high amount of solar radiation and produce higher yields. But in areas with long growing season wider spacing is better to avoid mutual shading and mortality of shoots. Rough estimates show that 80% of water loss is associated with solar energy, 14% with wind and 6% with temperature and humidity. High wind velocities exceeding 60-km/hour are harmful to grownup canes, since they cause lodging and cane breakage. Also, winds enhance moisture loss from the plants and thus aggravate the ill effects of moisture stress.

Effect of climate on sugarcane yields and sugar recovery:

The sugarcane productivity and juice quality are profoundly influenced by weather conditions prevailing during the various crop-growth sub-periods.

Sugar recovery is highest when the weather is dry with low humidity; bright sunshine hours, cooler nights with wide diurnal variations and very little rainfall during ripening period. These conditions favour high sugar accumulation.

Soil Requirement

Soil is a medium for plant growth. It provides nutrients, water and anchorage to the growing plants. Maintenance of proper physical, chemical and biological conditions of the soil is necessary for realizing higher growth, yield and quality of sugarcane. Sugarcane does not require any specific type of soil as it can be successfully raised on diverse soil types ranging from sandy soils to clay loams & heavy clays.

A well drained, deep, loamy soil with a bulk density of 1.1 to 1.2 g/cm^3 (1.3-1.4 g/cm^3 in sandy soils) and total porosity, with an adequate balance between pores of various sizes, is higher than 50%; ground water table below 1.5 to 2.0 m from soil surface and an available water holding capacity of 15% or more (15 cm per meter depth of soil is considered ideal for sugarcane cultivation).

The optimum soil pH is about 6.5 but sugarcane can tolerate considerable degree of soil acidity and alkalinity. Hence, it is found growing in soils with pH in the range of 5 to 8.5. Liming is required if pH is less than 5.0, or gypsum application if pH is more than 9.5. Nematode infestations are likely to occur in very sandy soils.

Soil testing before planting is desirable as it helps in determining the optimum quantity of macro and micro nutrient application. Chemical constraints in the soils, such as acidity and low fertility, are relatively easy to correct or control.

Poor physical conditions like soil compaction due to intense mechanization when limiting, are much more difficult to ameliorate. For this reason, physical properties of soil are given as a factor in sugarcane growth. Based on the experience gained in Brazil, a few criteria to define soils, which are apt for sugarcane growing, were suggested (Table 2).

Table 2. Criteria to Classify the Aptitude of Soils for Growing Sugarcane

Characteristics	Class			
	Good	Average	Restricted	Unfit
Effective depth	Deep	Medium	Shallow	Too shallow
Soil texture	Clayey	Medium to clayey	Sandy	Too sandy
Relief	Flat	Rolling	Too rolling	Hilly
Fertility	High	Medium or low	Too low	Too low
Drainage	Good	Medium to accentuated or incomplete	Incomplete	Excessive or deficient
Restraints to mechanization	Absent	Medium	Strong	Too strong
Susceptibility to erosion	Low	Medium	High	Too high

Source: Kofeler and Bonzelli (1987)

Management of compacted soils

Problem of sub-surface hard pans or compaction is a common phenomenon in intensive mechanization, more number of ratoons and sugarcane - rice rotation systems.

Effects of Soil Compaction

- Increases bulk density (Light to medium soils: 1.5 to 1.7 g/m^3 and Heavy soils: 1.45 to 1.57 g/m^3) and soil penetration resistance
- Reduction in porosity, infiltration rates, and water storage capacity
- Impedance to root penetration and proliferation. Shallow root system makes the plant susceptible to drought during dry spells.
- Reduced nutrient and water uptake
- Promotes lodging particularly in unusually wet conditions

Ameliorative Practices

- Deep ploughing, sub-soiling or chiseling up to a depth of 50 - 75 cm at 90 cm
- Application of organic manures (FYM at 25 tons/ha), growing of green manure crops and turning them into soil
- Incorporation of gypsum at 5 tons/ha

Management of Acid Soils

Usually acid soils are found in high rainfall areas and in soils where organic matter content is high. Soil acidity adversely affects sugarcane growth, yield and quality. Under acidic conditions, the adverse effects are due to aluminium, iron and manganese toxicity. Aluminium toxicity can cause P deficiency symptoms due to precipitation of alumino-phosphate complexes with in the plant and in the soil. In Australia, Ca deficiency is associated with Al toxicity on acid soils.

In acid soils conditions (pH less than 5.2), Al replaces Ca on cation exchange capacity. Aluminium toxicity may occur on mineral soils when Al occupies greater than 30% of the cation exchange capacity.

In sandy soils having a very low cation exchange capacity, lower concentrations of Al in the soil solution may cause toxicity problems. High applications of K may induce Ca deficiency in acid soil containing low Ca levels *(Photo Source: Anderson and Bowen, 1990).*

Root growth, tillering, shoot elongation and LAI are severely affected due to the above nutritional disorders thus causing poor cane yield and juice quality.

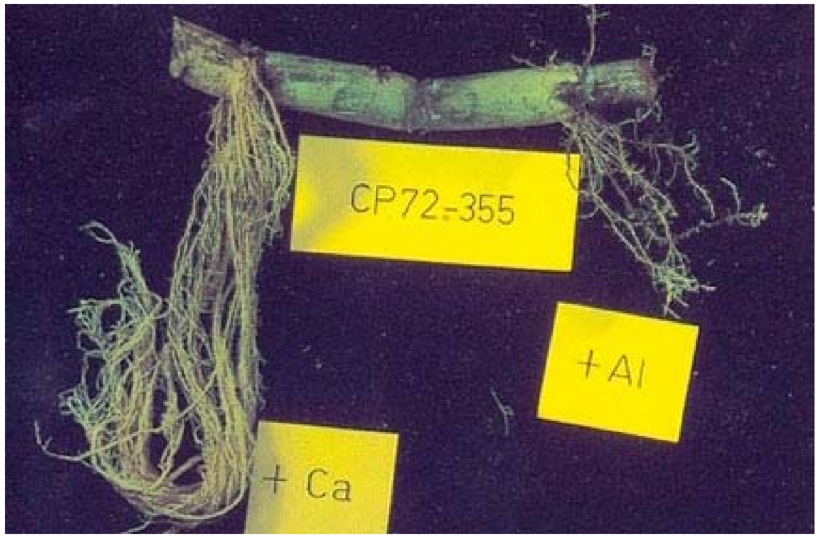
On acid soils in Brazil, better root development deeper in the soil horizon has been noticed when gypsum is used. Liming is the most important practice in the acid soils to improve productions.

The General Lime Requirements as Follows.

- Sandy soils 450 - 675 kg/ha every 2 years
- Clay loams 1800 - 2250 kg/ha every 3 - 4 years
- Clay soils 2700 - 3600 kg/ha every 4 - 5 years.
- Bone meal and rock phosphates are well suited to acid soils to supply phosphorous

Management of Soil Salinity and Sodicity

The saline and sodic soils are wide spread in sugarcane growing areas of the world. A soil with electrical conductivity below 2 dS/m, by and large, does not affect the growth appreciably. Sugarcane is moderately sensitive to soil salinity. The decrease in crop yield varies with the level of soil salinity *(Photo Source: Anderson and Bowen, 1990).*



The decrease in crop yield is 0% at an ECe of 1.7 dS/m, 10% at 3.3, 25% at 6.0, 50% at 10.4 and 100% at an ECe of 18.6 dS/m. Soil salinity also adversely affects sheath moisture content and nitrogen content.

Likewise, SAR more than 20 caused 50% yield reduction. Increase in exchangeable sodium percent from 14.4 to 23.5 lead to reduction in cane (9 - 26%) and sugar yield (12 - 29%) in 10 sugarcane cultivars studied at Karnal, India.

Varieties differ in their responses to soil salinity and acidity. Germination and early growth stages are more sensitive than later stages of crop growth. Ratoon crop is more sensitive to salinity than plant crop.

Symptoms of Soil Salinity and Sodicity

- Stunted growth and necrotic leaves with scorched tips and margins
- Poor tillering and root growth
- Reduction in internodal length and girth of cane
- Impaired cane quality with reduced juice purities
- Problems in processing for jaggery and sugar

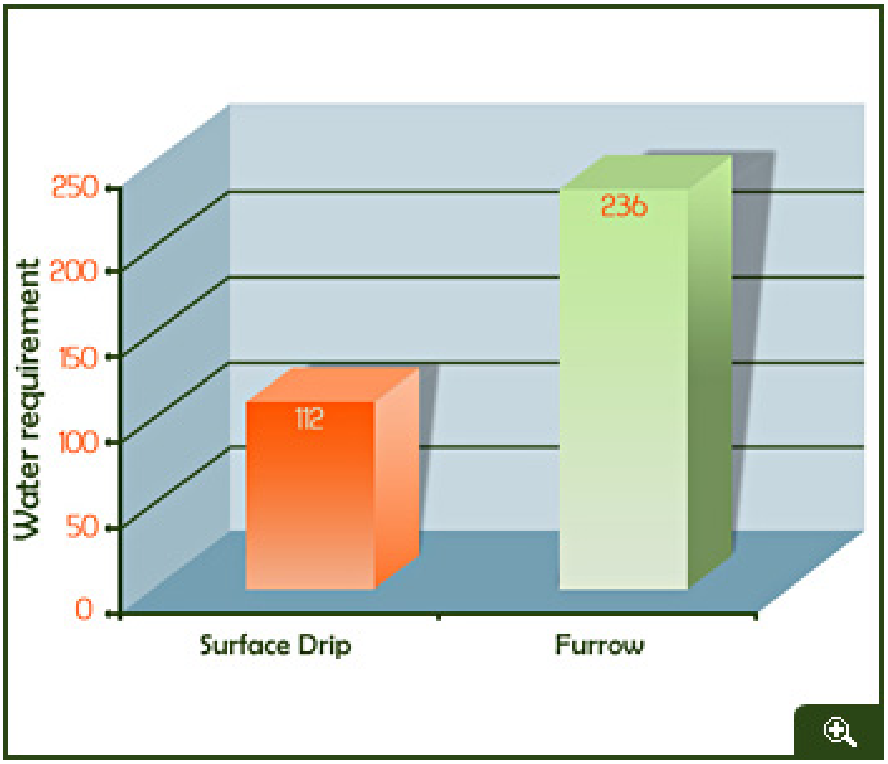
Ameliorative Measures

- Growing of slat tolerant varieties
- Manipulation of soil environment by reclamation and drainage
- Adoption of drip irrigation to maintain higher soil water potential in the root zone by light and frequent irrigations

Drip Irrigation Features

Introduction

Drip irrigation in sugarcane is a relatively new innovative technology that can conserve water, energy and increase profits. Thus, drip irrigation may help solve three of the most important problems of irrigated sugarcane - water scarcity, rising pumping (energy) costs and depressed farm profits.



Surface Drip *Subsurface Drip*

Whether or not drip will be successful depends on a host of agronomic, engineering and economic factors. "Drip irrigation is defined as the precise, slow and frequent application of water through point or line source emitters on or below the soil surface at a small operating pressure (20-200 kPa) and at a low discharge rate (0.6 to 20 LPH), resulting in partial wetting of the soil surface.

In the literature, "trickle" is used interchangeably with "drip". Most popular drip versions used in sugarcane are surface and subsurface drip.

- **Surface Drip:** The application of water to the soil surface as drops or a tiny stream through emitters placed at predetermined distance along the drip lateral is termed as surface drip irrigation. It can be of two types - online or integral type surface drip system. Integral dripline is recommended for sugarcane.

- **Subsurface Drip (SDI):** The application of water below the soil surface through emitters molded on the inner wall of the dripline, with discharge rates (1.0 - 3.0 LPH) generally in the same range as integral surface drip irrigation. This method of water application is different from and not to be confused with the method where the root zone is irrigated by water table control, herein referred to as subirrigation. The integral dripline (thin or thick-walled) is installed at some predetermined depth in the soil depending on the soil type and crop requirements. There are two main types of SDI - "one crop" and "multicrop".

Adoption of drip irrigation (surface or subsurface) system in sugarcane cultivation is technically feasible, economically viable and beneficial in many ways:

- Higher water application uniformity
- Deceased energy costs due to reduced pumping time to irrigate a given design area
- Saving in water up to 45 to 50% contributing to higher water use efficiency

- Saving in fertilizer (25 to 30%) due to fertigation consequently improved fertilizer use efficiency i.e., agronomic efficiency, physiological efficiency and apparent recovery fraction
- Less weed growth and saving in labour due fewer weed control, fertigation & plant protection operations
- Less pest & disease incidence due to better field sanitation
- Optimum soil water air relations contributing to better germination, uniform field emergence and maintenance of optimum plant population
- Early harvesting and more ratoons
- Day/Night irrigation scheduling is possible
- Facilitates growing of crop on marginal soils due to frequent irrigations and fertigation
- High frequency irrigation, micro-leaching and higher soil water potential enables use of saline water for irrigation
- Higher cane and sugar yields

Effective drip technology requires a more intense application of crop, soil, climatic, engineering, and economic factors than is usually present with furrow irrigation. New management perspectives and skills are required t planting configuration, land preparation, drip design features, irrigation scheduling, fertigation, operation & maintenance of the system.

The new management practices induced with drip technology seem to have significantly helped increase cane and sugar yields. Planting configuration and drip design features will be dealt in this section while others will dealt in different sections.

Planting Configuration

Widely followed sugarcane planting systems are viz., ridge and furrow system in tropical region and flat system in sub-tropical region. The spacing of crop rows ranges from 0.60 m to 1.5 m. The most common spacing followed is 0.90 m in ridge and furrow system as shown in Fig, because it facilitates easy irrigation and solid support when proper earthing up is done.

However, when the crop is raised under drip method of irrigation modifying the conventional ridge and furrow planting system to a paired-row or dual row system without sacrificing the plant population per unit area proved to be physiologically efficient and cost effective.

The spacing of paired-rows is dependent upon the soil type and planting season. Wider spacing is advisable in fine textured soils under high fertility conditions and for long duration crop (> 13 to 16 months) and high tillering varieties. While in coarse textured soils with poor soil fertility status, short season crop (10-12 months) and shy tillering varieties narrow spacing is desirable.

The paired-row planting pattern and associated spacing requirements both under surface and subsurface drip irrigation are depicted in the picture.
These planting patterns are for guidance only. If necessary, adjustments in planting patterns may have to be made depending upon the variety, planting season, and fertility status and soil textural conditions of the region.

Drip Design Guidelines - Summary

The summary of drip guidelines recommended for sugarcane in different countries based on varietal characteristics, soil type, management, cost-effectiveness, and a local condition is given in Table 3.

Table 3. Sugarcane: Drip Design Guidelines

Planting pattern	Drip system	Distance (m)			Dripline installation depth (cm)	Emitter distance (m)	Discharge (LPH)
		Two rows of a pair	Two paired rows / two	Two driplines			

			rows				
Single row	Surface	---	1.2 to 1.5	1.2 to 1.5	---	0.4 to 0.6	1.0 to 3.0
Paired row	Surface	0.4 to 1.0	1.4 to 2.0	1.8 to 2.5	---	0.4 to 0.6	1.0 to 3.0
Paired row	SDI	0.4 to 1.0	1.4 to 2.0	1.8 to 2.5	0.15 to 0.30	0.4 to 0.6	1.0 to 2.3

Design of Drip Irrigation Scheme

Drip irrigation offers the grower the potential for increasing cane yields & quality; and opportunity for improving irrigation & energy efficiencies in irrigated sugarcane. However, to realize this potential and opportunity, drip irrigation schemes must be designed, installed and managed correctly.

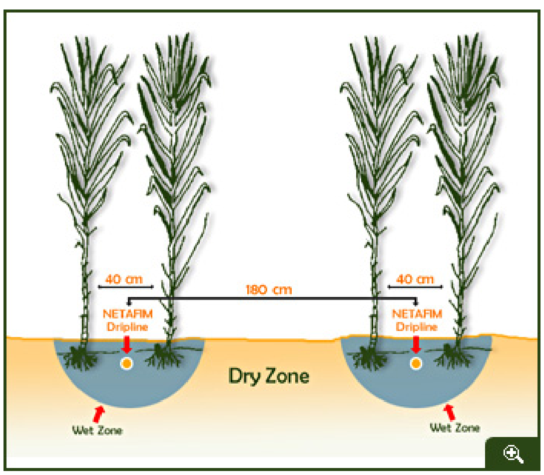
Design Factors

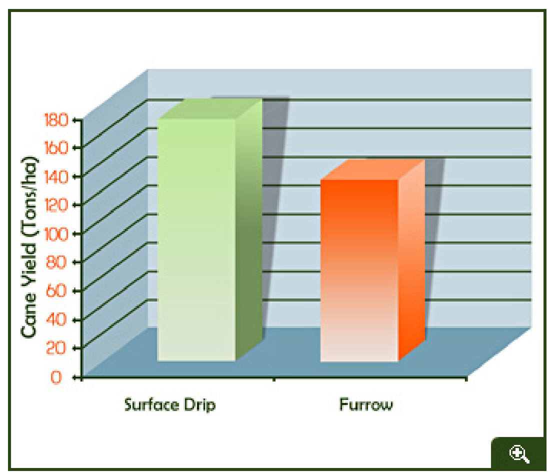
The main technical factors that should be considered when designing a drip irrigation scheme for sugarcane are as follows:

- Peak crop water requirements
- Area of fields to be irrigated
- Availability of irrigation water and power
- Irrigation water quality
- Soil characteristics
- Land topography

Components of a Drip Irrigation System

The pictures shows the main components of a drip irrigation system.





