CHAPTER 2

LITERATURE REVIEW

2.1. Sugarcane Root System, Formation and Pattern

The root system of sugarcane is similar to the fibrous root systems of other grasses. When sugarcane is propagated by sett, in technical point of view, there is no primary root at all. Setts roots are adventitious roots. The primordia of the sett roots are to be found in the root band located just above each node in other word, at the every bottom of the inter-node and below the growth ring. When a sett is put into germinate, the sett root begin growth at the same time that the buds begins growth. Depending on the growing conditions (Blackburn, 1984; Clements, 1980), all the primordia or very few of them, or none of them may produce roots.

Sugarcane has two types of roots; sett-roots which are thin and brunched, and shoot roots which are thick, fleshy and much less brunched (Blackburn, 1984). The shoot roots are again classified as fibrous surface feeding roots, buttress roots (thick white) and dark brown or black rope roots (Yadava, 1991; Evans, 1964 cited in Blackburn, 1984). In general, sett roots and shoot roots are superficial in initial stage. Later, sett roots become freely brunch and act as superficial absorbing roots, and finally the buttress and rope root systems are formed (Hunsigi, 1993). Clements (1980) has described the initial root development and formation with variety H 51-4336, very young shoot produced its own root system soon after sett-roots appearance. Yadava (1991) reviewed on sugarcane root system; sett roots die off under favorable conditions after emergence of shoot about three to four weeks. On the other hand, shoot root initiates about 9-10 weeks, so do sett roots remain functions until that period (Shrivastava and Ghosh, 1970). The roots proliferate wherever conditions of available water and aeration are favorable, however, the precise pattern of root development is particular to local soil conditions.

Sugarcane has remarkable root systems, their roots well distributed beyond 1.9 meter, and as far down as 6.1 meter in some species (Clements, 1980), usually, the growth rate decline with the age of the root system. The pattern of root development is particular to local soil conditions. In practice, it is difficult to distinguish between superficial and buttress roots, and the rope roots systems are remarkably rare. Srivatava and Ghosh (1970) reported that most of the root mass was confined to 0-15 cm among different layers of soil during eight months of plant growth. Yet, Sundara (1998) recorded that the 75% of roots distributed in the 45 cm depth of soil layer. In addition, roughly 50% of roots occur in the top 20 cm of soil layer, and the 85% had occupied in the top 60 cm (Blackburn, 1984). Normally, about 50-60% of root occurs within 25-30 cm and 85% within 60 cm depth of the soil (Yadava, 1991). The above studies indicated that most of the root was distributed within top soil layers.

The depth and spread of roots in soil are matters of much important to grower not only for irrigation and fertilizer placement but also for an understanding of the plant's reactions to climatic circumstances and its environment. And, therefore, to obtain the high sugarcane yield, it is essential to induce extensive root system a key to high sugarcane yield.

2.2. Functions of Sugarcane Roots

Functions of sugarcane root system like as many of higher plants. Generally, the major functions of roots are; anchoring at soils and supporting for standing, absorption of water and nutrients for plant growth and development involving in physiological processes of the plant through out the growing seasons.

During root growth and development, the sett roots appears at first, and then, they may becomes very long and much brunched. They may persist very long time. their well-being does not appear to be crucial to the welfare of the shoot that arise from the adjustment, since the shoot develops its own root system (Clements, 1980). On the contrary, Blackburn, (1984) stated that the sett -roots die after the formation of shoots roots and each shoot produces its own shoot roots. Yadava, (1991) explained the function of sett roots in the initial stage as follow. The germination bud and initial plant vigor depend on sett roots for nutrients and water and remains functional for about 9-10 weeks, and die off gradually after developed shoot roots. Blackburn (1984) identified the function of different root systems of sugarcane. He explained that the superficial roots absorb moisture and nutrients, the buttress roots as their name implies, provide stability; the rope roots penetrate to the depth of 3-6 m, where the soil remains moist even in time of severe drought. Moreover, the fibrous and buttress roots are real feeding roots go deeper and, hence help in evading drought. Sugarcane roots are remarkable since it renewed periodically by which vigorous sustained shoot growth.

Absorption of water containing nutrients by root is very similar to the water movement from lower concentration to higher concentration and from colder to warmer condition due to the molecular activity (Clements, 1980). In a water-culture solution containing nutrient salts, the epidermic cells of the root contain a higher osmotic pressure than does the culture solution. Thus, more water pushes into the epidemis than move out, and turgor pressure develops in the cell. Sometimes, if the osmotic pressure of culture solution is higher than that in the cell, exosmosis occurs, and the cell will wilt. The water can be absorbed anywhere along the root but most seem to enter in the root hairs region. Even blackened roots with living interiors undoubly carry on absorption (Clements, 1980). Among the nutrients, as for nitrogen, the nitrate and ammonical forms of nitrogen were absorbed by roots and transported to above ground plant's parts, both of these forms are equally effects in encouraging growth and yield of sugarcane (Hosz, 1972).

The higher plants' roots serves for several physiological processes in terms of uptake of nutrients and water, assimilation, storage, translocation, reduction, incorporation of N into organic forms and remobilization of assimilates. These processes are interrelated each other with complicated ways, and affected by both internal and external factors so it too difficult to fully understand (Haynes, 1986a). Sugarcane can assimilate nitrate and ammonium by both mass flow and diffusion through root hairs. Most of the ammonium has to be incorporated into organic compounds in the roots whereas nitrate is mobile in the xylem (Marschner, 1986).

2.3. Factors affecting on Sugarcane root growth and development

In some literature studied on sugarcane root system have reviewed on the root initiation and development. The root system is influenced by many internal and external factors such as variety, soil type, aeration and oxygen supply, soil temperature, bulk density, soil depth, available soil volume nutrient and water availability in rhizosphere, high alkali and acidity. Moreover, such practices like high dosage of nitrogen and phosphorous fertilizations during early growth phase, tillage, planting practices, etc., are affecting on root growth and development (Shrivastava and Ghosh, 1970; Evans, 1964; Blackburn, 1984;Yadava, 1991; Sundara, 1998)

Clements (1980) has described that numbers of sett-roots produced from primodia is depended on growing conditions. A factor contributing to earliness of shoot-root appearance has to do with the nature of the shoot growth that depends on position of bud at growing time and governing factor of auxin movement in down ward direction. In the point of view of planting practice in plant depth, the more such bands underground, the greater is the root development. Moreover, in a germination study on the different depth of sowing using the one bud sett, result showed that the shoot grew poorly, because root contact with soil was very poor. The growth cycle of the cane root system illustrates heterogenic growth in relation to other parts of the cane plant indicates that the root system closely relates to plant system itself (Evan, 1964).

The external factors include moisture absorption permits the maintenance of happy balance with the energy the plant is receiving. Insufficient soil nutrients interfering the normal integration of the physiological processes operating in it. Insufficient soil oxygen and heat interfering with the respiration of the roots there by interfering their works of growth, water and nutrient absorption. The presence of materials toxic in the soil to the particular plant also effected. Biotic factors such as disease organisms, weeds, rodents, insects and certainly not the least, man; whatever the determination factor may be, the plant react to it (Clements, 1980). Satisfactory preparation of the soils involves the production of the root environment for the cane plant, which will make its development vigorous and easy. Clearly, it is advantageous to plants to have as extensive a root system as possible. If the soil is very compact so that root development is restricted (Clements, 1980). Cane setts germination could be adversely affected by higher dose of basal nitrogen application (Yadav, 1981). It was mainly due to the high concentration of free ammonia produced by hydrolysis of urea in the soil near the germinating buds and roots (Verma *et.al.,* 1985). However, sugarcane root biomass had significantly found at 6th and 18th month in Nitrogen fertilized treatments (Sampiao *et.al.,* 1987). Adequate phosphorous availability encourages early shoot-root development, and also increases the activities of sett roots till shoot root become activity to support the shoot observed during the initial growing first two months (Kakde, 1985).

The initial root growth relates with the soil water status. A study had reported that a greater percentage of roots in deeper soil layer was found in unirrigated plots than irrigated plots and the roots were more spread on the surface soil layer under the drip irrigation (Hunsigi, 1993). Similarly, greater percentages of root in deeper soil layer are found in un-irrigated plots than irrigated plots (Batchelor *et.al.,* 1989). The effects of soil moisture on the overall growth and development will be reviewed in the next topic.

The results of the above studies indicating that the root system is a key for the management of water and nutrient applications in order to get high yield with better efficiency. However, there is no finding the effects of basal nitrogen application under rainfed condition and synergetic effects with irrigation for initial cane plant growth and development and its root system.

2.4. Water regimes in sugarcane

Since the water is universal solvent and essential source for synthesizing of carbohydrate in photosynthesis process, there is no doubt that plant growth and development is governed by water. Plant nutrients uptake is very closely related to water contents in the soil and it movement in soil and plant systems interacting with environment. Water can be absorbed anywhere along the sugarcane' root system, but most seen to enter in the root hairs regions of root system (Clements, 1980).

There are many studies on water management with various approaches and mainly aimed to achieve the optimal water use and maximized cane yield. Moreover, the factor, nutrient management combined as well. Most of studies found that the soil water has been strongly correlated with sugarcane yield components. Kirtikar *et.al.,* (1973) stated that germination is governed by soil moisture and aeration rather than temperature. Yadav and Prasad (1988) found that number of tillers was reduced under water stress condition and leave area, stem elongation and girth, as well (Singh and Reddy, 1980). Water scarcity gives stunted growth as observed in hot desiccating summer (Yadav and Prasad, 1988; Clements, 1964).

2.4.1. Water Requirement of Sugarcane

Sugarcane requires substantial inputs of both water and nitrogen to achieve maximum yield. Sugarcane produces giant amount of biomass, therefore, has high amount of water requirement. Water requirement depends on soil type, climatic condition, i.e., temperature, wind, etc., and, sugarcane variety, age and crop duration. The transpiration coefficient of sugarcane is around 400. This means 400 m^3 water requires to produce one ton of dry matter (Sundara, 1998).

The literature is replete with water requirement studies and values vary from 1000 to 3000 mm depending on the agroecological conditions and crop cycle (Hunsigi, 1993). Water requirement of sugarcane is different due to the distinct growth phases of sugarcane; namely germination, tillering, grand growth and ripening. Approximates water requirement of a 12 months crop sugarcane are 300, 550,1000, 650 mm at above phases in order, respectively (Sundara, 1998). Soil type profoundly influences the water requirement as it determines water holding capacity, infiltration rate and permeability. The approximate available moisture holding capacity of coarse textured soils have 6-10 cm m^{-1}, moderate textured soils have 12-19, and fine textured soils have 13-20 cm m^{-1} respectively (Sundra, 1998). Thus, available water holding capacity increases with the increasing of fine textured soil content (Hunsigi, 1993). The crop coefficient values of water requirement at different crop age are considered together with climate parameters have been suggested for irrigation (FAO, 1977), since the water requirement varies with crop age. In sugarcane cultivation, the interval and amount of water needed to irrigate at once depends on soil texture and depth, crop age, climate, effective root zone and intake rate of crop. (Zende, 1983; Cross, 1984).

2.4.2. Effects of water stress or drought on sugarcane

When availability of water in the soil becomes inadequate, a high water tension or stress is created and water absorption fall behind the water loss through transpiration. Low level of the soil moisture in the root zone with desiccating wind develops such a stress. Atmospheric temperature and soil conditions effects, this stress much more. Yadava (1991) explained the effects of water stress, sugarcane plant growth that reduces growth through reduction in various essential physiological processes. High water stress that may also be called as drought adversely affects on the respiration, photosynthesis, and growth of root. Under stress condition, plant reduces nitrogen uptakes, utilization, and translocation of complete and intermediate products of photosynthesis. However, increase thickness of cell wall formation and increase in sugar of leaves of most plants, which breakdown in RNA and DNA and reduction in translocation and auxin formation in growing points whose growth activities are suppressed. In the aspects of the biochemical effects, abnormal presence of incomplete photosynthates of nitrogenous compounds in which various amino acids predominate with drastic changes due to their continue synthesis and reduce protein synthesis. Since these water deficit affect adversely various metabolic activities, which in turn, over all crop performance as cell division and enlargement are greatly influenced by water stress.

As the moisture stress increases, water availability to plant roots reduces. Therefore, plants have to adjust physiological to this situation and growth rate decrease with decrease absorption of water absorption from soil. In this adjustment, some of vital processes are adversely affected depending on the degree of sensitivity of each process to increasing moisture stress. Under stress conditions, shoot growth is more restricted than root growth. This adjusting phenomenon reflects the fact that pointed by Hunsigi (1993). He figured out that a greater percentage of roots in deeper soil layer are found in non-irrigated plots than irrigated plots and the roots are more spread on the surface soil layer under the drip irrigation.

Although the growth of sugarcane is not much affected by minor stress, its qualities get adversely affected under such situations. The tillering and elongation phases are more sensitive to stress. Varieties having more rapid growth rate, this effects more. However, under moisture stress, sugarcane shows high brix and purity much earlier and maintains it for longer period through yield is lower than the crop receiving no stress. In severe cases, the deficit increases fiber and baggase percentage and also contents of various intermediate products of metabolism through proteins and carbohydrate in the sugarcane juice whose clarification becomes difficult. Fiber percentage may or may not increase depending on the variety. Susceptibility to borer attacks also increases (Yadava, 1991).

In a summery, moisture stress effect on sugarcane in several aspects: shorter inter-nodes, stunted growth, and reduced leaf size, increased shoot-root ratio, reduced photosynthesis and various changes in the nature and courses of biochemical activities. All of these consequent changes leading to reduce fresh cane yield. Yadava and Parasad (1988) reported that un-irrigated sugarcane suffered 48% of yield loss while irrigated was only 23% and ratoon cane suffered 22% by drought and degree of yield loss varying with variety.

2.4.3. Effects of excessive moisture or water lodging on sugarcane

Though sugarcane can tolerate to water lodging and flooding with partial submergence for quite long period, the prolong submergence and swampy conditions of soil have much adverse effects on growth, yield and quality of cane. The swampy and water logging can effect on cane growth and development. It creates poor aeration and oxygen supply, unfavorable soil reactions and biological activities and unfavorable microclimate for root activities and development. