

CHAPTER II

REVIEW OF LITERATURE

1. Introduction

Sugarcane (*Saccharum officinarum*) belongs to the grass family Gramineae. It originated in New Guinea island in the Pacific. Genus *Saccharum* can be separated to six species (Daniels and Roach, 1987; Thuljaram Rao, 1889 refer to Sooksathan, 1999). These included 1) Noble cane (*Saccharum officinarum*) which originated in New Guinea islands, 2) Chinese cane (*S. sinense Roxb.*), 3) Indian cane (*S. barberi*) Jesweit, the place of origin being North India, 4) Wild cane of tropical (*S. spontaneum*) being the wild cane which grows in tropical area, 5) Wild cane of New Guinea (*S. robustum* Brands, Jesweit Ex Grassl.), 6) *S. edule* Hassk.

Sugarcane is a tall, robust, clump-forming grass. Clumps, usually called stalks or stems, shed their lower leaves. Aerial stalks are unbranched, stout to slender, differentiated into nodes and internodes with prominent, annular leaf scars; adventitious root primordia in a several-tiered band at each node; an intercalary meristem or growth ring above each root band; and an ovoid or deltoid axillary bud prominent in the root band. The lateral buds are inserted alternately along the stalk in the axil of leaves. Leaves are differentiated into long (1 to 2 m) blades and shorter (0.5 m), clum-clasping sheaths.

Each node is capable of giving rise to a new plant and is used for crop propagation. The shoot roots arise from underground nodes, and the axillary buds located at these nodes give rise to tillers. Depending on the clone and growing conditions, more than 100 stalks can be produced from one bud, but only 5 to 10 survive the competition in densely planted field conditions.

Sugarcane can be propagated through sexual seed. The sugarcane inflorescence is a large, open panicle with several orders of branching upon which are pairs of spikelets composed of short segments easily separated by brittle joints. Each spikelet of a pair is oblong and contains a single complete flower with long tufts of hair at its base, imparting a general silky appearance to the entire panicle.

Following fertilization and development of the mature seed, the panicle disarticulates to scatter the hair-covered caryopses called “fuzz”.

Sugarcane root is fibrous root system which distributes around stool 50 – 100 centimeters (cm) and depth 100 – 150 cm. There are two kinds of roots: firstly the set roots and secondly the shoot roots. The set roots, originating from the root ring of cutting, are thin and much branched. The shoot roots, which spring up from the lower root rings of shoots, are thick and fleshy, white and less branched.

2. Factors Affecting the Growth of Sugarcane

2.1 Climate

Sugarcane can grow from sea level to 1,300 m above sea level. The optimum climate of sugarcane requires a growing period of warm and humid with sunlight, but with dry and cool period at ripening. The temperature range suitable for sugarcane growing is 20 – 38°C and 10 – 20°C for ripening (Humbert, 1968; Blackburn, 1984).

2.2 Soil

The suitable area for growing cane should be a piece of leveled land with slope less than 3% (Field Crops Research Institute, 1983). The soil should be at least 50 - 80 cm deep because sugarcane is a long cycle crop with deep root system (Sooksathan, 1980, Sooksathan and Poolkate, 1984). Soil should be loose, well-aerated and well drained. Bulk density should be about 1.3 g/cm³ with soil texture of either loam, silt loam or clay loam. Chemical characteristics of suitable soil are pH of 6.5, cation exchange capacity of more than 15 me per 100 grams soil, and organic matter of 2.4 per cent (Blackburn, 1984). The salinity level should be below 4 ms per cm at 25°C (Field Crops Research Institute, 1983). Available P and exchangeable K should be more than 16 ppm and 70 ppm, respectively (Chaiwannakupt, 1998).

2.3 Rainfall and Irrigation

High requirement of water is a major factor for sugarcane growth. An average rainfall of 1,500 mm per annum is required for sugarcane (Sooksathan, 1999). Not only water availability but also the distribution of rainfall is very important,

especially during growing period. Whenever the distribution or rainfall is poor, irrigation should be supplied to cane (Sooksathan *et al.*, 1986).

2.4 Cultivation

Row spacing for cane is optimum at 80 – 150 cm. Cultural practices after planting include irrigation, fertilizer application, weed control either by mechanical or manual or chemical, plant protection and harvest (Suphanburi Field Crops Research Center, 1987). These practices are very important to sugarcane in obtaining high yield and sugar quality.

2.5 Nutrient Requirement

Sugarcane requires a large amount of nutrients from soil, depending on cultivars (Field Crop Division, 1977). To obtain one tonne cane, sugarcane nutrient requirement, calculated from nutrient content in all above-ground parts of cane, is 1.15, 1.00 and 2.50 kg of N, P₂O₅ and K₂O, respectively (Baikow, 1982). Zende (1990 quoted by Hunsigi, 1993) reported that nutrient uptake per tonne cane is 0.56 – 1.20 kg of N, 0.38 – 0.82 kg of P₂O₅, 1.00 – 2.50 kg of K₂O, 0.25 – 0.60 kg of Ca, 0.20 – 0.32 kg of Mg and 2.00 – 2.70 kg of SO₄. Nutrient required per rai is 19 – 24 kg of N, 8 – 10 kg of P₂O₅, 24 - 52 kg of K₂O, 8 kg of CaO, 6 kg of MgO and 5 kg of S (Fauconnier, 1993). There are reports on micro-nutrient deficiency in some area which can be recovered by applying the deficient nutrient.

3. Soil Characteristics of Northeast of Thailand

Generally, the soils in northeast Thailand are sandy to loamy in texture to at least 1 – 3 meter depth. In some areas there may be a lateritic layer on the top 0.50 m layer of the soil. Soil color ranges from reddish yellow to reddish brown and gray (Na Nakorn, 1987). The 80% of soil in this region is mainly structured with sand whereas another 13% is composed of shallow laterite (Mitsuchi *et al.*, 1986). Soil is easily eroded, infertile, and low in water holding capacity, so plants are water deficient during dry spell. Soil reaction tends to be acid to highly acid with pH of 4 – 6. Organic matter ranges from 0.3 to 1.0 per cent, which is considerably low. Organic matter content is related to amount of many nutrients available in soil.

Cation exchange capacity (CEC) ranges from 2.4 – 10.0 me per 100 grams soil (Impitak and Vityakon, 1989), so most soils have no potential to store cation, thereby losing nutrients. Total phosphorus ranged from low to medium level, 30 – 500 ppm, which is under requirement of sugarcane. Moreover acid soil reaction affects availability of nutrients, especially changing phosphorus to unavailable forms. There is very low total potassium, 300 – 900 ppm (Cholitkul *et al.*, 1987). Due to extensive parent-material decomposition and soil erosion, the soil contains a large amount of iron and manganese, which are highly resistant to erosion. It is found that there are 35 and 26 ppm of exchangeable iron and manganese, respectively, whereas other nutrients are deficient for plant requirement (Viboonsuk *et al.*, 1988).

4. Phosphorus as Plant Nutrition

There are three forms of phosphorus in soil, namely monovalent anion (H_2PO_4^-), divalent anion (HPO_4^{2-}) and trivalent anions (PO_4^{3-}). Formation of phosphorus depends on soil pH. If pH is less than 6.8, phosphorus will mostly be in a form of H_2PO_4^- . If pH ranged from 6.8 to 7.2, it will be in HPO_4^{2-} form and in soil with pH more than 7.2, it will mostly be in PO_4^{3-} form which plants can not use at all. Plants can uptake phosphorus best in the form of H_2PO_4^- and quite good in the form of HPO_4^{2-} . Under strongly acidic condition, the soil usually is deficient in phosphorus because phosphorus normally forms undissolved complex compounds with ions of aluminum and iron in soil. But in alkali soil, it is fixed in forms of calcium phosphate and magnesium phosphate. Therefore there is very little soil phosphorus which plants can uptake.

4.1 Roles of Phosphorus

Osothspar and Jintaganon (1978) explained the roles of phosphorus as followings. Phosphorus is an important composition of various organic compounds in plants, for examples:

- a) nucleic acid concerning cell division and genetic character transfer through chromosomes.
- b) Phospholipids which is widely accepted that one type of compound, lecithin, being a composition of cell membrane.

- c) NADP^+ and NADPH being related to movement of H^+ in pentosephosphate pathway and in light reaction of photosynthesis.
- d) ATP, ADP (high – energy compounds) being important in sucrose and protein synthesis.
- e) Phytic acid (the hexaphosphate ester of *myo* – inositol) a form of phosphate stored in seeds.
- f) Pyridoxal phosphate a coenzyme in many biochemical and reactions.

Phosphorus plays an important role in photosynthesis by storing light energy in the forms of ATP and NADPH in photochemical reaction. Phosphate in plant cell can be separated into two groups. The first group (12%) is in cytoplasm and is used for metabolism and the other group (88%) is in vacuole and called “nonmetabolic pools”. Due to slow translocation rate of phosphate from vacuole, phosphorus deficiency may limit plant growth (Osothspar and Jintaganon, 1978).

4.2 Phosphate and Phosphatases in Plants

Plants, green algae or diatoms, all show identical symptom when they suffer from phosphorus deficiency. Phosphorus deficient plant accumulates more carbohydrate in leaves. Leaves then become dark green while growth of stem and leaves are slow and finally stop. Physiologically, phosphorus deficiency can easily be distinguished from other nutrient deficiency, i.e. plant can respond to phosphate application immediately.

When a plant is deficient in phosphorus, it will produce enzyme called “phosphatase” because there is a controlling process called “de-repression”, i.e. inorganic phosphate compound will inhibit the production of the enzyme but when all the phosphate is exhausted, the inhibition is terminated and plant can produce the enzyme once again. Phosphatase can react with many substrates, e.g. hexose diphosphate, glucose - 6 - phosphate, inositol hexaphosphate, insoluble phosphates of calcium, iron and aluminum in soil. The function of the enzyme is to release inorganic phosphate. Therefore phosphorus deficient plants produce this enzyme to cleave phosphate esters and release phosphates temporarily. Phosphatase is also known as a Zn-metallo enzyme (Osothspar and Jintaganon, 1978).

4.3 Phosphorus Requirement of Sugarcane

Sugarcane requires about 1 kg of P_2O_5 to produce one tonne of cane (Baikow, 1982) which is comparable to the work of Fauconnier (1993) who reported about 0.83 – 1.20 kg of P_2O_5 per tonne cane calculating from phosphorus in various parts of sugarcane. Amount of phosphorus application recommended is about 8.0 – 9.6 kg of P_2O_5 per rai or up to 40 kg of P_2O_5 per rai depending on amount of phosphorus and phosphorus fixation in soil (Blackburn, 1984).

Measurement of phosphorus requirement using index tissue indicates the status whether there is a shortage, a balance or an excess of phosphorus. Anderson and Bowen (1990) collected data on phosphorus concentrations in sugarcane tissues from different countries. For example, in South Africa the third leaf of 3 – 9 month old cane was used for phosphorus analysis, optimum phosphorus concentration in the tissue was 0.19 – 0.32% and critical level of phosphorus in the tissue is 0.19%. In Brazil, the third leaf of 4 – 9 month old cane was used for phosphorus analysis, optimum phosphorus was 0.2 – 0.35% while critical concentration value was 0.15% and if any concentration was less than the critical value, application of 4.8 – 36 kg of P per rai was recommended. In Puerto Rico, the first leaf of three-month old cane was used, optimum phosphorus level was 0.18 – 0.25% whereas a critical value was 0.10%, lower phosphorus level would require 10 – 24 kg of P per rai. The result from soil phosphorus analysis is useful for calculating phosphorus fertilizer requirement. It was found that if available phosphorus in soil extract, using Bray II method, was less than 16 ppm, phosphorus would be a limiting factor of sugarcane yield and the rate of phosphorus recommended was 5 kg of P_2O_5 per rai or more (Chaiwannakupt, 1998).

4.4 Effect of Phosphorus on Sugarcane Growth, Yield and Quality

Phosphorus in sugarcane is concentrated in tissue where there is a lot of activities i.e. in meristematic tissues and elongating cane, as these parts obtain phosphorus from mature parts all the time. When there is limitation of phosphorus, it will be translocated from mature to young parts with most activity so phosphorus in mature parts is reduced drastically (Sooksathan, 1976). Phosphorus is vital during early stage of growth, especially for shoots and roots. Phosphorus plays an important

role in development of primary shoots, tillering and elongation (King *et al.*, 1965). Phosphorus deficient cane will reduce size and length of stem, being stunted, short with small internode, lack of tillering, poor root development, small, narrow, thin and short leaves, older leaves are blue green or purple in color (Humbert, 1968; King *et al.*, 1965; Blackburn, 1984). Phosphorus deficiency results in poor root development and tillering, then followed by low yield and sugar content (Sooksathan, 1976). Matin *et al.*, (1997a) found positive relationship between phosphorus in soil with dry weight and leaf area index. Matin *et al.* (1997b) reported that residual phosphorus after harvesting affected ratoon growth. More residual phosphorus led to higher leaf area index and dry weight, having faster growth, producing higher number of millable stalks, and thus resulting in higher cane and sugar yields.

4.5 Effect of Phosphorus on Germination

Germination of sugarcane bud commences only when phosphorus in the form of phytates is released as inorganic phosphate (Perumal, 1995a). About 85% of phosphorus in seedcane is translocated to the new plant and distributed to all tissues (Burr and Hault, 1952 quoted by Humbert, 1968). During germination process, sugarcane bud absorbs a large amount of phosphorus in a short time. The phosphorus may come from the internode. After germination, it is found that phosphorus in seedcane increases by more than 50% of the initial stage. This indicates that sugarcane root absorbs more phosphorus from external sources (Clements, 1980). Phosphorus application can enhance germination of sugarcane. Applying 17 and 57 kg of phosphorus per hectare, percent germination increased from 30.2 (without phosphorus application) to 35.6 and 39.2, respectively (Rahman *et al.*, 1992). Moreover Croft and Hogarth (1998) reported that applying 20 and 40 kg of P per hectare in seedcane plot for 8 weeks before cutting, would speed up the germination process significantly. Consequently, enough phosphorus should be applied in nursery plot to increase phosphorus in the setts. If seedcane is suspected to contain low phosphorus, phosphorus fertilizer should be applied at planting to increase germination rate (Perumal, 1995a).

4.6 Phosphorus and Root Growth

Root growth is highly related to available phosphorus in soil. When there is more available phosphorus in soil, faster development and increased dry weight of root was observed (Matin *et al.*, 1997a). Lack of phosphorus in soil is limiting root growth because roots cannot grow deep in the soil profile. However after applying rock phosphate of 1,500 – 2,000 pounds per acre, roots can penetrate to lower depth (Humbert, 1956 quoted by Humbert, 1968). More residual phosphorus gave higher fresh weight of roots in comparison to lower residual phosphorus. (Matin *et al.*, 1997b).

4.7 Effect of Phosphorus on Tillering and Number of Millable Stalks

Lack of phosphorus in soil limits tillering, young tillers will be dead before emerging above the ground (King *et al.*, 1965). Fewer primary stalks mean no more second set of tillers and therefore stool development is poor (Humbert, 1968). Increase of phosphorus fertilizer rate affects tillering by increasing number of stalks, and hence more millable cane. Phosphorus fertilizer application of 17 and 57 kg of phosphorus per hectare increased number of tillers from 92,820 to 113,800 and 124,700 tillers per hectare and a number of stalks increased from 78,240 to 86,020 and 92,340 per hectare, respectively (Rahman *et al.*, 1992). Rattanarak *et al.*, (1990) reported that application of phosphorus increases the number of stalks. Applying 12 kg of P_2O_5 per rai increased the number of stalks per rai to 7,877 whereas applying only 3 kg of P_2O_5 did not show any effect compared to control (4,923).

4.8 Effect of Phosphorus to Stalk Height and Diameter

Phosphorus is highly concentrated in elongating part of cane and is necessary for cell division. Phosphorus deficiency results in reduced stalk diameter and height, thus low yield and sugar content (Humbert, 1968).

Application of 12 kg of P_2O_5 per rai increased plant height over the control by 74.5 cm and by 62 cm when as little as 3 kg of P_2O_5 was applied (Rattanarak *et al.*, 1990).

Tiwari *et al.* (1997) found an increase in plant height and stalk diameter with increasing rate of phosphorus application. Stalk height of 224, 237, 263 and 279

cm and stalk diameter of 2.81, 2.94, 3.37 and 3.47 cm was obtained when phosphorus fertilizer was applied at 0, 17.5, 26.25 and 50.4 kg P per hectare, respectively.

4.9 Effect of Phosphorus on Yield and Sugar

Phosphorus is vital to sugarcane growth, e.g. stalk diameter, stalk length and affects components of yield, viz. stools per rai, stalks per stool, and etc. These components are related to sugarcane yield (Serywichayasawas *et al.*, 1997). When there is not enough phosphorus, sugarcane growth slows down and yield components are affected so cane and sugar yields are reduced (Sooksathan, 1976). Prasad (1976) reported that cane positively responded to phosphorus fertilizer. Phosphorus application increased cane yield significantly in both plant and ratoon cane, even though plant cane responded more than ratoon cane. Yields were 4.91 and 7.02 tonnes per rai when 3 and 12 kg of P_2O_5 per rai were applied, respectively, whereas zero application resulted in 2.23 tonne cane per rai (Rattanak et al., 1990). Jong-rouy-sab *et al.* (1998) reported that cane responded to phosphorus. Zero application produced the yield of 19.7 tonne cane per rai, while application of 6, 12, 18 and 24 kg of P_2O_5 per rai yielded 19.6, 20.4, 23.8 and 24.5 tonne per rai respectively. By spraying foliar phosphorus fertilizer using single super phosphate (16% P_2O_5), 20 kg per 300 litre of water, on 4.5 month old cane, Perumal (1995b) found that medium maturity cane cultivar responded to the sprayed phosphorus by giving higher yield, i.e. 84.5 tonnes per hectare. Zero application gave 63.5 tonnes per hectare. Co 6304, a late maturity cane cultivar gave a higher yield of 119.13 tonnes per hectare from phosphorus spray and 113.63 tonnes per hectare from zero application. However there was no significant difference in this case. Anderson *et al.* (1996) observed that cane and sugar yields responded positively to phosphorus application. The response was higher in ratoon cane than plant cane. It was also emphasized that phosphorus application was vital to maintain phosphorus level in soil and to maintain cane yield. Higher application of phosphorus increased cane and sugar yields significantly i.e. applications of 0, 17 and 57 kg of P per hectare led to 73.52, 93.6 and 99.21 tonnes cane per hectare and 6.1, 7.9 and 8.63 tonnes sugar per hectare, respectively (Rahman *et al.*, 1992).

4.10 Effect of Phosphorus on Cane Quality

Sooksathan (1976) defined cane quality as to produce high sugar content in cane and physical condition of the cane which are indicators of cane value. In general, it is sugar or sucrose content in cane juice which can be analysed by various methods. Method widely used is Commercial Cane Sugar (CCS), a content of sucrose or cane sugar in a given amount of cane and could be extracted to pure white sugar. Cane juice comprises of sugar or sucrose and other compounds or impurity. Soluble compound is called brix of cane juice. Cane juice with higher purity will have sugar content closer to brix. Purity means percent soluble substances which is pure sugar. Sugar recovery is defined as actual sugar separated from impurity.

Generally, cane quality is defined as values of CCS, purity, brix, sugar recovery and phosphate in cane juice which is important to first stage of clarification. Cane juice with phosphate ranging from 300 – 600 ppm is considered as standard in which non-sugar can be easily settled after applying lime and heat. With the optimum phosphate, the cane juice will be purer (Honig 1959 quoted by Sooksathan, 1976). Phosphate in cane juice at clarification should not be less than 300 ppm, otherwise phosphoric acid should be added before treating with lime and heat (Baikow, 1982).

Phosphorus fertilizer has varying effect on cane quality. Prajoubmao *et al.* (1990) reported no significant differences in CCS of cane applied with phosphorus of 12 kg of phosphate per rai compared to control, however CCS with phosphorus application tends to be higher. Jong-rouy-sab *et al.* (1998) reported that phosphate fertilizer has no significant effect on CCS and brix. Tiwari *et al.* (1997) reported that higher rates of phosphorus application significantly reduced cane quality, brix and sugar recovery. Application of 0, 17.5, 26.25 and 50.4 kg of P per hectare, resulted in brix values of 20.74, 20.69, 20.64 and 20.59, respectively and sugar recovery of 12.6, 12.5, 12.5 and 12.4%, respectively, with no significant differences. This is in contrast with Rahman *et al.* (1992) who reported that cane quality responded to phosphorus fertilizer as the application of 17 and 57 kg of P per hectare, resulted in higher sugar recovery than control by 8.44 and 8.70%, respectively. From his study of three sugarcane cultivars planted in three locations, Perumal (1995b) sprayed sugarcane leaves with phosphorus fertilizer and found that CCS and P₂O₅ in cane juice increased significantly from 292 ppm to 392 ppm. Foliar phosphorus application increased

phosphorus content in leaf and leaf sheath which was directly related to phosphorus in cane juice. If there is high level of available phosphorus in soil, phosphorus in juice increases (Sundara, 1996).

4.11 Effect of Phosphorus on Other Nutrients in Cane

Phosphorus fertilizer has an effect on uptake and concentration of other nutrients in sugarcane (Sooksathan, 1976). Perumal (1995b) found that there was a relationship between amount of foliar applied phosphorus and concentrations of nitrogen, phosphorus and potassium in sugarcane tissue. Foliar fertilization increased concentration of phosphorus in sugarcane tissue at maturity but reduced concentration of nitrogen and potassium. After phosphorus spray, nitrogen and potassium in the third to sixth leaf and sheaths started to decline when the cane was 8 months old and then reduced dramatically at the age of 10 to 12 month. There were no changes in nitrogen and potassium contents in the non phosphorus spray treatment. Elwari and Gascho (1983) reported the effect of phosphorus on nitrogen, phosphorus, potassium, calcium, magnesium, iron and copper in the top most visible dewlap leaf. Increasing rate of phosphorus fertilizer resulted in increased concentration of phosphorus during the grand growth period and at the end of grand growth period. In the grand growth period, nitrogen and copper contents were significantly reduced, when high rates of phosphorus were applied, while potassium, calcium, magnesium and iron contents remained unchanged. At the end of grand growth period, magnesium content increased significantly but that of copper reduced significantly whereas other nutrients remained unchanged. However, Jong-rouy-sab *et al.* (1998) reported that phosphate fertilizer had no effect on concentration of nitrogen, phosphorus and potassium. The results could be due to samples being taken from older plant parts or matured leaves (10th leaf) and thus concentration of nitrogen was 0.6 – 0.8%, phosphorus 0.2% and potassium 1.3 – 1.5%.

From the review of literature, phosphorus is vital for sugarcane growth. Phosphorus deficiency leads to reduction in metabolic rate, photosynthesis, growth rate and quality of sugarcane. Consequently, management of phosphorus fertilizer is one of the means to improve sugarcane production, especially in such soil condition in northeast of Thailand which is low in available phosphorus. Therefore the study of

effect of phosphorus fertilizer on sugarcane growth was undertaken to find out the optimum level of phosphorus application in sugarcane cropping.