Agronomic Advantages of Drip Over Sprinkler & Furrow Irrigation

System Capacity

Drip irrigation system must have a design capacity adequate to satisfy the peak crop water requirement of the crop to be irrigated within the design area. The capacity shall include an allowance for water losses that may occur during application periods. The system shall have the capacity to apply a stated amount of water in the design area in a specified net operation period. The system should have a minimum design capacity sufficient to deliver the peak daily crop water requirements in about 90% of the time available or not more than 22 h of operation or not more than the power availability period per day.

Operating Pressure

The design operating pressure shall be in accordance with the recommendations of the manufacturer. The system operating pressure must compensate for pressure losses through system components and field elevation effects.

Equipment Selection Control Head

The control head station includes facilities for water measurement, filtration & treatment, injection of fertilizers & chemicals, flow and pressure control, timing of application and backflow prevention.

Filtration System

Filtration system is the assembly of independently controlled physical components used to remove suspended solids from irrigation water. Filtration of irrigation water is vital for drip irrigation schemes in order to avoid blockage of emitters as the internal passages of emitters are very small.

The choice of filter depends mainly on the kind of impurities contained in the water and the degree of filtration required on the emitter. It is recommended that Netafim expert advise is sought on water quality analysis for pH, suspended solids, dissolved solids and bacterial population. Filtration system design recommendations should include location, size, specification of allowable suspended material sizes, types of filters, and maintenance requirements.
Location: A primary filter shall be located after the pump and fertigation unit to remove both large and fine particles from the flow. Secondary filters may be used downstream from the primary filter to remove any particles, which may pass through the primary filter during normal or cleaning operations. When secondary filters are used, the size of the openings is usually larger than that of the primary filter to minimize needed attention.

Size: Filter flow openings shall be sufficiently small to prevent the passage of unwanted particles into the system. The filter size should be based on the diameter of the emitter opening or the type and size of contaminants to be filtered. The capacity of the filter should be sufficiently large to permit the rated flow without frequent cleaning. Filters that are to be cleaned by hand should not require more than daily maintenance. The size should be the most economical with the lowest friction losses ranging from 0.3 to 0.5 bars.

Types: Filtration may be accomplished through the use of different types of filters viz., screen (for inorganic impurities and moderate quality water or following a primary filtration with sand or disc filters) disc (for removal of impurities of organic and inorganic origin, algae included), hydrocyclones (for separation of sand or silt from well or river water) and media or sand filters (for open wells, open reservoirs, streams etc).

Fertigation Unit

Drip irrigation systems provide a convenient method of applying fertilizers and chemicals with the irrigation water using special fertigation devices. The fertigation devices include pressure differential systems (fertilizer tank), suction produced by a venturi principle (venturi injectors) and pumps (diaphragm or piston or electrically operated). The fertilizer unit is an integral part of control head.

The important considerations are injection method & rate, concentration, storage tank capacity, contamination of water supply, reliability and accuracy of operation, warranty and service, automation suitability, field performance, price including acquisition and maintenance cost, life expectancy etc

Water Carrier System - Supply Lines, Main Lines and Submains

The design objective of supply lines, main lines and submains is to deliver the required, pressurized quantity of water to the laterals (driplines) as efficiently as possible. The cane grower should attempt to minimize the total cost of the supply lines and mainlines needed to meet the engineering specifications.

Sub-main pipe should be based upon capacity requirement, maintenance cost, investment cost and pressure uniformity. Buried pipelines are less subject to damage than surface lines and do not require special handling during the crop season. Appropriate risers and valves exist for each kind of pipe. Supply lines, main lines and submains generally account for 20-35% of total investment cost/ha.

Riser Assembly

Connected to the water carrier system and located at each field block is a riser assembly. Typically, this will consist of a control valve, a disc filter, a pressure relief valve and pressure regulator, a water pressure test point, and an air release valve.

The volume of water applied to each field block is controlled by the opening and closing of valves. These can be simple gate valves, semi-automatic volumetric valves or automatic solenoid valves connected back to a central controller. Although semi-automatic and automatic systems reduce labour running costs and facilitate night-time irrigation, they are more expensive. It is recommended, wherever possible, that cane growers choose the simplest control systems and systems that are easy to use and easy to maintain.

The air relief valve, which may also act as a water pressure test point, is necessary to prevent water hammers whenever air is escaping from the water carrier system. The discharge of driplines other than those with pressure compensating emitters is dependent on the water pressure in the dripline.

The pressure regulator at the riser is used to maintain water pressure in the driplines at the level recommended by the Netafim design engineer. It should be noted that riser assemblies should be protected from damage through vandalism, cane fires and infield operations such as mechanical harvesting, loading etc. A concrete box with a metal door usually provides sufficient protection.

Dripline Type

In most sugarcane drip irrigated systems water is conducted from the riser assembly into a sub-main into which the driplines are connected. Although there are many different types of Netafim driplines that are used in sugarcane, they are all designed to distribute water uniformly over the entire design area of a given field block. A variation in discharge rate from dripline emitters that is acceptable is of the order of ± 8-10%.

Driplines vary in emitter design, quality, uniformity of discharge and cost. From the outside, most integral driplines look alike. Yet there are major differences between products, particularly emitters. Consistent and superior performance of an integral dripline lies in the quality of its emitter. Several years of experience has shown that the following factors should be considered when selecting a dripline that is to remain either on surface or buried throughout a complete life cycle of a plant cane and 2 to 8 ratoons.

Technical Factors

- Precision-molded emitters for uniform and constant low discharge of water & nutrients
- Wider and deeper flow path cross section for clog free discharge of water
- Sharp teeth for increased turbulence, flow control & flushing the emitter
- Seamless pipe construction for maintaining greater tensile and burst strength facilitating higher operation pressures for longer runs
- Raised filter inlet emitter for drawing clean water from the pipe center to prevent clogging
- Emitters with filters to prevent plugging, less maintenance & longer life.
- Flexible emitter spacing and choice of flow rates to suit different sugarcane varieties, planting patterns, soil types etc.
- Low emitter exponent and manufacturing coefficient of variation
- Flow rate insensitive to temperature differences
- Insect resistance, resistance to sunlight, no moving parts and anticipated life
- Driplines come in a range of wall thicknesses. Construction and wall thickness of the dripline should be sufficient to reduce the risk of the pipe being crushed or pinched by cane stools or roots or by in-field traffic such as mechanical loaders, farm machinery etc. Recommended successful driplines are given in Table 4:
- Flap mechanism to prevent the risk of sucking of fine soil material into the dripline emitters leading to plugging
- Nominal diameters are 16 mm and 22mm. A larger diameter will allow the supply of water to a greater length of dripline before pressure drops below design requirements. This results in saving in the cost of submains.
- Availability of machinery to recover the driplines at the end of the crop cycle and used for a second crop cycle if possible after refurbishment

Table 4. Recommended Driplines for Sugarcane

Dripline thickness	Category	Crop type
34 mil (0.8 mm) - 47 mil (1.2 mm)	Thickwalled & PC or Non PC	For surface and subsurface drip, rougher soil conditions and where insect damage is expected. Lasts 10+ years with proper operation and maintenance techniques
12 mil (0.3 mm) - 25 mil (0.63 mm)	Thinwalled & PC or Non PC	For subsurface drip and good soil conditions. Lasts for 3-5 years.

Agronomic Factors

- Both surface and subsurface drip irrigation system were technically feasible in sugarcane under diverse conditions

- Availability of dripline types for application in sugarcane viz., thick-walled for surface drip irrigated cane, thin-walled for subsurface drip irrigated cane, non-pressure compensated driplines for leveled land, pressure compensated driplines for undulated topography etc
- Subsurface drip irrigation was superior over surface drip in terms of water availability, uniformity, water use, water use efficiency, cane yield and quality, management etc
- Paired row or dual row or pineapple planting configuration with variable spacings depending upon the soil texture with one dripline for every two rows was found to be technically feasible, economically viable and potentially profitable in comparison to rectangular single row planting configuration with dripline for every crop row.
- Driplines can be successfully buried before planting cane with out waiting for planting and germination of cane.
- Cane germination and field emergence was adequate to give satisfactory plant stand both under surface and SDI systems with out any supplementary use of surface furrow or overhead sprinkler system for germination irrigation

Emitter Spacing, Discharge Rate and Depth of Placement

The area wetted as a percent of the total crop area i.e., wetting patterns that are obtained under drip irrigation depend on a number of factors which include the soil hydraulic properties, emitter spacing, dripline placement with respect to the cane rows, emitter discharge rate, planting configuration, crop evapotranspiration and irrigation regime. The following information concerning wetting patterns has been obtained by Netafim Agronomists & Design Engineers from several years of experimentation and experience under diverse agro-ecological conditions:

- **Emitter Spacings:** Spacings of 0.3 to 0.75 m and discharge rates of 1.0 to 3 LPH were acceptable to most soil types on which sugarcane is grown in different countries today. It is recommended, however, that the lower discharge rates and closer emitter spacings are used on light textured sandy, loamy sands, sandy loams, which have low water retention capacities. Conversely higher discharge rates and wider emitter spacings are recommended for medium to heavy textured soils viz., loamy, silty clay, clay loams and clays. Emitter discharge rate should not create runoff within the immediate application area. In fields with varying soil types, this criterion shall apply to the soil with the lowest infiltration rate unless it is less than 15% of the area irrigated. It should be noted that wider the spacing between emitters the more difficult it is to achieve uniform wetted strip and in turn uniform cane germination and field emergence.

- **Wetted Area:** The area wetted as a percent of the total cane cropped area ranged from a low of 28% in widely spaced paired-row planting configuration with dripline for every two rows (placed midway in between two rows) to a high of 60% in single-row rectangular planting configuration with dripline for each row.

- **Depth of Placement:** Subsurface dripline placement is the most popular technique used in cane. Driplines buried underground are protected from mechanical damage. Depth of placement is critical to optimize the potential for drip irrigation. Soil type and topography dictates depth of placement. Light textured soils (sandy, loamy sand and sandy loam) require shallow depth of dripline placement so that water is not lost by deep percolation. Medium to heavy textured soils (loamy, silty loam, clay loam & clay) which will wet-up laterally (larger wetted diameter) can have deeper placement. This is an advantage in minimizing damage to dripline from insects and rats and intrusion of roots; it also allows planting over the top of the dripline. In sloping blocks dripline placement can be offset to the uphill side of the sett so that water will gravity drain to the root zone but care must be taken to avoid damage during cultivation. The overall aim when considering dripline placement is to maintain the most efficient supply of water to the effective root zone of the plant under the conditions of soil type, soil depth, topography and any other limiting conditions (Table 5). Shallow depth can cause crushing of driplines by mechanical loaders and cane fires. Shallow depth of installation of driplines may also lead to irrigation water being lost to direct soil evaporation as a result of puddles formed above the driplines during irrigation. Try not to allow water to reach the soil surface as it will allow germination of weed seeds. In dry conditions it will be beneficial to wet-up to the surface after harvest to assist in ratooning.

Table 5. Depth o Placement of Dripline in SDI System

Soil texture	Placement depth below ground	Remarks
Loamy sand & Sandy loam	**15 to 20 cm**	These soils benefit from short & frequent irrigations. Irrigate to refill the soil profile to effective rooting depth only. Note that drip irrigation wets only a narrow band under the dripline in these soils and the storage capacity of the soil is small.
Silty loam & Clay loam	**20 to 25 cm**	Less frequent irrigations, larger volume of irrigation water application can be allowed since water spreads laterally more into the root zone. Water storage capacity of the soils is high.

Clay soil	**25 to 30 cm**	Less frequent, longer irrigation cycles and larger volume of irrigation water application can be allowed since water spreads laterally more into the root zone. Water storage capacity of the soils is very high. However, watch for ill-drained conditions and waterlogging in the crop root zone.

Economic and Managerial Design Factors

The main managerial and economic factors that should be considered when designing a SDI for sugarcane are as follows:

- Potential yield and CCS increment
- Cost of subsurface drip irrigation system
- Cost of installation and interest rate
- Operation and maintenance costs
- Availability and cost of water
- Availability and cost of trained skilled staff to operate the drip scheme
- Price of sugar

Other Factors

- Water - Source, availability and quality evaluation for determining filtration system type, maintenance of irrigation system, crop management and selection of fertilizers
- Soil evaluation for fertility status, clay content, CEC, bulk density etc for determining the fertigation programme
- Determination of moisture holding properties and evaporative demand of the atmosphere for irrigation scheduling
- Contour survey for selection of dripline type (pressure compensating or non-pressure compensating), to determine dripline length and sub-main spacing
- Soil characteristics for determining appropriate emitter spacing and depth of dripline placement

Installation

- It is essential that high quality installation and maintenance is adopted for dripline which is installed below ground. The following points are important when installing a system:Follow the Netafim Design Engineer instructions scrupulously, for example when glueing PVC pipes, installing mains & submains as pipe sizes will have been dimensioned to enable specified flow rates and pressure throughout the system.
- After installation, check each part of the system carefully for leaks as these will cause pressure problems at the tail end of the scheme

- Check every dripline being injected for correct placement, orientation and depth and to ensure there is no crimping of the riser, which connects dripline to the submain.
- Bury mains and submains to ensure that rocks in the back fill do not damage pipes.
- After hook-up, partially backfill portions of submains and pressure test before completely backfilling trenches.
- Flush out the water carrier system to remove extraneous material before riser assemblies and driplines are connected.
- Check water pressure at the risers and dripline flow rates: if these are not according to the specification there has been a problem at either the design or the installation stage.

Dripline Monitoring

Driplines and emitters, for both surface and subsurface systems, are subject to plugging and breaking with passing time. Microbial and inorganic deposits are the two principal causes of emitter plugging. Algae and bacterial slimes are of particular concern when water is pumped directly from an irrigation ditch, reservoir, open well, or natural channel. Even with sand media filters, microorganisms may grow in the lines and become a major problem.

Maintaining a pH of 6.5-6.8 with periodical acid injection reduces precipitation of inorganic compounds (phosphates, calcium, bicarbonates) and discourages algae growth. Chlorine, also, may be used to treat algae. Shock treatments, with acids (sulphuric, hydrochloric and phosphoric), which periodically reduce pH to 2-3 also kill algae and eliminate some inorganic plugging.

Acidified fertilizers are used or are being developed to deal with emitter plugging.
Rodents, rabbits, and coyotes may chew holes in driplines, roots may clog subsurface emitters, or lines may be mechanically damaged. For the most part, drip irrigated cane growers world over have nor found these to be major problems. Broken or damaged lines (from all causes) have affected less than 4% of the total system. Broken lines are usually easily and inexpensively repaired.

Chemicals (like Trifluralin) help keep roots from clogging emitters under SDI. And subsurface driplines are better protected from mechanical as well as rodent damage with deeper line placement and more careful machinery operation in the field.

Improved Varieties

Variety is the pivot around which entire production system revolves. Therefore, scientific sugarcane cultivation must start with choosing an appropriate variety for the agro-climatic zone, soil type and season concerned. Improved varieties are now available for almost all the growing conditions in the world.

New varieties are continuously evolved by the Sugarcane Breeding Institutes, Agricultural Universities, and Sugarcane Research & Development Centres world over. It would be therefore worthwhile for the growers to manipulate the environment in such a way as to bring out the maximum expression of the yield potential possessed by these varieties.

Classification of Sugarcane Varieties

Sugarcane is considered to be mature and ready for harvesting if it attains over 16% sucrose and 85% purity of cane juice. The varieties, which attain such level at 12, 14 and 16 months age, if planted in December/January are broadly classified as early, mid-late and late maturing types.

The terms early, mid and late are, therefore, not natural classfication and only represent relative grading among varieties under comparative assessment. The main idea of maturity-based classification of varieties is to facilitate harvesting of variety at proper time in order to enhance over all recovery and consequently the sugar production.

Proper Varietal Proportions

Proper proportion of area should be kept under early, mid-late and late maturing varieties to ensure proper supply of cane of desired quality throughout the crushing period. Proper varietal proportion will not only increase the total sugar recovery but will also maintain it throughout the crushing season. a ration of 30:40:30 has been suggested for early, mid-late and late ripening varieties for optimal performance and utilization of the crushing seasons.

With in a maturity group, there should be more than one variety in the factory zone. It is for simple reason of providing insurance against epidemic of pest or disease of the crop, which may otherwise completely wipe out the crop.

Choice of Variety

Important considerations in choosing an appropriate variety include cane yield, juice quality, age group, suitability to the growing conditions viz., soil type, irrigation regime, season etc., ratooning potential, resistance to pests & diseases and adverse growing conditions.

Some of the desirable varietal attributes one should look for are high yield potential, high sucrose content, good field appearance, higher tillering capacity, medium thick to thick and long stalks, long internodes, erect growing habit, non-lodging, non-flowering or shy flowering, good ratooning ability, absence of spines on the leaf sheaths, absence of splits on the stalks, less bud sprouting and resistance to prevailing local problems.

Varietal defects include lodging tendency, flowering propensity, disease susceptibility, cavity development, high fibre content, big and bulged buds which may be damaged during transportation, heavy spines on leaf sheath, drying of green top at maturity, tight leaf clasping, presence of heavy pith, growth cracks or splits.

These defects may appear as minor and insignificant, at first, but they understandably draw the growers attention when the varieties come into cultivation.

World over sugarcane cultivars receive a designation, which corresponds to the country wherein they were developed/obtained. A few examples could be given: Argentina - NA; South Africa - N; Australia - Q; Brazil - CB, IAC, PB, RB and SP; Colombia - ICA; Cuba - C; USA - CP; Philippines - Phil; India - Co; Indonesia - POJ; Peru - PCJ; Egypt - E; Puerto Rico - PR; and Mauritius - M. Three or more digits usually follow the sigla. Improved varieties under cultivation in major sugarcane countries are given in Table 6.

Table 6. Sugarcane: Improved Varieties Under Cultivation in Different Countries

S.No.	Country	Improved varieties
1	Brazil	SP-77-5181, RB-85-5453, SP-81-3250, SP-80-1816, RB-85-5113, SP-80-3280, RB-1049, SSSP-71-5181, BR85-5113, BR72-454, BR83-5486
2	India	CoS.687, CoPant.84211, CoJ.64, CoLk.8001, Co.1148, CoS.767, CoS.802, CoC.671, CoC.85061, Co.8021, Co.6304, Co.1148, CoJ.79, CoS.767, Co.740, CoM.7125, Co.7527, CoC.671, Co.740, Co.8014, Co.7804, Co.740, Co.8338, Co.6806, Co.6304, Co.7527, Co.6907, Co.7805, Co.7219, Co.7805, Co.8011
3	Louisiana	CP 65-357, CP 70-321, CP 72-370, CP 74-383, CP 79-318, LCP 82-89, LHo 83-153, LCP 85-384, HoCP 85-845, LCP 86-454, HoCP 91-555
4	Thailand	91- 2 -29, K 92 -181, K 95 -84
5	China	
6	Hawaii	
7	South Africa	CP 66 - 1043, NCo 376, N 12, N 14, N 16, N 17, N 19, N 21, N 22, N 23, N 24, N 25, N 26, N 27, N 28, N 29, N 30, N 31, N 32, N 33, N 35, N 36, N 37, N 39, N 40, N 41

Land Preparation

For higher sugarcane yields, providing optimum soil environment is an essential pre-requisite since the crop remains in the field for about 5 to 6 years due to the practice of raising several ratoon crops.

Good Land Preparation

Improper Land Preparation

Further intense mechanization involving traffic of heavy machinery from planting to harvesting and transporting to the sugar mill or distillery, can cause the deterioration of soil physical conditions. This translates into soil compaction with a cohort of harmful side effects viz., reduction in storage & movement of air and water, mechanical difficulty for root growth and difficulty in absorption of nutrients from the soil itself and from the fertilizer.

Therefore a through land preparation every time a new crop is planted is absolutely essential to bring the soil to fine tilth for proper germination of the sets and field emergence and root growth.

Tillage is the physical manipulation of the soil with appropriate implements to loosen the surface soil layer.

Objectives of Land Preparation

- To prepare a seed bed which permits optimal soil water air relations
- Good physical conditions for early root penetration and proliferation
- To incorporate preceding crop residues and organic manures
- To destroy weeds and hibernating pest & disease organisms
- To facilitate proper soil chemical and microbial activity

Tillage operations through tractor drawn implements are most ideal and quick. For initial ploughing use either mould board plough or disc plough. Whenever, soil turning is desired, a mould board plough should be used.

On the other hand when the soil is hard, uneven and composed of crop stubbles, a disc plough is preferable. Ploughing at optimum soil moisture content is very essential to achieve tilth. Too wet soil interrupts movement of machinery and causes destruction of soil structure.

On the other hand too dry soil will not allow tynes to penetrate deep and results in frequent mechanical breakdowns, increased power requirement and cloddy soil surface affecting soil water air relations.

Without Subsoiling

With Subsoiling

The secondary tillage operations are carried out using disc harrows, tyned harrows or rotavator. The rotavator is a very useful multi purpose implement, which cuts the crop residues, shred them and incorporates in the soil in one pass. Use mechanical methods (subsoiling or chiseling or deep ploughing) or biological means (green manuring between last ratoon harvest and start of a new crop) to destroy the compacted layer and to allow roots to develop normally. Subsoiling was also shown to reduce fuel consumption, working time and facilitate optimum plant population.

Steps in Land Preparation Involve the Following:

- Subsoiling or chiseling to a depth of 50 to 75 cm to break hard compact sub-pan layer
- Ploughing to incorporate previous crop's crop residues and organic manures
- Discing to break clods
- Land shaping to provide the required gradient for draining excess water during rainy season
- Field layout - Construct ridges & furrows and shape them. Depth of furrows should be 25 cm. The furrow bottom should be loosened to about 10 cm.
- Provide drainage channels, which are deeper than the furrows along the field borders as well as within the field at regular intervals. Drainage channels are particularly important in the high rainfall areas to drain the excess water during rainy season.
- Table 7 summarizes the power requirement and output during land preparation.

Table 7. Sugarcane: Power Requirement and Work Ouput for Land Preparation

Operation	Power requirement/ha		Output (ha/hr)
	kWatts	Diesel (Litres/ha)	
Pre-discing	125	18	2.5
Ripping	165	48	0.5
Ploughing	165	24	1.7
Post-discing	125	18	2.5
Land leveling	125	7	3.5
Ridging	70	16	0.5

Planting Material

Sugarcane is vegetatively propagated for commercial cultivation. Different kinds of planting materials viz., cane setts; settlings and bud chips are used for raising sugarcane crop.

Cane Setts

Stem cuttings or sections of the stalks are called "setts" or seed pieces. Each sett contains one or more buds. Always use fresh, genetically pure, pest and disease free setts as seed material. Generally, three bud setts are used for planting throughout the world, while in some areas two-bud setts are also used.

Three Bud Sett (Source: Verma, 2004)

Experimental evidence shows that germination percentage of 3-bud setts is higher than the setts having more or less than 3-buds. The middle bud of a 3-bud sett has the highest germinating capacity followed by top end bud and the bottom end bud, respectively (Verma, 2004). The middle bud has an advantage in germination because, as a non-terminal bud having nodes on either side, its moisture resources are better protected than those of the terminal buds.

Middle bud showing the highest germinating capacity in 3-Bud Sett
(Source: Verma, 2004)

Germination capacity of single-bud sett is very poor due to loss of moisture from cut ends on either side. Further the plants arising from single-bud setts also lack vigour and yield low as compared to those from three-budded setts. Thus the preference given to three-budded setts over single-bud setts is partly based on germination capacity and partly on initial vigour of the germinated plants and cane yield.

If whole cane stalk is planted without being cut into setts, usually few buds at its top end germinate and the lower end buds remain inactive due to top dominance. The effect of top dominance is eliminated when stalk is cut into pieces.

Settlings

Cane setts with roots and shoots are known as settlings. Settlings can be raised either in nursery beds or in polythene bags. Single node settlings are used as a planting material in spaced transplanting technique of raising sugarcane crop.

Single bud settling (Source: Verma, 2004)

Bud Chips

Little portion of stem with one bud is known as bud chip. Bud chips are used to raise settlings in nursery. They were found to produce a good crop when transplanted in main field. The principal advantage of bud chips is substantial saving in seed material.

Seed requirement is reduced to less than one ton per ha. Adopting the following procedure raises settlings from bud chips:

- Prepare the bud chips from whole cane using a sharp edged knife in such a way that each bud has a little portion of stem
- Plant the bud chips on raised nursery beds adopting a inter-row spacing of 7.5 cm at the rate of 300 buds/m^2
- Alternatively nursery can be raised in polybags of 15 cm x 10 cm size
- Fill the polybags with homogeneous mixture of equal quantity of soil, sand and well rotten compost
- Plant the bud chips in polybags with the bud facing upwards and cover with soil mixture to avoid drying of the bud
- Bottom of the bags should have holes to facilitate drainage
- Ensure regular watering of bags or nursery area
- Settlings are ready in 5 - 8 weeks for transplanting in the main field
- Under good management conditions establishment of transplanted seedlings in the main field is high (90-100%)

Raising of Seed Cane Crop

The normal practice in many parts of the world is to use commercial crop of sugarcane for seed purposes. Characteristics for good seed are seldom taken into consideration. Many growers do not care for seed quality and many of those who do, select the seed only at the sett cutting and planting stage. This is not enough. If a grower wants to be sure of getting good and disease free seed cane he should raise the seed crop separately. This crop should be kept completely free from pests and diseases by constant field scouting from the very beginning.

Moreover, seed quality is not merely a matter of pest and disease freedom. Seed has to be in high water content and of good nutritional status. Neglect in raising good seed crop is one of the major defects in sugarcane cultivation all over the world. *(In the picture above: Bud Chip)*

Use of sugarcane seed from the commercial crop has been responsible for rapid multiplication of a large number of diseases like red rot, wilt, smut, ratoon stunting and grassy shoot which adversely affect the cane yield and quality. It is, therefore, raising of healthy and vigorous sugarcane crops for seed purpose is essential and recommended.

- Select an upland field for raising seed crop with no soil problems (soil salinity, acidity, waterlogging etc) and adequate irrigation facility
- Prepare the soil thoroughly and incorporate 20-25 tons/ha of FYM 15 days before planting
- Provide field channels and field drains to prevent rain water traversing from adjoining field to check spread of red rot disease
- Select seed material from previously raised seed nursery crop and prepare the setts. Use only sterilized setts to avoid transmission of certain diseases like RSD and GSD
- Give heat treatment (heat therapy) to eliminate seed borne diseases and organomercurial treatment to protect the setts from soil borne diseases to ensure better germination
- Adopt narrow spacing of 75 cm to obtain higher yield of setts per unit area
- Use 25% higher seed rate than normal cane crop
- Apply higher nutrient dose of 250 kg N + 75 kg P_2O_5 + 125 kg K_2O/ha
- Irrigate the crop at optimum levels to avoid any water stress during crop life taking in to account evaporative demand of the atmosphere (ET_o) and Crop characteristics (K_c) at different crop growth stages
- Provide weed free environment for better growth of the crop and also to avoid infestation of pests and diseases
- Adopt field scouting for timely control of pests and diseases
- Rouge out the affected clumps and plants of other varieties
- Protect the crop from lodging, binding and propping
- Crop is ready in 7 - 8 months. Setts obtained from such crop contain healthy and sound buds, higher moisture content, adequate nutrients, higher amounts of reducing sugars, therefore, establish quickly and grow vigorously thus ensuring a good commercial main field crop.

Preparation of Setts for Main Field Planting

- Harvest the seed crop one day before planting to obtain higher percentage and uniform germination.
- Prepare the setts always one day before planting by giving sett treatment.
- Planting material or seed cane should be free from aerial roots and splits.
- Avoid damage to buds while cutting setts.
- Change the seed material after every two to three seasons. In case if it is inevitable to use mature cane as seed, the top one-third portion can be used satisfactorily.

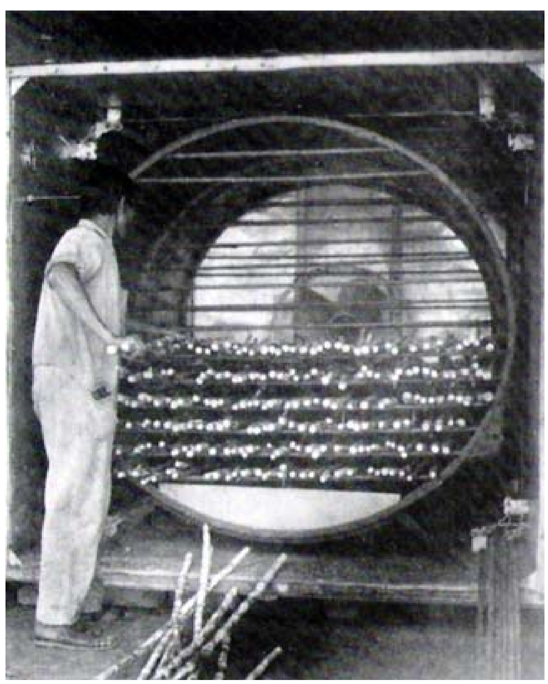
Ideal Seed Cane

- Always use seed cane obtained from a seed crop of 7-8 months
- Free from disease and pest infestation like red rot, wilt, smut, ratoon stunting disease etc
- Possesses healthy buds without any damage in handling and transport.

- Buds with higher moisture content, adequate nutrients, higher amount of reducing sugars and viability.
- Free from aerial roots and splits.
- Pure in quality.

Seed Cane Treatment

- Objective: To protect the crop from soil borne diseases causing pathogens, which usually gain entry into the setts through the cut ends following planting and cause sett rotting and damage to buds, thus affecting germination.
- Most farmers don't treat the setts before planting which results low plant population per unit area consequently reducing the yield



In the Pictures above: Sett treatment with fungicide against soil borne pathogens + moist hot air treatment of setts against seed borne diseases

In the picture below: Termite damaged setts (Source: Verma, 2004)

- Treat the setts soon after cutting in 0.1% (at 1g/liter) Carbendazim solution for 15 minutes.
- Three important diseases viz., grassy shoot disease, smut and ratoon stunting disease are carried forward through seed cane material. These diseases lead to progressive decline in yields and degenerate sugarcane varieties. For control of these diseases treat the seed material (setts) with moist hot air at 52°c for 30 minutes.
- To control termites early shoot borer and scale insects treat the setts in a systematic insecticide viz. Malathion 50EC (at 2 ml/liter) or Dimethoate 30EC (at 3 ml/liter) for 15 minutes.

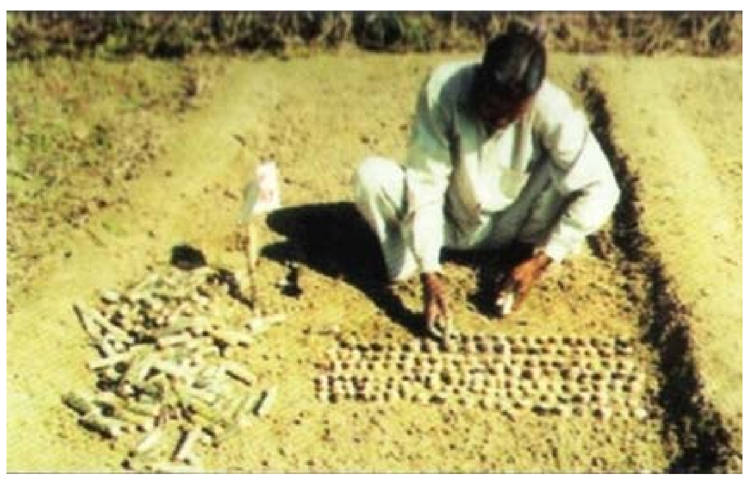
Seed Rate

Under drip irrigated paired-row system of planting [(0.6m + 1.20m) x 0.12m], about 60,000 two-bud or 40,000 three-bud treated setts would be required to plant one ha of land. With proper germination of buds, this seed rate is adequate to give a gapless stand and raise a successful crop.

Nearly 10-12 tons of seed cane is required to plant one ha of field. However, it is better always to go by number of setts per ha rather than weight basis as sett weight in sugarcane varies largely with varieties.

Measures to obtain higher germination

Some important yet simple measures to obtain higher uniform plant population are as follows:



- Using quality setts as seed material obtained from a short seed crop devoid of any primary infection
- Using preferably two eye bud setts instead of three bud setts as seed material
- Careful preparation of setts without damaging the buds or setts

- Using sterilized knives for preparing setts to avoid transmission of root stunting and grassy shoot diseases
- Planting freshly prepared and treated setts
- Giving adequate and frequent irrigation's during germination phase
- Control of weeds through pre-emergence herbicides
- Seed treatment with fungicide and pesticides

Transplanting Technique

Seedlings are raised in a nursery bed using single bud setts. When the seedlings are of about 6 week old, they are transplanted in the prepared main field.

In the pictures on the right and below (Source: Verma, 2004):
- *Single bud sett nursery*
- *Single bud sett settlings from nursery for transplanting in main field*
- *Transplanting In main field*

Advantages

- Saving in the seed cost as the seed requirement is only about 2-3 tons/ha against the normal seed requirement of 10-12 tons/ha.

- Synchronous tillering leading to uniform growth and maturity of stalk population, which usually gives better yield and sugar recovery.
- Sufficient time for main field preparation
- Saving in water and fertilizer
- Better weed management

Planting Time

Sugarcane is grown under diverse agro-climatic conditions in the world. Therefore there is a considerable variation in the planting dates. The optimum planting periods in different countries are presented in Table 8.

Table 8. Recommended Planting Time in Different Countries

S.No.	Country	Season	Planting time
1	Brazil	Central-South	May to October
		Northeastern	September to March
2	India	Tropical	October to March
		Subtropical	September to April
3	China	---	November to April
4	USA	Hawaii	Year round
		Southeastern	August to March
5	Mexico	---	November to June
6	South Africa	---	May to November
7	Australia	---	June to December
7	Argentina	---	May to November
8	Cuba	---	November to May
9	Thailand	---	June to July and November
10	Philippines	---	October to May
11	Pakistan	---	February to March

Machinery Planting

Due to increase in labour scarcity use of cane planting machinery is on the rise in different countries not only to achieve efficiency in planting operation but also to save fuel expenses and time to cover large areas. Several types of planting machinery have been developed in different countries to suit the local conditions.

Research on depth of soil cover over seed cane indicates that soil cover in excess of four inches can cause yield losses. Growers should use a covering tool that will cover the cane without pushing the cane closer than the width it was planted. Packing of rows should be done immediately after covering.

In the picture: Planted Cane and Sett Coverage Using Machine

Germination Irrigation

To get uniform and higher germination (sprouting) percentage of planted setts is quite a technique in drip irrigated cane production. This operation demands full attention of the farmer.

In the picture: Subsurface dripline laying machine

In the following paragraphs we explain the procedure to be adopted to get best results:

- Prepare the main field to fine tilth

- Lay the drip laterals (driplines) at 15 to 20 cm depth using SDI laying machine and test for their design performance. Under surface drip driplines are spread on the soil surface.

- Plant the treated two or three budded setts at 10-15 cm depth by planting machine adopting recommended planting pattern and spacing.

Surface drip

Subsurface drip

- After ensuring proper coverage of setts start the irrigation. Continue irrigation until a uniform wet band (not standing water) is formed along the dripline to a depth of not less than 30 to 40 cm.
- Depending upon the soil texture and soil tilth achieved during land preparation it would take about four to six hours.
- Examine the soil frequently at various places in the planting zone i.e, 10 to 15 cm of soil depth, for ascertaining the moisture status. As the days pass on soil moisture content decreases.
- Depending upon the soil texture and the climatic conditions (i.e, evaporative demand of the atmosphere), in about 3 to 5 days the soil moisture content in the planting zone will deplete to a level not congenial for germination process of the cane. When this happens start the second round of irrigation in time so that the bud sprouting process is not interrupted. Continue the second irrigation operation similar to the first round i.e., until uniform wet moisture band is achieved. But this time the irrigation duration will be less may be 50% of the first irrigation cycle (i.e., 2 to 3 hours) to achieve the same level of moisture status and wetting pattern in the soil. However, this needs to be confirmed before terminating the irrigation.
- Normally after 3 to 4 such irrigation cycles an experienced grower can obtain a very high germination percentage and uniformity of growth by adopting the above-described method.

- Poor soil conditions and improper land preparation affect but sprouting, germination and crop emergence.

In the pictures above:

- *Germination irrigation in surface drip to achieve a wetted strip*
- *Uniform emergence of sugarcane under drip irrigation*

Weed Management

In sugarcane weeds have been estimated to cause 12 to 72 % reduction in cane yield depending upon the severity of infestation.

The nature of weed problem in sugarcane cultivation is quite different from other field crops because of the following reasons

- Sugarcane is planted with a relatively wider row spacing
- The sugarcane growth is very slow in the initial stages. It takes about 30 - 45 days to complete germination and another 60-75 days for developing full canopy cover
- The crop is grown under abundant water and nutrient supply conditions
- In ratoon crop very little preparatory tillage is taken up hence weeds that have established in the plant crop tend to flourish well

Major weed flora observed in sugarcane fields are: Sedges- Cyprus rotundus; Grasses-Cynodon dactylon, Sorghum helepense, Panicum spp, Dactylocternium aegyptium, Broad leaved weeds - Chenapodium album, Convolvulus arvensis L., Amaranthus viridis L., Portulaca oleraceae L., Commelina bengalensis L., Trianthema portulacastrum L.

Weeds flora in sugarcane field besides competing for moisture and light also remove about 4 times N and P and 2.5 times of K as compared to crop during the first 50-days period. Weeds also harbour certain diseases and pests that attack sugarcane and thus lead to indirect losses.

Doob grass (Cynodon dactylon), the cogan grass (Imperata cylindrica) are known to play as alternate hosts to ratoon stunting disease of sugarcane. Thus weeds essentially harm young sugarcane sprouts by depriving them of moisture, nutrients and sunlight. Poor growth of cane resulting from weed infestation also affects quality.

Weeds that are present in the furrows i.e., along the cane rows cause more harm than those present in the inter-row spaces during early crop growth sub-periods. Thus the initial 90-120 days period of crop growth is considered as most critical period of weed competition. Therefore the weed management practice adopted should ensure a weed-free field condition for the first 3-4 months period.

In the picture:
Weed control through herbicides pays in sugarcane (Source: Verma, 2004)

Recommended Herbicides

A chemical program for weed control can help Louisiana growers produce maximum yields of sugarcane when combined with sound agronomic practices such as timely cultivation, selection of adapted varieties, proper fertilization, and disease and insect control. Herbicides are expensive, and, unless applied properly and at the correct time, they will not provide maximum control of weeds.

Spray equipment should be in good condition, properly calibrated (several times during a season) and should have vigorous agitation capability (especially important for wettable powders). Herbicides also should be accurately measured or weighed.

Herbicides to control weeds are essential to prevent weed competition and losses in sugarcane production. Sugarcane is most susceptible to weed competition during the first eight to 10 weeks after cane emergence. Unless herbicides are applied immediately after planting, weed seed present in the soil following a fallow program will germinate, producing viable seeds and/or rhizomes.

As a result weeds can quickly re-infest a field, with the benefits of weed control in the fallow period rapidly lost.
Selection of pre-emergence herbicides should be based on soil texture and organic matter content, weed problem and the variety of sugarcane. For best results, apply pre-emergence herbicides im mediately after planting

Recommendations for use of herbicides for weed control in sugarcane are summarized in the table below:

Table 9. Pre and Post-Emergence Herbicides For Weed Control in Sugarcane

S.No.	Herbicide	Control (weeks)	Dosage (kg/ha) based on clay%		
			< 20%	21 - 30%	>30%
			Pre-Emergence		
1	Atrazine 50 FW	6- 8	2.0	2.5	3.0
2	Ametryn 80 WP	6- 8	2.0	2.5	3.0
3	Diuron 80 WP	5-7	2.0	2.0	2.5
4	Metribuzin 70 WP	10-12	2.0	2.5	3.0
5	Alachlor 48 EC	6- 8	3.0	3.0	4.0
6	Trifluralin 48 EC	5- 7	1.5	1.5	1.5
7	Pendimethalin 50 EC	8-10	1.5	1.5	1.5
8	Terbacil	---	1.0	1.2	1.5
9	Diuron + 2, 4-D	---	1.2 + 1.8	1.2 + 1.8	1.2 + 1.8
10	Atrazine + Dalapan	---	1.25 + 2.5	1.25 + 2.5	1.25 + 2.5
			Post - Emergence		
1	2, 4-D Sodium salt 80 WSP	5-6	1.0	1.2	1.5
2	Paraquat	---	2.0	3.0	4.0
3	Glyphosate 41 WSC	8	1.2	1.5	2.0
4	MAMA				

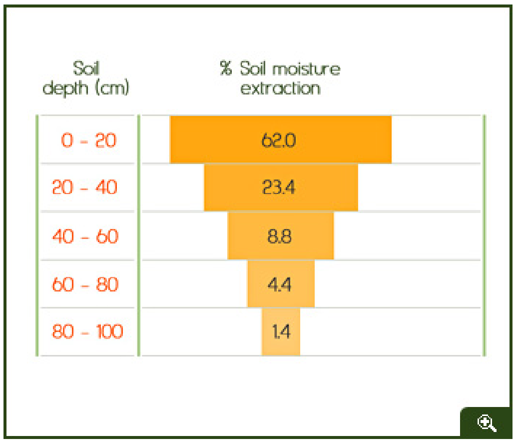
Irrigation Water Management

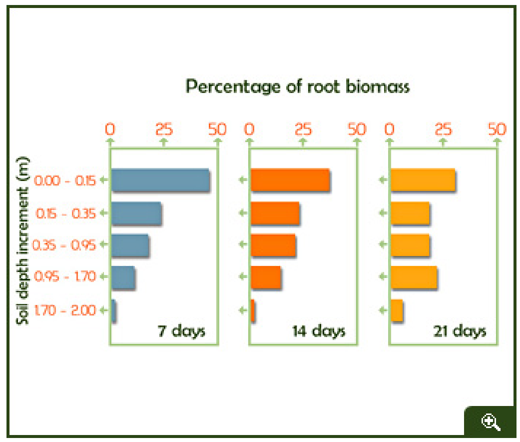
Sugarcane being a long duration crop producing huge amounts of biomass is classed among those plants having a high water requirement and yet it is drought tolerant. It is mostly grown as an irrigated crop. The plant crop season being 12-18 months in India, 13-14 months in Iran, 16 months in Mauritius, 13-19 months in Jamaica, 15 months in Queensland (Australia) and 20 - 24 months in Hawaii.

Moisture Extraction Pattern

Most root biomass for sugarcane is found close to the surface and then declines approximately exponentially with depth. Typically, approximately 50% of root biomass occurs in the top 20 cm of soil and 85% in the top 60 cm. The percentage of roots in the 0-30 cm horizon was 48-68%; from 30 to 60 cm, 16 - 18%; 60 to 90 cm, 3-12%; 90 to 120cm, 4-7%; 120 to 150 cm, 1-7%; and 150 to 180 cm, 0-4%. Thus the moisture extraction pattern from different soil layers follows the root biomass distribution.

Root growth responds strongly to the soil environment, creating plasticity in the form and size of the root system. The size and distribution of the root system is strongly affected by the distribution and availability of soil water, causing differences in the capacity of crops to exploit deeper soil reserves.





Root distribution of sugarcane crop raised on loamy soil irrigated at 7, 14 and 21 days interval. Roots of a 12-month old plant crop were more deeply distributed under less frequent irrigation presumably in response to drying of the surface. Deeper rooting reduces the vulnerability of crops to soil water deficits by providing increased capacity for uptake of deep reserves of soil water. It also aids in reducing lodging. Hence, drip irrigated cane should be scheduled irrigations at less frequency during the initial 2 to 3 months period to promote deeper rooting. *(In the graph above: Distribution of root riomass with depth for sugarcane irrigated at frequencies of 7 days, 14 days and 21 days (Baran et. al., 1974)*

Nutrient supply has also been shown to similarly affect the rooting patterns. High soil strength causes slower root growth with reduced branching and thickened roots. High water markedly affects root distribution, with a majority of studies showing that rooting ceases within approximately 0.1 m of static water tables.

Restricted root growth above shallow water tables does not necessarily reduce crop growth, as capillary rise can supply the crop with water and instances of water uptake from within the saturated zone have been observed.

A risk of water stress does result from the lack of root penetration in soils with high water tables if ground water height falls rapidly, leaving the root system restricted to dry soil.

Physiological Characteristics to be Considered for Efficient Water Managment

- A liberal water supply reduces the cane yield and/or sugar yield, while mild water stress enhances the yield
- Excessive watering at tillering should be avoided since it coincides with active root development and hinders nutrient uptake due to poor O2 diffusion
- Length of the cane determines the sink available for sugar storage since there is no secondary thickening of the stem in sugarcane
- A drying off or cut out period of 4-6 weeks prior to harvest ensures an optimum sugar yield
- Reduction of water during the ripeness to flower stage helps to control flowering or arrows

Field Irrigation Schedule

The goal of an efficient irrigation scheduling programme is to "provide knowledge on correct time and optimum quantity of water application to optimize crop yields with maximum water use efficiency and at the same time ensure minimum damage to the soil". Thus,

- Irrigation scheduling is the decision of when and how much water to apply to a cropped field.
- Its purpose is to maximize irrigation efficiencies by applying the exact amount of water needed to replenish the soil moisture to the desired level.
- Make efficient use of water and energy.

Therefore, irrigation scheduling for sugarcane involves precise estimation of depth of water to apply at each irrigation, and the interval between irrigation, for each soil-plant-climatic condition. With drip irrigation, intervals of irrigation are usually daily irrespective of the evaporative demand of the atmosphere.

The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease free, well-fertilized sugarcane crop, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic condition. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement.

Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost in evaporation + transpiration.

The irrigation water basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and to compensate for non-uniformity of water application.

Adequate soil moisture throughout the crop-growing season is important for obtaining maximum yields because vegetative growth including cane growth is directly proportional to the water transpired. Depending on the agro-ecological conditions, cultivation practices adopted and crop cycle (12-24 months) seasonal water requirements of sugarcane are about 1300mm to 2500mm distributed throughout the growing season (Table 10). The amounts of water required to produce 1.0-kg cane, dry matter and sugar are 50 - 60, 135-150 and 1000-2000g, respectively. The transpiration coefficient of sugarcane is around 400. This means 400 m^3 of water is required to produce one ton of dry matter.

Table 10. Sugarcane Water Requirements in Various Countries

S.No.	Country	Water requirement (mm)
1.	Australia	1522 (Drip)
2.	Burundi, Central Africa	1327 to 2017 (Furrow)
3.	Cuba	1681 to 2133 (Plant)
4.	Hawaii	2000 to 2400 (24 months)
5	Jamaica	1387
6	Mauritius	1670 (Drip)
7	Philippines	2451 (Furrow)
8	Pongala, South Africa	1555
9	Puerto Rico	1752
10	South Africa	1670
11	Subtropical India	1800 (Furrow)
12	Taiwan	1500 to 2200 (Furrow)
13	Tropical India	2000 to 2400 (Furrow)
14	Venezuela	2420 (Furrow)
15	Thailand	2600 (Furrow)
Source: Several		

The Calculation Procedure for Crop Evapotranspiration, ETc, Consists of:

Calculation of Reference Crop Evapotranspiration (ET_o)

Collect available climatic data; based on meteorological data available, select prediction method viz., either Penman-Monteith or Pan evaporation method to calculate ETo. Compute for necessary periods considering the growth subperiods of the crop in question.

Construction of Crop Coefficient (K_c) Curve

Determine time of planting, identify the crop growth subperiods, determining their lengths; Select Kc for a given crop growth sub-period under prevailing climatic conditions. Construct the crop coefficient curve (allowing one to determine Kc values for any period during the growing period); and

Calculation of ETc under standard conditions as a product of ETo and Kc.

The reference crop evapotranspiration (ET_o) estimated based on Penman-Monteith or Adjusted USWB Class A Pan evaporation method reflects the evaporative demand of the atmosphere for the location in question.

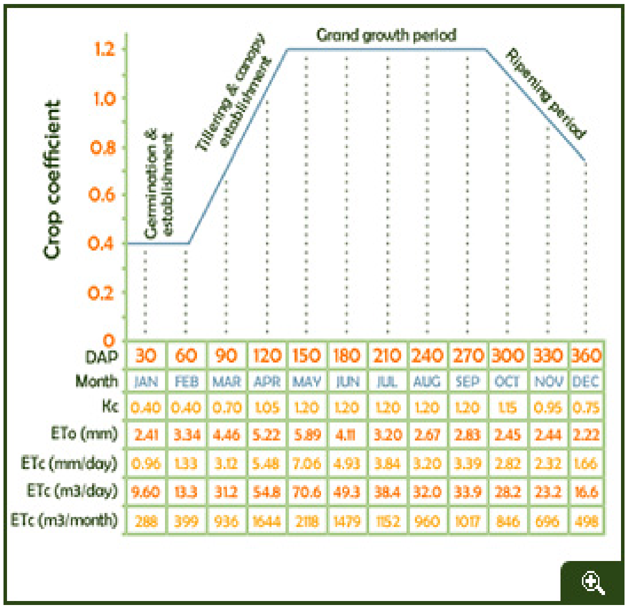
In the picture: USWB Class a Pan Evaporimeter for Estimating ET_o

While the crop factor (a dimensionless ratio) reflects the crop characteristics and indicates the combined loss of water from a sugarcane field both by transpiration and soil evaporation (Crop ET_c) relative to ET_o over the same period.

Several workers have worked out estimates of crop factors experimentally for different crop growth stages of sugarcane. The daily requirement in millimeters is converted to the equivalent volumetric quantity for the area under drip (1 mm = 10 m^3/ha).

A field irrigation schedule prepared based on above approach for irrigating sugarcane grown in Tropical region of India is presented in the picture for field application.

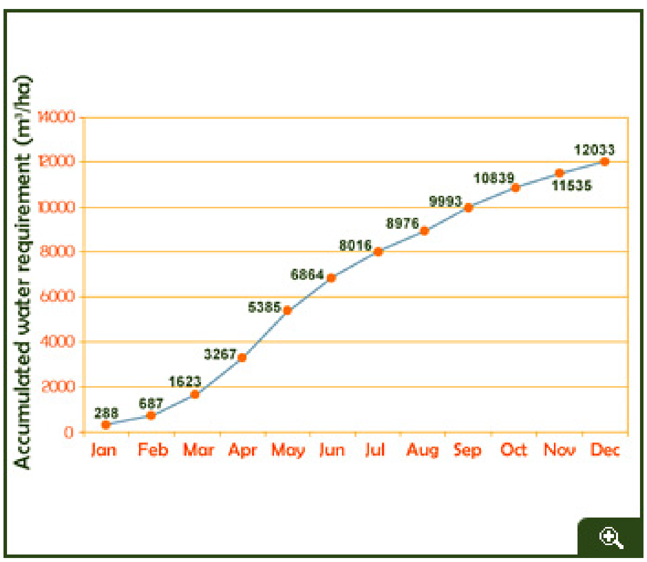
While the water requirement during different crop-growth subperiods and cumulative ETc is depicted in the picture here. Such type of irrigation scheduling programmes can be prepared for each location (depending up on the climatic data availability) in real time operation.



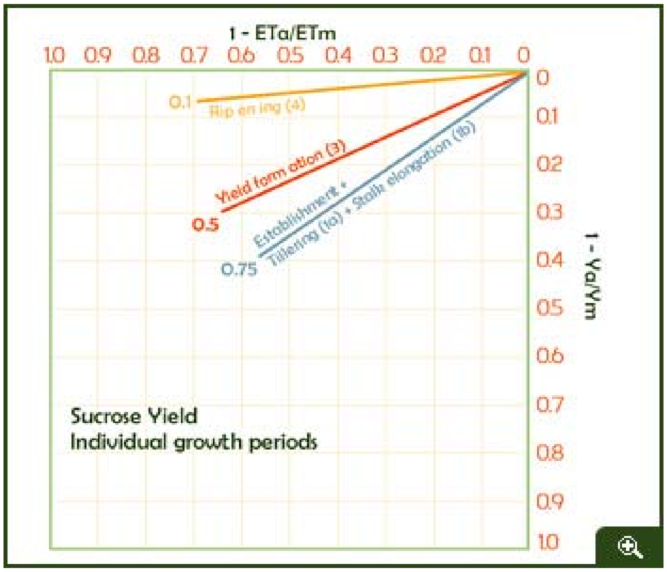
DAP	30	60	90	120	150	180	210	240	270	300	330	360
Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Kc	0.40	0.40	0.70	1.05	1.20	1.20	1.20	1.20	1.20	1.15	0.95	0.75
ETo (mm)	2.41	3.34	4.46	5.22	5.89	4.11	3.20	2.67	2.83	2.45	2.44	2.22
ETc (mm/day)	0.96	1.33	3.12	5.48	7.06	4.93	3.84	3.20	3.39	2.82	2.32	1.66
ETc (m3/day)	9.60	13.3	31.2	54.8	70.6	49.3	38.4	32.0	33.9	28.2	23.2	16.6
ETc (m3/month)	288	399	936	1644	2118	1479	1152	960	1017	846	696	498

Water Supply and Cane Yield

Frequency and depth of irrigation should vary with growth periods of the cane. The relationship between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit for the individual growth sub-periods is shown in the picture. During the initial germination, field emergence and establishment of young seedlings the crop requires less water, hence light and frequent irrigation water applications are preferred.

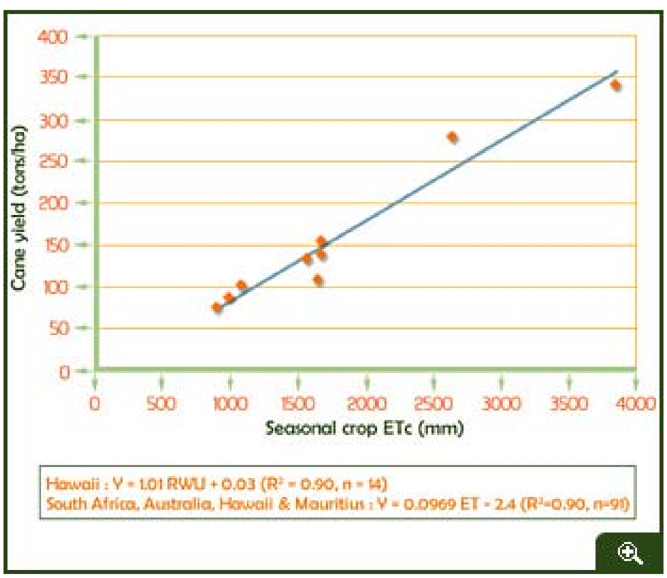


The water supply must be just sufficient to keep the soil moist with adequate aeration. If the soil is allowed due to infrequent and less water application, the germinating buds get desiccated leading to a lower and delayed germination.



On the other hand over irrigation leads to bud rotting due to lack of aeration, fungal attack and soil reducing soil temperature. Thus both under and over irrigation are detrimental for germination, resulting in low stalk population per unit area.

During the early vegetative period (formative) the tillering is in direct proportion to the water application. An early flush of tillers is ideal because this furnishes shoots of approximately same age. Any water shortage during tillering phase would reduce tiller production; increase tiller mortality and ultimately the stalk population-an important yield component.



However, excess irrigation during tillering phase is harmful particularly in heavy soils, since it coincides with active root development, which may be hampered by anaerobic condition created in the soil as a result of over irrigation.

The yield formation or grand growth period is the most critical period for moisture supply in sugarcane. This is because the actual cane yield build-up or stalk growth takes place in this period. The production and elongation of inter-nodes, leaf production on the stalk and its expansion, girth improvement, ultimately the stalk weight takes place in this period. It is also the period for production of sugar storage tissues. Therefore, crop reaches its peak water requirement in this stage. With adequate water supply to maintain a sheath moisture content of 84-85% in the leaf sheaths, 3,4,5 and 6 from the top during this period of active growth produces longest inter-nodes with more girth (thick cane) and the total cane weight is greater.

On the other hand water deficits in yield formation period reduce stalk elongation rate due to shortening of inter-nodes resulting in less cane weight and the effect is well marked on yield at harvest. A severe water deficit during the later part of the grand growth period forces the crop to ripen. In many an areas in India the tillering/early yield formation period coincides with hot weather period (March - June).

The evaporative demand of the atmosphere is very high during hot weather period vis-Ã -vis the crop water needs. Therefore management of available water supplies to meet the peak water requirement is very crucial to realize optimum yield potential.

In ripening period the a restricted water supply or mild water deficits (sheath moisture content of 74-76%) is necessary to bring the crop to maturity by reducing the rate of vegetative growth, dehydrating the cane and forcing the conversion of total sugars to recoverable sucrose. With the check of vegetative growth, the ratio between dry matter stored as sucrose and that used for new growth increases.

On the other hand plentiful supply of water leads continued vegetative growth thus affecting sugar accumulation process. However, when the plant is too seriously deprived of water, it would disrupt the plant metabolism and loss of sugar content can be greater than sugar formation. An important consideration is that soil should not be allowed to crack, as it would cause root pruning and damage the root system.

When the crop is in the ripening period, a farmer may also have a just planted crop on his farm in most situations. Therefore, the tendency of the farmer will be to provide sufficient water to the new (young) crop and neglect the grown up crop that is to be harvested. This situation is particularly true under limited water availability situations. If the grown up crop is not irrigated as required it experiences severe water deficits and there could be cane breakage, pith formation, significant reduction in cane weight, increase in fibre content and deterioration in juice quality.

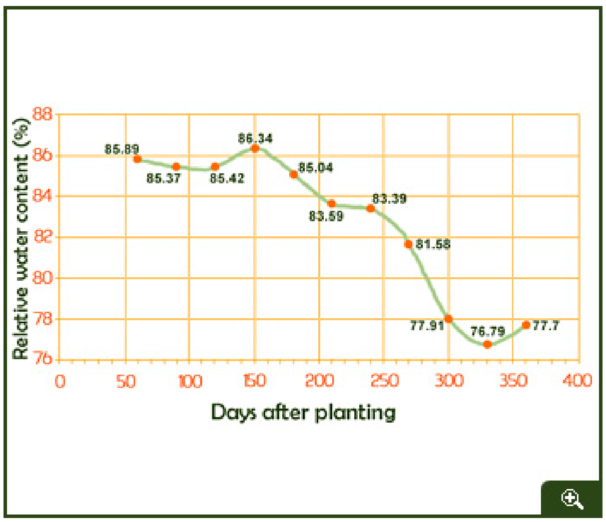
The situation is further aggravated if the harvesting is delayed. Thus both the farmer and the factory would suffer. Therefore, even for the grown up crop, reasonable amount of water with restricted supply is necessary to obtain good cane yield.

Sheath Moisture Content

The sheath moisture or relative water content determined by crop logging technique is presented in Fig. It has long been used to control water application to commercial sugarcane crop, more particularly during ripening phase, when gradual increase in water stress is used to stimulate sugar storage in the stem.

A ripening log is used to compare measured and desired sheath water content during approximately 12 to 24 weeks (depending upon the crop duration) prior to harvest.

Sheath water content is measured on a periodic basis, and irrigation intervals and amounts are varied to produce a gradual decline of sheath water content, from about 83% at the beginning of ripening to about 75% at harvest.



In the graphs / pictures above:

- *Cane yield response to water deficits (Doorenbos and Kassam, 1979)*
- *Optimum Sheath Moisture content indices for sugarcane (Lakshmikantham, 1983)*
- *Cane Yield Response to seasonal evapotranspiration [Thompson (1976) & Jones (1980)]*

In Hawaii and Taiwan sheath water content has been found to be a good indicator of stem sugar content. Similar methods involving other tissues are in use in Mexico, South Africa, India and Zimbabwe.

Irrigation water is often limited and costly input. Therefore determination of optimum amount of water over a crop period to achieve higher water use efficiency assumes significance.

Several experiments conducted world over have indicated that the relationship between cane yield and seasonal crop water use under a given climatic condition was linear.

When irrigation plus rainfall is greater than the crop water requirement, anaerobic soil conditions or N losses may reduce crop growth rates and cane yield.

Fertigation

Sugarcane being a giant crop producing huge quantity of biomass generally demands higher amounts of nutrient elements. A large number of research experiments have clearly demonstrated that for producing higher cane and sugar yields on a sustainable basis application of adequate amounts of fertilizer nutrients viz., N, P and K is essential.

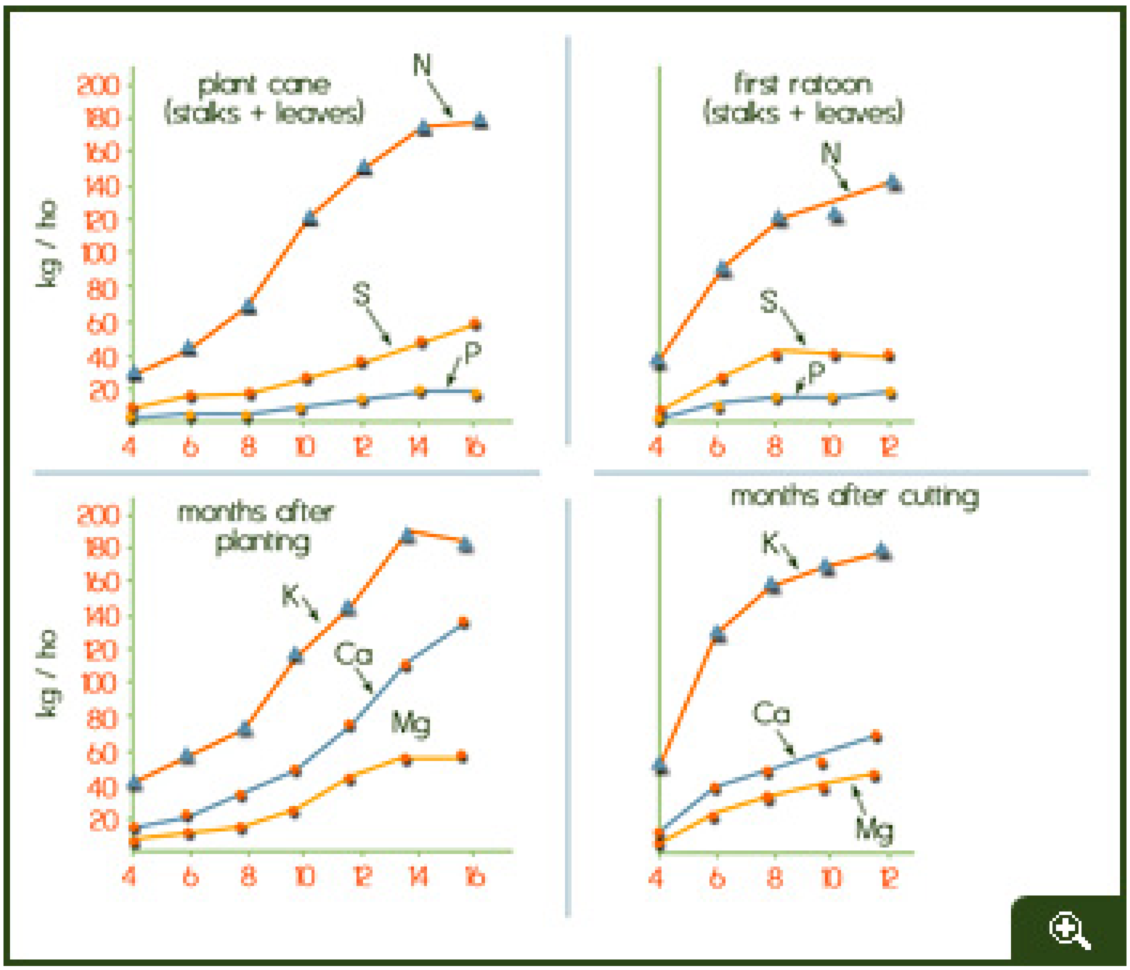
At the same time the cost of chemical fertilizers have increased and there is a need to improve fertilizer use efficiency for more benefits. The best answer to this challenge is "Fertigation", where both water and fertilizers are delivered to crop simultaneously through a drip irrigation system. Fertigation ensures that essential nutrients are supplied precisely at the area of most intensive root activity according to the specific requirements of sugarcane crop and type of soil resulting in higher cane yields and sugar recovery.

Fertigation Offers Several Distinct Advantages in Comparison to Conventional Application Methods:

- Distribution of plant nutrients more evenly throughout the wetted root zone resulting in increased nutrient availability & uptake contributing to higher crop growth rates and cane yields
- Supply of nutrients incrementally according to the crop developmental phases throughout the season to meet the actual nutritional requirements of the crop
- Careful regulation and monitoring the supply of nutrients
- Application of nutrients to the soil when crop or soil conditions would otherwise prohibit entry into the field with conventional equipment
- Minimal nutrient losses through consumption by weeds, leaching and runoff
- No damage to the crop by root pruning, breakage of leaves, or bending of leaves, as occurs with conventional fertilizer application methods/equipment
- Less energy is expended in application of the fertilizer

- Usually less labour & equipment are required for application of the fertilizer and to supervise the application
- Soil compaction is avoided because heavy equipment never enters the field
- No salt injury to foliage
- Allows raising of crop on marginal lands, where accurate control of water and nutrient ion in the plant's root environment is critical

Nutrient Uptake by Sugarcane



Absorption of macronutrients by the variety CB41 - 76 (Malavolta, 1982)

Fig. shows the accumulation of macronutrients by the variety CB 41-76 under Brazilian conditions. Several works have indicated that there is a close relationship between increase in stalk production and accumulation of N and K, which suggests that these two elements "go together" in the nutrition and fertilization of the sugarcane plant. The maximum rate of uptake of macronutrients by plant cane and first ratoon in the period of higher growth rate is given in
Table 11.

Table 11. Maximum Rate of Uptake of Nutrients by Plant Cane and Ratoon Cane (Malavolta, 1994)

Element	Plant cane	Firfst ratoon
	kg ha^{-1} day^{-1}	
Nitrogen	0.59	0.73
Phosphorus	0.08	0.11
Potassium	0.71	0.95
Calcium	0.45	0.33
Magnesium	0.24	0.26
Sulphur	0.16	0.31

Generally speaking, the content of the macro and micronutrients in the plant obeys the following decreasing order:

K»gt; N»gt; P»gt;Ca»gt;S»gt;Mg»gt;Cl»gt;Fe»gt;Zn»gt;Mn»gt;Cu»gt;B»gt;Mo

Further most of the published data on the mineral requirements of sugarcane refer only to the above ground parts, which are stalks and leaves. Table 12 is an attempt to show the quantities of macro and micronutrients contained in the entire plant cane.

Table 12. Quantity of Macro and Micronutrients in the Below Ground and Aerial Parts of Plant Cane

Element	Roots	Millable stalks	Leaves	Total
	Kg/ha			
Nitrogen	8	83	77	168
Phosphorus	1	15	8	24
Potassium	4	109	105	218
Calcium	2	30	45	77
Magnesium	1	29	18	48
Sulphur	2	25	22	49
Chlorides	--	--	1	1
Silicon	--	98	150	248
	g/ha			
Boron	34	214	144	392
Copper	13	201	105	711
Iron	4900	3800	7900	16600
Mangnese	84	1170	1981	3235
Molybodynum	--	4	10	14
Zinc	72	437	336	845
Catani *et al.* (1959), Orlando Filho (1978), Haag *et al.* (1987), Sampaio *et al.* (1987), Korndorfer (1989)				

Role of Nutrients

Nitrogen

1. N constitutes only a fraction of 1.0% of the total dry weight of mature cane
2. Key element influencing growth, yield & quality
3. Adequate and timely supply promotes - Tillering, Canopy development, Stalk formation & stalk growth [internode formation, elongation, increase in girth & weight
4. Root penetration and proliferation
5. Deficiency of N causes chlorosis, early leaf senescence, thinner & shorter stalk and longer and thinner roots
6. Excess N prolongs vegetative growth, delays maturity and ripening; increases reducing sugar content in juice and thus lowering juice purity, and increases soluble N in juice affecting clarification; makes crop susceptible to lodging and pest and disease attack

Phosphorus

1. Requirement is relatively less than N and K
2. Vital for plant metabolism and photosynthesis
3. Essential for cell division and thus indispensable for crop growth & development
4. Promotes tillering, canopy and stalk development
5. Promotes root penetration and proliferation
6. Adequate P [3-4mg/liter] in cane juice is necessary for proper clarification
7. Phosphorus deficiency causes - Poor tillering & reduction in internodal length, Delay in canopy closure and Reduction root surface area

Potassium

1. Required for several plant activities - Photosynthesis, carbon assimilation & translocation of carbohydrates
2. Promotes sugar synthesis & its translocation to storage tissue
3. Imparts resistance against pests & disease attack and lodging
4. Regulates stomatal opening & closing and thus maintains turgor pressure under unfavourable soil moisture conditions
5. Luxury consumption adversely affects the crystallization of sugar & higher sugar losses in molasses
6. Deficiency of K affects growth by reducing internodal length, sugar synthesis and recovery

Causes of Nutrient Deficiency Symptoms

When a given nutrient is not present in the soil solution in a concentration sufficient for normal growth and differentiation, visual symptoms of malnutrition may eventually show up. The shortage of nutrients, which translate into symptoms of deficiency, could be due to several causes as shown in Table 13. It is clear that the three chief causes are low reserves to begin with, as it is the case of old weathered soils in the tropical regions, decrease in availability, and absence or lack of the element in the fertilizer programme at the rates it is applied.

Table 13. Main Causes of Deficiency Symptoms in the Sugarcane Plant

Element	Cause
Any	• Low soil reserve • Absence or inadequate quantity in the fertilization or liming programme
Nitrogen	• Low organic matter content • High acidity (lack of mineralization) • High rainfall (leaching)
Phosphorus	• High acidity and high sexquiooxides (fixation) • Excess liming (lower availability)
Potassium	• Excess liming (competition for uptake) • High rainfall (sandy soils, leaching)
Calcium & Magnesium	• Excess K in the fertilizer programme (competition)
Sulphur	• See nitrogen • Use of "concentrated" fertilizers
Boron	• See nitrogen • Excess nitrogen ("dilution" or inhibition in uptake) • Excess liming (loss in availability)
Copper	• Excess P in the fertilization programme(inhibition in uptake) • Excess liming (loss in availability)
Iron	• High organic matter and moisture (loweravailability) • Excess liming (loss in availability)
Manganese	• High organic matter, Excess liming (loss in availability)
Molybdenum	• High acidity (lower availability) • Excess sulphate (inhibition in uptake)
Zinc	• Excess liming (loss in availability) • High P in fertilizer programme (inhibition uptake)

Source: Malavolta (1994)

Fertilizer recommendations in different states

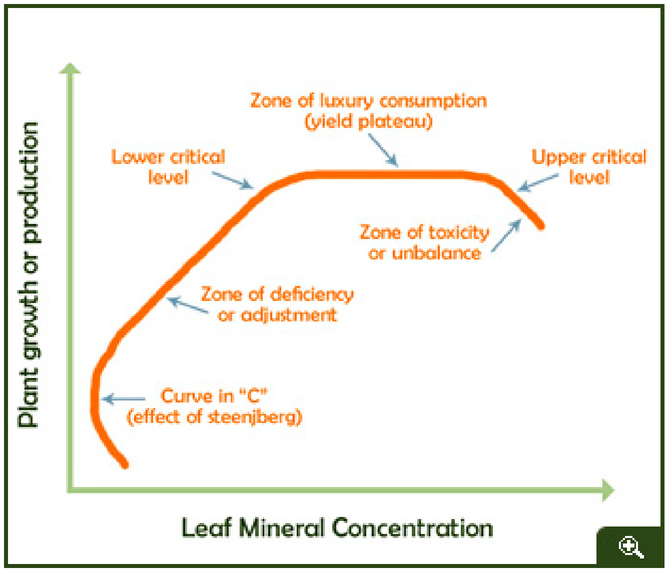
Sugarcane being a heavy feeder requires very large quantities of nutrients for growth and yield, accounting for 20 to 25% of the total cost of the production. The fertilizer recommendations for sugarcane in different countries are given in Table 14.

Table 14. Sugarcane: Recommended Nutrient Doses in Different Countries

Country	Crop	Nutrients (kg/ha)			Remarks
		N	P_2O_5	K_20	
Argentina	--	100	Adapt to requirement		--
Australia	Plant cane Ratoon	56 78	25-80 --	75-150 --	In addition to Bureau mixture
Bangladesh	--	120	85	110	--
Brazil North East South East Central West South	Plant cane Ratoon Plant cane Ratoon Plant cane Ratoon Plant cane Ratoon	60-80 60-80 50-90 50- 90 30-40 40- 60 40-100 20-40	80- 180 20-100 50-110 25-50 30-120 15-60 0-120 20-60	30-120 40-140 20-120 10-80 30-120 20-90 30-120 0-60	N - 2/3 side-dressed P & K according to soil analysis P & K according to soil analysis As above As above As above
British Guyana	--	65-90	50-100	60-150	--
Colombia	Plant cane Ratoon	50-70 50-100	50-100 60-120	60-150 60-150	N - Side dressed according to leaf analysis P & K rates depending upon soil analysis
Costa Rica	Plant cane Ratoon	80-200 100-250	60-180 50-200	80-200 80-250	--
Cuba	Plant cane Ratoon	0 35-150	0-50 0-50	0-120 0-150	P & K rates depending upon soil analysis and yield level
Ecuador	Plant cane Ratoon	120 90	75-135 --	75-195 --	N-1/3 side dressed P & K rates according to soil analysis
India	--	SEE NEXT TABLE			--
Indonesia	--	120	--	--	P & K rates according to soil analysis
Jamaica	--	80-160	--	--	P & K rates according to soil analysis
Mauritius	--	100-125	--	--	2 - 1 -1 mixture
Mexico	--	120-180	0-150	0-150	Most frequent rates: 120 N+60 P_2O_5+60 K_2O
Pakistan	--	90-160	--	--	--
Philippines VMC District Luzon Puerto Rico	--	125 120-140 135-200	120 -- 62	180 -- 112	--
South Africa Coastal Lowland Natal Midland Lowveld	Plant cane Ratoon Plant cane Ratoon Plant cane Ratoon	100-120 140 80 120 120 100	40 20 60 40 30 10	100 150 125 175 125 175	N and K_2O for plant cane in 2 split applications
Hawaii (USA) Irrigated Rainfed	Plant cane Plant cane	400 300	280 280	400-450 400-450	N in 2 split applications

Leaf Analysis

Leaf analysis may be considered a method, which evaluates the soil supply of available elements using the plant itself as an extracting agent. A general representation of the relationship between leaf concentration and cane yield is presented in fig.



Relationship Between Leaf Concentration and Cane Yield
(Prevot & Ollagnier, 1956)

The picture describes several situations, which may occur. Clockwise the following segments are shown:

- **Curve in "C"** - Yield is increased but leaf level is reduced; this happens when the rate of dry matter production is higher than the velocity of uptake or transport of the element into the leaf tissue which causes its dilution
- **Zone Of Deficiency Or Adjustment** - Only in this section is the relationship between leaf level and growth or yield is observed, and very often there is a linear relationship between increase in leaf concentration and yield;
- **Lower Critical Level** - Usually a narrow band below which yield is reduced due to a shortage of the element
- **Zone Of Luxury Consumption** - It is wider in the case of macronutrients like K, and much shorter in other cases such as that of B; leaf level increases wheras production remains constant, there is therefore, a waste of fertility or fertilizer;
- **Upper critical level** - A zone which separates the yield plateau from the toxicity zone;
- **Zone of toxicity** - Leaf content increases even further and yield drops, either as consequence of a toxic effect of the element, or as a result of unbalance among

In the agricultural practice, the goal is not the maximum physical production but rather the realization of the maximum economic yield (MEY). For this reason the concept of critical level or lower critical level was redefined with the introduction of an economical component: it is the range of an element in the leaf below which production is restricted and above which fertilizer application is no longer economical.

This means that above this physiological-economical critical level, both yield and leaf content of the element could rise in response to the fertilization. The increase in yield, however, does not pay the additional fertilizer and the cost of its transport and distribution. Thus levels of nutrients considered adequate for economic yield are presented in Table 15 & 16.

Table 15. Levels of Macronutrients Considered Adequate for Maximum Economic Yield

Country	*Crop*	*% of dry matter*					
		N	**P**	**K**	**Ca**	**Mg**	**S**
Australia	Plant	1.90-2.50	0.21-0.30	1.30-2.00	0.20-0.60	0.10-0.30	--
	Ratoon	1.90-2.50	0.21-0.30	1.30-2.00	--	--	--
Brazil	Plant	1.90-2.10	0.20-0.24	1.10-1.30	0.80-1.00	0.20-0.30	0.25-0.30
	Ratoon	2.00-2.20	0.18-0.20	1.30-1.50	0.50-0.70	0.20-0.25	0.08-0.35
British Guyana	Plant	2.1	0.21-0.35	1.25-2.00	0.15-0.20	0.12-0.18	0.08-0.35
	Ratoon	1.9	0.21-0.35	1.25-2.00	0.20-0.24	0.12-0.18	--
Colombia	--	1.80-2.00	0.25-0.35	1.60-1.80	> 0.25	> 0.20	--
India	--	1.96	0.086	1.99	--	--	--
Puerto Rico	--	1.60-2.00	0.18-0.24	1.55-2.00	--	--	0.13
South Africa	--	1.70-1.90	0.10-0.20	1.05-1.10	0.15-0.18	0.08	0.12-0.13
USA	--	1.50-1.75	0.18-0.22	1.25-1.75	0.28-0.47	0.14-0.33	0.13-0.18

Reuter (1986), Malavolta (1986), Evens (1967), Garcia Ocampo (1991), Srivastava (1992), Samuels (1971), Gosnell & Long (1971), Anderson & Bowen (1990)

Table 16. Levels of Macronutrients Considered Adequate for Maximum Conomic Yield

Country	Crop	%							
		B	**Cl**	**Cu**	**Fe**	**Mn**	**Mo**	**Si**	**Zn**
Australia	--	--	--	2	50	--	--	--	10
Brazil	Plant	9-30	--	8-10	200-500	100-250	0.15-0.30	--	25-50
	Ratoon	9-30	--	8-10	80-150	50-125	--	--	25-30
British Guyana	--	2-10	smaller than 0.5%	5-100	4-15	20-200	0.08-1.0	--	15-50

South Africa	--	1.6-10		49-915	3-12	15		--	12-25
USA	--	3-8	0.068%	7-600	20-21	14-235	0.05-4	1.5-4%	19-38

Anderson & Bowen (1990), Malavolta (1982), Evens (1967), Wood (1987), Scroeder et.el (1983), Anderson & Bowen (1990)

Fertigation Programme

The aim of the fertigation programme is to cover the difference between requirement and supply, that is:

(M) Fertilizer = [M (requirement - supply)] f

Wherein M = a macro or micronutrient, f = is a factor higher than 1 destined to compensate for losses due to volatilization, leaching, fixation and immobilization.

Whenever the soil supply is lower than the crop requirement, fertilizers have to be added in order to increase and to keep M (in soil solution) at a level compatible with the plant needs. In order to make practical fertilizer recommendations, we have to answer several questions, namely:

What? Which Element(s) is (are) Limiting Growth and Production; How Much? What Quantity Has to be Added?

The capacity of the soil to supply nutrients can be evaluated through leaf analysis already dealt with, and more frequently via soil chemical analysis. Further the cation exchange capacity, clay content, efficiency factor etc have to be considered to quantify the nutrient requirement.

When? In What Stages Fertilization is to be Done?

As shown in fig. accumulation pattern as a function of crop ontogeny has to be taken in to account for timing of fertilizer application. Both nitrogen and potash fertilizers tend to increase the osmotic pressure of the soil solution which when too high could damage the seed cane or the roots. Nitrogen in mineral forms can be leached from the rhizosphere. The same is true for K in the case of soils with low CEC. These facts seem to point out the need to apply only part of the N requirement at planting and doing the same for potash in sandy soils.

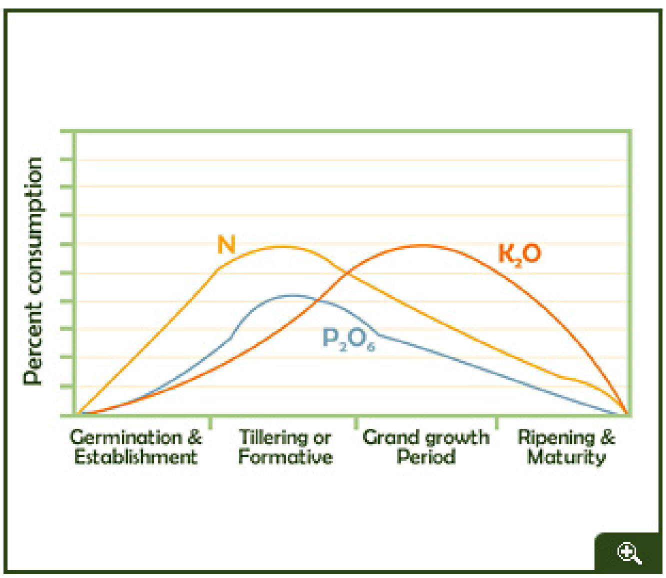
Nitrogen requirement of sugarcane is greatest during the tillering (formative) phase. This is required for adequate tiller production and canopy development. Tillering in field grown sugarcane commences around 30 to 45 days after planting. Therefore, adequate N supply should be made available to the crop in the soil from the start of tillering phase. Further, crop requirement for N is higher in early grand growth period.

This facilitates cane formation; checks tiller mortality and promote cane growth. Application of more N at later phase of active crop growth period not only promotes late tiller formation, but also affects sugar recovery due to reduced juice sucrose (Pol) percent, increase in soluble N in juice, water shoot formation besides attracting pests and diseases.

Phosphorus need of sugarcane is greater in the formative phase of the crop. Thus, the optimum time of P application is during initial stages of crop growth. Therefore, sufficient P must be made available in the soil during formative phase for absorption by the crop.

Potassium applications are usually done along with N application. This is because of better utilization of N by the crop in the presence of K; therefore, potassium should be applied along with N. However, late application of K at around six months has also been found to improve sugar recovery.

In general all the phosphorus should be applied before 4 months, nitrogen before 6 months and potassium before 7 months period. Relative requirement of NPK (%) at different crop growth stages is shown in Fig.



Relative requirement of NPK at different crop growth stages of sugarcane (Bachchhav, 2005)

How? What is the Most Efficient Way of Fertilization?

The efficacy of fertilizer depends on several factors, such as: process of contact between the element and the root, distribution of the root system, type of crop (plant crop or ratoon) and spacing, type of fertilizer and application rate. Root interception, mass flow and diffusion make the following percent contributions to the total of the element, which reaches the root surface: N (1, 99 & 0), P (2, 4 & 94); K (2, 20 & 78).

While in the case of nitrogen mass flow plays an almost exclusive role for the contact, diffusion is the chief mechanism (94%) for P and for K (78%). It follows therefore that as long as P is placed adequately, both N and K will be taken equally well. Thus from the above it appears that fertigation is the best option of fertilization.

With what? Which fertilizers are to be Used?

Table 17 lists the main water soluble fertilizers used in the sugarcane world. It is desirable to use water soluble specialty fertilizers in view of the following features:

Table 17. Fertilizers Suitable for Fertigation Via Drip Irrigation System

Nutrient	Water soluble fertilizers	Nutrient content
Nitrogen	Urea	46-0-0
	Ammonium Nitrate	34-0-0
	Ammonium Sulphate	21-0-0
	Calcium Nitrate	16-0-0
	Magnesium Nitrate	11-0-0
	Urea Ammonium Nitrate	32-0-0
	Potassium Nitrate	13-0-46
	Monoammonium Phosphate	32-0-0
Phosphorus	Monoammonium Phosphate	12-61-0
	Monopotassium Phosphate	0-54-32
	Phosphoric Acid	0-82-0
Potassium	Potassium Chloride	0-0-60
	Potassium Sulphate	0-0-50
	Potassium Nitrate	13-0-46
	Potassium Thiosulphate	0-0-25
	Monopotassium Phosphate	0-52-34
NPK	Polyfeed	19-19-19 20-20-20
Micronutrients	Fe EDTA	13
	Fe DTPA	12
	Fe EDDHA	6
	Zn EDTA	15
	Ca EDTA	9.7
	Rexolin CXK (B+Cu+Fe+Mn+Mo+Zn+Mg)	---

- Free from chlorides and sodium
- No salt build up in the crop root zone
- Contain 100% plant nutrients
- Fast acting nitrate nitrogen, soluble phosphorus and soluble postassium

- Completely water soluble with any residues
- Most of the fertilizers are acidic in nature, hence no special chemical treatment is required to check emitter plugging
- Maintain optimum soil pH contributing to more uptake of nutrients
- Most of the fertilizers are blended with micronutrients

Effect on Quality? Not Only Total Tonnage of Millable Stalks are to be Considered, the Effect of the Fertilizer on Sugar Yield Has Also to be Taken into Account:

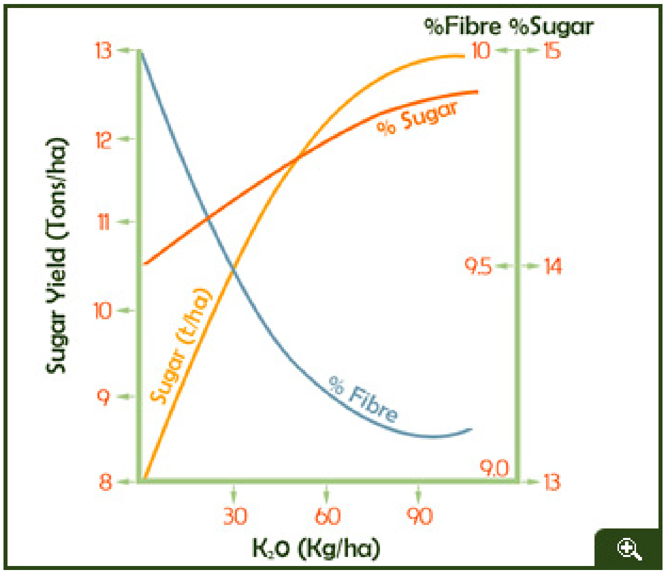
It is well known that "sugar is made in the field, not in the factory". Sugar formation and accumulation is a function of several variables viz., variety and age or duration of the crop cycle, climatic conditions, soil fertility and fertilization. The effect of fertilization of course reflects to a large extent the role played by the nutrient in the physiological process within the plant, particularly photosynthesis, transport and accumulation of sucrose (the sink source relationship).

Increase in the rate of N raises yields of stalk and sugar until yield reaches a maximum. If N is applied in excess of the optimum, sugar production may drop. Timing of N application has a profound influence on sucrose content at harvest. N application at beginning of vegetative growth has no negative effect on sucrose content. However, late application at 10 months caused a decrease in sugar yield of 14 g per stalk when compared to the application before 7 months.

Higher rates of P (100 kg P2O5/ha) application can reduce yield, sugar concentration, pol % and purity, particularly in ratoons and in soils not deficient in phosphorus. On the other hand, in P deficient soils higher p levels increase pol % and purity. The amount of P in cane juice has an effect on clarification and should be in the range of 132 to 264 ppm P when lime is used for clarification. Other methods of clarification may need lower values.

Potassium application raises millable stalk yield, sugar % of cane and in brix % juice also. K deficiency impairs sucrose transport from the leaf into the stalk (Fig.). There is a positive interaction between N and K - the reduction in sugar content caused by high rates of N is ameliorated by an adequate supply of K. Excessive dosages of K i.e., over and above optimal rates may exert a negative effect on apparent sucrose percent in cane (pol % cane) and may promote an increase in the ash content of juice. Increased ash content in cane juice has a negative influence on sugar quality since K is the main constituent of juice ashes.

When k exceeds 1000 ppm in juice it is undesirable and affects manufacturing process. Potassium passes through the clarification process affecting the exhaustion of the final syrup, keeping a certain amount of sucrose in solution. K is a mellassigenic substance because one mol of K holds one molecule of sucrose. The unfavourable effects of K however, should be anticipated only when excessive rates are used; in low potassium soils improvement in cane quality are to be expected, as shown in Fig.



Effect of K Supply on Sucrose Yield, Sucrose and Fibre Content (Malavolta, 1994)

Considering the above factors a model fertigation programme is given in Table 18 for 12 months crop and Table 19 for 14-16 months crops. This is only a guideline, based on the local soil, variety, climatic and management factors necessary adjustments can be made to the programme.

Table 18. Fertigation Schedule for Seasonal (12 months)/Ratoon Sugarcane

Days After Planting	Nutrients (kg/ha/day)		
	N	P_2O_5	K_2O
1-30 Days	1.20	0.10	0.20
31-80 Days	1.50	0.40	0.24
81-110 Days	2.00	1.00	0.40
111-150 Days	0.75	0.30	0.75
151-190 Days	--		1.50

Table 19. Fertigation Schedule for Preseasonal (14 to 16 months) Sugarcane

Days After Planting	Nutrients (kg/ha/day)		
	N	P_2O_5	K_2O
1-30 Days	1.5	0.15	0.25
31-80 Days	2.0	0.60	0.30
81-110 Days	2.5	1.50	0.50
111-150 Days	0.75	0.50	1.0
151-190 Days	--		1.80

Earthing Up

Earthing-up operation is also known as "hilling-up". This operation is carried out in two or three stages.The first earthing-up operation is known partial earthing-up and the second/third operation is known as "full earthing-up".

The partial earthing-up is done at 45 days after planting. In partial earthing-up, little amount of soil from either side of the furrow is taken and placed around the base of the shoots. While doing partial earthing-up, the furrow in which the cane row is present gets partially filled-up.

Full earthing-up is done after 120 days after planting coinciding with the peak tiller population stage. During full earthing-up the soil from the ridge in between is fully removed and placed near the cane on either side. This operation converts the furrows into ridges and ridges into furrows.This operation could be done either manually or by using a bullock-drawn/tractor drawn furrower depending upon the spacing adopted. *(In the picture: Earthing up or hilling up by machinery)*

Full earthing-up at the end of formative phase (i.e., 120 DAP) checks further tillering, provides sufficient soil volume for root proliferation, promotes better soil aeration and provides a sound anchorage or support to the crop and thus preventing lodging.

One more earthing-up after cane population is stabilized at 180 DAP may be helpful in preventing lodging and water shoots formation. It also improves aeration and helps to control weeds.

Detrashing

Detrashing refers to removal of unwanted bottom dry and green leaves at regular intervals. Sugarcane stalk bears large number of leaves (30-35) equal to the number of inter-nodes under good management systems.

However, all these leaves are not productive, only top eight to ten leaves are required for optimum photosynthesis. In fact the bottom green leaves are parasitic on the upper productive leaves and drain out the food reserves (photosynthates) which other wise could be used for stalk growth. Therefore, in sugarcane it is important to remove the lower dry and green leaves.

In the picture: Detrashing in sugarcane is beneficial in many ways

Detrashing should be taken up after the cane formation around 150 days after planting. There after it could be done at bi-monthly interval depending up on the labour availability.

Detrashing helps in:

Maintaining clean field

- Enhances air movement and enriches Co^{2} with in the crop canopy providing an ideal micro-climate for unrestricted growth of cane
- More food material is made available for stalk growth
- Reduces the problem of infestation of several insect-pests like scales, mealy bug, white flies etc
- Reduces bud sprouting due to accumulation of water inside the sheath in some varieties.
- Bud sprouting is not desirable as it would reduce main stalk growth and affect sugar accumulation
- Facilitates easy entry and movement in the field, particularly to inspect the condition of the crop and drip laterals and thus accordingly plan the fertigation and plant protection schedules
- A clean field minimizes rodents, rats, squirrels in the field which may otherwise cause damage to the crop
- Facilitates easy and economy in harvesting besides clean canes for crushing
- Detrashed trash can be used as a mulch for moisture conservation

- Clean leaves can be used for composting

Propping

The operation of tying the leaves together using the bottom dry and green leaves is known as propping. It is primarily done to check lodging of cane. Usually the trash without removing from the cane is twisted to form a sort of rope and cane stalks are tied together. This is known as trash-twist propping. Propping can be either done for each row or two rows can be brought together and tied.

In India bamboo poles are used and propping is done in certain pockets, but it is too expensive. In areas where cane top growth is heavy and wind velocities are high, propping is very much necessary to prevent lodging. This is because lodging leads to several problems:

- Cane breakage and thus loss of stalk number at harvest and thus loss of cane yield
- Infestation of certain pests and diseases causing microbes through lodged and damaged canes
- Damage by rats and rodents
- Bud sprouting leading to reduced cane quality
- Aerial root formation which also affects cane quality
- Difficulty in inspection of driplines and harvesting

In the Picture: Propping in sugarcane prevents lodging and minimizes pests

Removal of Water Shoots

Water shoots are the late-formed tillers or side shoots, which are robust and fast growing. They originate mainly due to plentiful supply of water, inadequate earthing-up and late fertigation. These water shoots, as the name indicates, contain lot of water and less sucrose and more of reducing sugars.

Water shoots affects the growth of adjacent stalks. They harbour insect-pests and when they are harvested and sent to mill for crushing, lead to reduced juice quality and affect sugar recoveries. Therefore it is advisable to remove water shoots as and when they arise. The water shoots can be used as cattle feed.

Harvesting Management

Harvesting of sugarcane at a proper time i.e., peak maturity, by adopting right technique is necessary to realize maximum weight of the millable canes (thus sugar) produced with least possible field losses under the given growing environment.

On the other hand harvesting either under-aged or over-aged cane with improper method of harvesting leads to loss in cane yield, sugar recovery, poor juice quality and problems in milling due to extraneous matter.

Therefore, proper harvesting should ensure:

- To harvest the cane at peak maturity (i.e., avoiding cutting of either over-matured or under-matured cane)
- Cutting cane to ground level so that the bottom sugar rich internodes are harvested which add to yield and sugar
- De-topping at appropriate height so that the top immature internodes are eliminated
- Proper cleaning of the cane i.e., removing the extraneous matter such as leaves, trash, roots etc.
- Quick disposal of the harvested cane to factory

Several standard analytical methods are available to determine the peak maturity or quality so that the cane is harvested at right time. Without such analysis also several farmers take-up cane harvesting based on crop age and appearance. Sometimes farmers harvest the crop even before the crop fully matures due to necessity to supply cane to the mills early.

Likewise delays in harvesting are also quite common, particularly when there is excess cane area. To avoid such extremes harvesting should be done at right time employing right method. The following criteria enable harvesting of cane at right time adopting proper procedures:

Crop Age

Harvesting is done based on maturity (age) group. Farmers who grow a particular variety are usually conversant with the harvesting time. Even most sugar factories give cutting orders to farmers based on crop age. This is not a scientific method since, planting time, crop management practices, weather conditions etc influences maturity.

Visual Symptoms

Yellowing and drying of leaves, metallic sound of mature canes when tapped, appearance of sugar crystal glistening when a mature cane is cut in a slanting way and held against the sun are some of the visual indices of assessing maturity of cane.

Quality Parameters

Important sugarcane quality parameters for assessing cane maturity are the juice Brix, pol or sucrose percentage and purity.

- **Juice Brix:** Juice Brix refers to the total solids content present in the juice expressed in percentage. Brix includes sugars as well as non-sugars. Brix can be measured in the field itself in the standing cane crop using a Hand Refractometer. This is usually referred as a Hand Refractometer Brix or HR Brix. In the field using a pierce collect composite juice samples from several canes. Then place a drop of the composite juice sample in the Hand Refractometer and measure the Brix reading. The circular field gets darkened relative to the Brix level, which could be easily read. The HR Brix meter has graduations from 0 to 32 per cent. The HR Brix readings can be separately taken from both top and bottom. A narrow range indicates ripeness of the cane, while a wide difference indicates that the cane is yet too ripe. On the other-hand if the bottom portion of the cane has lower Brix value than the top, it means that the cane is over-ripened and reversion of sugar is taking place.
- **Juice Sucrose Or Pol Per Cent:** The juice sucrose per cent is the actual cane sugar present in the juice. It is determined by using a polarimeter, hence sucrose per cent is also referred to as pol per cent. For all practical purposes pol % and sucrose % are synonyms. Now a days an instrument called sucrolyser is also available for determining sucrose % in juice.
- **Purity Coefficient:** It refers to the percentage of sucrose present in the total solids content in the juice. A higher purity indicates the presence of higher sucrose content out of the total solids present in juice. The purity percentage along with sucrose percent aids in determining maturity time.

Purity Percentage = (Sucrose %/HR Brix)100

A cane crop is considered fit for harvesting if it has attained a minimum of 16% sucrose and 85% purity.

- **Reducing Sugars:** The reducing sugars refer to the percentage of other sugars (fructose and glucose) in the juice. A lower reducing sugars value indicates that much of the sugars have been converted into sucrose.
- **Commercial Cane Sugar:** The commercial cane sugar (CCS) refers to the total recoverable sugar percent in the cane. This could be calculated by the following formula:

CCS (tons/ha) = [Yield (tons/ha) x Sugar Recovery (%)] /100

Sugar Recovery (%) = [S - 0.4 (B - S)] x 0.73

Where, S= Sucrose % in juice and B= Corrected Brix (%)

Manual Harvesting

In many countries even today harvesting is done manually using various types of hand knives or hand axes.Among the several tools the cutting blade is usually heavier and facilitates easier and efficient cutting of cane.

Manual harvesting requires skilled labourers as improper harvest of cane leads to loss of cane & sugar yield, poor juice quality and problems in milling due to extraneous matter.

(In the picture: Manual harvesting of sugarcane)

Mechanical Harvesting

Harvesting labour is becoming scarce and costly in view of diversion of labour to other remunerative work in industry, construction, business etc. Mill stoppages because of non-availability of canes are not uncommon owing to shortage of harvesting labour. And, most of the new mills are of higher crushing capacity and many are expanding their crushing capacities. Therefore daily requirement of cane is increasing and hence greater demand for harvesting labour.

Added to this most of the present day agricultural labourers are not interested in field operations involving much drudgery. Thus in years to come, the labour position is likely to deteriorate further. Therefore mechanization is inevitable and hence, adoption of mechanical harvesting of cane in future is inevitable. *(In the picture: Mechanical harvesting of sugarcane)*

In countries like Australia, Brazil, USA, South Africa, Taiwan, Thailand etc where sugarcane cultivation is highly mechanized huge harvesters are employed for cane harvesting. In these countries, sugarcane is grown on large plantation scale in large farms owned by either mills or big farmers. The field capacity of mechanical cane harvesters varies with the size (2.5 to 4 ha per day of 8 hours.

The limitation of mechanical harvesters is use of such machines in small, irregular and fragmented holdings, diversified cropping patterns, limited resource capacity of small & marginal farmers in several countries.

Yield

Sugar yield depends on cane tonnage, sugar content of the cane and on the cane quality. It is important that the cane is harvested at the most suitable time when the economic optimum of recoverable sugar per area is reached.

Cane tonnage at harvest with best management practices under drip ferti-irrigation can vary between 150 and 175 ton/ha in sub-tropical zone and between 150 to 300 tons/ha, which depends particularly on the length of the total growing period and whether it is a plant or a ratoon crop. The water utilization efficiency for harvested cane yield containing about 80 percent moisture is around 15 to 20 kg/m^3

Toward maturity, vegetative growth is reduced and sugar content of the cane increases greatly. Sugar content at harvest is usually between 10 and 12 percent of the cane fresh weight, but under experimental conditions 18 percent or more has been observed. Sugar content seems to decrease slightly with increased cane yields.

Luxurious growth should be avoided during cane ripening, which can be achieved by low temperature, low nitrogen level and restricted water supply. With respect to juice purity, low minimum temperatures positively affect this several weeks before harvest.

Nutrient Deficiency Symptoms

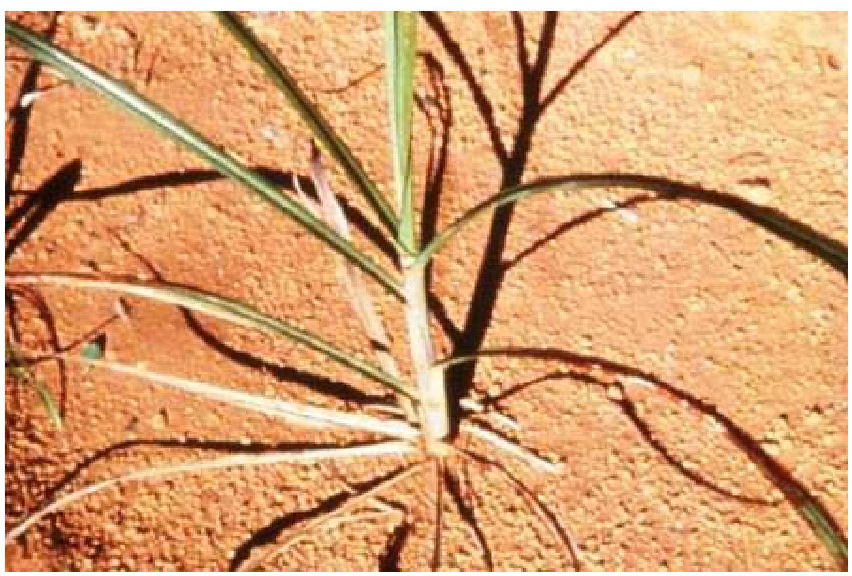
Nitrogen

- Die back of older leaves.
- Leaf baldes turn light green to yellow.

In the picture: Nitrogen deficiency symptom (Source: D.L. Anderson)

- Short and slender stalks
- Tips and margins of older leaves become necrotic.

Phosphorus



In the picture: phosphorus deficiency symptom

- Red and purple discolouration of tips and margins
- Slender leaves
- Short sand slender stalks
- Poor or no tillering

Potassium

- Yellow-orange chlorosis of leaf borders & tips
- Stalks slender
- Older leaves brown or "fired"
- Spindles distorted producing "bunched top" or "fan' appearance.

Calcium

- Mottling and chlorosis of older leaves
- Spindles often become necrotic at the leaf tip and long margins
- Rusty appearance and premature death of older leaves

Magnesium

- Mottled or chlorotic appearance at the tip and margins
- Red necrotic lesions resulting in "rusty" appearance
- Internal browning of rind

In the picture (Source: D.L. Anderson):
Magnesium deficiency symptom

Sulphur

- Chlorotic young leaves
- Narrower and shorter leaves with faint purplish tinge
- Slender stalks

Copper

- Green splotches with leaves eventually showing bleaching
- Stalk and meristems lack turgidity
- Reduced internodal length and tillering.

Iron

- Varying degrees of chlorosis
- Interveinal chlorosis from tip to base of leaves.

In the picture :
Iron deficiency symptom

Manganese

- Occurrence of interveinal chlorosis from leaf tip towards the middle of leaf.
- Bleaching of leaves under severe deficiency.

Boron

- Distorted leaves
- Formation of translucent lesions or water sacks along leaf margins
- Brittle and bunched with many tillers
- Death of apical meristem.

Molybdenum

- Short longitudinal chlorotic streaks on the top one-third of the leaf.
- Short and slender stalks
- Slow vegetative growth.

In the picture: Molybdenum deficiency symptom (source: J.E. Bowen)

Zinc

- Midrib and leaf margin remain green and yellowing of leaf blade
- Red lesions on leaves
- Reduced tillering and shorter internodes
- Thin stalks with loss of turgidity.

Pests and Diseases

Matching with long diversity of conditions under which sugarcane is grown in the world, there is wide spectrum of pests and diseases which have come to acquire a place of priority for control on regional or inter-regional basis due to the agro-climatic management conditions associated with the area.

In addition the susceptibility of the variety to the diseases and pests aggravates the situation and creates additive problems. Below herein is given a brief account of symptoms of important pests and diseases occurring in several parts of the world. For more information and pest and disease control measures consult the local Netafim Agronomist or Plant protection expert.

Early Shoot Borer (Chilo infescatellus)- Symptoms

- Attacks the crop during the early part of cane growth, before internode formation. It also attacks the cane stalks in the years of scanty rainfall
- Larvae enter the cane laterally through one or more holes in the stalks (shoot) and bores downwards as well as upwards killing the growing point. Thus it cuts of the central leaf spindle, which eventually dries forming a â€˜dead heart'. The dead heart can be easily pulled out. It emits an offensive odour.
- Borer infestation during the germination phase kills the mother shoots resulting in the drying up of the entire clump. This leads to gaps in the field.
- Causes heavy yield losses as it affects the plant stand/unit area. It also leads to canes of different age, which will be poor in juice quality, with less cane weight. When borer infects cane stalks, both yield and quality are reduced.

Internode Borer (Chilo Saccharifagus Indicus) - Symptoms

- Damages the crop soon after internode formation and its activity continues till hatvest
- Lodging, high dosage of nitrogen, waterlogged condition and presence of water shoots favour buildup of pest
- Fresh borer attack is mostly found in the top five immature internodes
- Caterpillars bore at the nodal region and enter the stem and tunnel up-wards in a characteristic spiral fashion. Entrance hole is usually plugged with excreta.

- Larvae feed and multiply in water shoots. One larvae found in a single cane damages 1-3 internodes. The length and girth of the infected internodes get reduced.
- Yield loss and juice quality deterioration occurs when the infestation is severe *(In the picture above: Internode borer damage)*

Top Borer (Scirpophaga Excerptalis)

- Waterlogging favours moth attack
- Larva first tunnels into the midrib of the leaves and causes a white streak which later turns reddish brown usually in the second to fifth leaf from the top. As a result of biting across the spindle, a number of shot holes are formed in the leaf. As larva nibbles into the central core of the cane a portion of the internal tissue is eaten resulting in dead heart formation. Dead heart when formed is reddish brown, appears charred, and cannot be easily pulled out. In tillering phase of the crop, the attacked shoots die, side shoots (tillers) develop producing a bunchy top appearance. In the grand growth period, the crop growth is arrested, and the crown with dead heart dries and may be blown off leaving the stump.
- Severe yield loss and quality deterioration occurs due to top borer. Depending upon the incidence level yield loss may be up to 20-30%.

Scale Insect (Melanaspis Glomerata)

- Waterlogging, high temperature and humidity favour buildup of scale insect population. Rainwater and high wind velocity facilitate dispersal of the pest. It spreads to new areas through seed material. Men and animals passing through the infested fields also lead to spread of the pest to the adjoining areas.
- Scales usually establish on internodes covered with leaf sheath. The leaves of infested canes show signs of tip drying and unhealthy pale green colour and with continued infestation turn yellow. Desapping leads to non-opening of leaves also, which also turn yellow and finally dry out. Nodal region is more infested than internodal region.
- Infested crop losses its vigour, canes shrivel, growth is stunted and the internodal length is reduced drastically. Ultimately cane dries up. Such canes when slit open appear brownish red. Thus yield and quality suffer. The yield loss could range from negligible to total crop failure.

Pyrilla (Pyrilla purpusilla Walker)

- Pyrilla is the most destructive foliage-sucking pest of sugarcane
- Heavy rainfall followed by 75-80% humidity, intermittent drought periods, high temperature (26-30°c) and wind movement favour rapid buildup of pyrilla. Other factors favouring pyrilla buildup are dense and luxuriant crop, excess nitrogen

application, water logging, lodging of cane and varieties with broad and succulent leaves.

- Adults and the nymps suck leaf sap from the under surface of the lower leaves. When the infestation is heavy, leaves turn yellowish white and wither away. Due to continuous desapping by large number of hoppers top leaves in the affected canes dry up and lateral buds germinate. The hoppers exude a sweet sticky fluid known as honeydew, which promotes quick and luxuriant growth of the fungus, capanodium species and as a result the leaves are completely covered by the sooty mould. This affects photosynthesis.
- The loss in cane yield due to pyrilla have been estimated to be around 28% with about 1.6% unit loss in sugar.

Termites (Coptotermes Heimi Wasmann; Odontotermes Assmuthi Holmgr; O. Obesus Rambur; O. Wallonensis Wasmann; Microtermes Obesi Holmgr; Trinervitermes Biformis Wasmann)

- Polyphagous and found throughout the world. More serious under prolonged drought conditions and in light textured soils viz., sandy and sandy loam soils
- The termites attack setts, shoots, canes and also stubbles
- The termites gain entry through the cut ends or through buds of the setts and feed on the soft tissue. The tunnel excavated is filled with the soil. This affects germination and thus the initial crop stand and ultimately the cane yield. The germination failure could be up to 60%.
- In the stalks the termites feed on the inner tissues leaving the rind intact. The cavity formed is filled up with moist soil, having galleries, in which, they move about. The affected canes die.

Whitefly (Aleurolobus Barodensis Mask)

- Waterlogging and nitrogen starvation cause severe out break of whiteflies. Summer droughts and dry spells during monsoon season also favour buildup of this pest
- Varieties with broad and long leaves are more susceptible to this pest
- The nymphs of white flies suck the sap from the under surface of leaves which turn yellow and pinkish in severe cases and gradually dry up.
- Heavy infested leaves are

covered by the sooty mould caused by the fungus, which adversely affects photosynthesis. The whitefly infestation retards cane growth and reduces sugar content

- Considerable loss on yield and sugar recovery has been observed. At 80% leaf infestation 23.4% loss in cane yield and 2.9% units loss in sucrose has been reported. *(In the picture above: White fly infestation)*

Red Rot (Colletotrichum Falcatum)

- It is the most dreaded disease of sugarcane which has caused the elimination of several important sugarcane varieties from cultivation
- Yellowing and drying of leaves from margin to midrib, drying of the entire top including the crown, loss of natural colour and considerable shrinkage of the stalk, appearance of reddish lesions on the rind are some of the external symptoms of red rot disease.
- Most characteristic and diagnostic symptom of the disease is the presence of reddish discoloured patches or lesions interspersed with white horizontal patches on the internal tissue. As the diseases progresses the internal tissues become dark in colour and dry resulting in longitudinal pith cavities.

Smut (Ustilago Scitaminea)

- Primary spread of the disease is through infected setts and the secondary spread is through wind borne teliospore
- Stunting of infected stools, profuse sprouting of lateral shoots i.e., tillers, reduction in internodal length, formation of thin stalks and narrow erect leaves are certain symptoms of smut.
- Characteristic symptom is the production of long whip like structure from the terminal bud of the stalk, which is black in colour covered by thin silvery membrane. This silvery membrane ruptures releasing millions of reproductive spores of smut fungus, which are present in the form of powdery mass.
- Losses due to smut in sugarcane depend on various factors viz., primary or secondary infection, plant or ratoon crop that is affected and early or late infection and have been reported to range from 30 - 40% in plant crops and even up to 70% in ratoons. Sucrose content of infected cane is reduced to 3 - 7%.

Pineapple Disease (Ceratocystis Paradoxa)

- Essentially a disease of seed material i.e., setts. Typical disease symptoms are detected in setts after 2 - 3 weeks of planting.
- Pathogen enters the sett mainly through the cut ends and destroy the central soft portion i.e., parachymatous tissues of the internode and then damages the buds.

- Affected tissues first develop a reddish colour, which turns to brownish black in the later stages. Cavities are formed inside the severely affected internodes. The presence of the fungus inside the sett prevents their rooting. In most cases setts decay before bud sprouts or the shoots grown to an height of 6 - 12cm. Thus causing germination failure leading to reduced initial crop stand per unit area.
- Occasionally, the disease occurs in standing crop too due to the entry of the pathogen through stalk damaged by borers, rat damage or any such injuries. Drought accelerates the damage. Pathogen spreads rapidly throughout the canes, foliage turns yellow, and ultimately plant withers. The diseased stalk when cut open smells like mature pineapple. The pineapple odour is due to production of ethyl acetate by the fungus.

Wilt (Cephalosporium Sacchari)

- Disease spreads through infected setts. The fungi gain entry mainly through injuries.
- Biotic stresses like nematode, root borer, termite, scales, mealy bugs etc and abiotic stresses like drought, water logging etc predispose the plants for wilt infection
- Moisture stress coupled with high temperature and low humidity reduces plant resistance to wilt.
- Typical wilt symptoms appear during monsoon and post monsoon periods.
- Affected plant appears wilted and conspicuously stunted. The crown leaves turn yellow, loose turgor and eventually withers.
- Wilt-affected canes loose their normal colour and are light in weight. The most characteristic symptom during the early stage of infection is the presence of diffused reddish brown patches on the internal tissue. Later canes become light and hallow and shrink.
- Disease reduces germination and in severe cases total cane yield losses occur due to drying up of shoots and wilting of the stalks.

Ratoon Stunting Disease

- Ratoon stunting disease has been considered as the most important cause for sugarcane varietal degeneration
- Primary spread of the disease is through infected setts.
- Also spreads through harvesting implements contaminated with the juice of diseased canes.
- Expression of disease is more under adverse conditions.

- Progressive yield decline takes place due to the disease. Ratoon crop suffers more damage due to RSD than the plant crop.
- Disease is known to reduce germination and yield
- Most characteristic symptom of the infected stalks is the presence of pin head like orange coloured dots of bacteria on the internal soft tissue in the nodal region.
- Other symptoms include stunted growth, thin stalks with short internodes, pale yellowish foliage and rapid tapering of the stem towards the top

(In the picture above: Ratoon stunting disease symptom)

Grassy Shoot Disease (Phytoplasma)

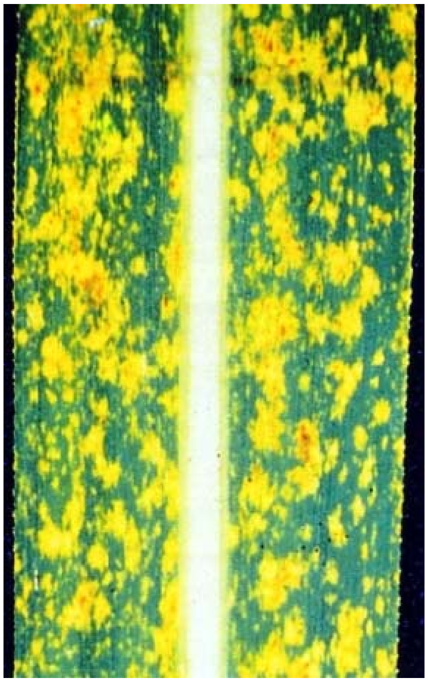
- It is a mycoplasamal disease.
- Primary transmission of disease is through disease infected setts
- Profuse tillering with narrow chlorotic leaves giving a grass like appearance is characteristic symptom of GSD incidence
- Very few tillers of GSD infected plants develop into canes, which are thin and produce white shoots from the side buds.

Leaf Scald (Xanthomonas Albileneans)

- It is a bacterial disease, widely spread in many countries.
- Disease is favoured by wet seasons, water stress due to drought, water logging and low temperatures.
- Disease symptoms appear in two phases, the chronic and acute phases.
- In the chronic phase, "white pencil line" extending entire length of lamina reaching the margin of young leaves and stripes diffuse later resulting in leaf etiolation. Drying from tip onwards presents a scalded appearance and hence the name. Different degrees of chlorosis from total albinism to interveinal chlorosis in young leaves during summer, germination of buds in acropetal manner with bushy appearance in standing cane, cut open stalks showing dark red vascular strands, prominent streaks at node invariably in the side shoots, are other prominent symptoms of chronic phase.

- In the acute phase the symptoms appear suddenly and die without any major leaf symptoms. The masking of symptoms is more common during monsoon and symptoms may appear suddenly any time during crop growth.

Yellow Leaf Spoot (Cercospora Koepkei)



- Prolonged rain with intermittent sunshine, waterlogged conditions and higher nitrogen doses are congenial for disease development.
- Warm humid weather favours rapid and abundant production of conidia by the pathogen and soapread of the disease.
- Characteristic symptoms are presence of small, yellow coloured, irregularly shaped spots over the leaf surface. Density of spots is minimum in the lower surface, moderate in the middle and maximum towards the tip of the leaf. Spots coalesce at late stages and cause drying of leaves. Badly affected foliage looks reddish-brown when viewed from a distance.

In the picture: Yellow leaf spot showing small yellow coloured spots

Eye spot (Helminthosporium sacchari)

- Usually a crop of 6 - 7 months is more susceptible to the disease.
- Fungus penetrates the host tissue either through stomota, bulliform cells or directly through the cuticle.
- Cloudy weather, high humidity with drizzle coupled with low night temperatures, wetting of leaves either through precipitation or dew greatly enhance disease development.
- Likewise water logging, high fertility status and excess nitrogen fertilization also favour the spread of the disease.
- Lesions first appear as small water soaked spots, darker than the surrounding tissues. The spot becomes more elongated, resembling the shape of an â€˜eye' and turns straw coloured within a few days. Finally the central portion becomes reddish brown surrounded by straw coloured tissues. Then reddish brown streaks of â€˜runners' develop extending from the lesions towards the leaf tip along the veins. Later the spots and streaks coalesce to form large patches and causes drying of leaves.

- The End -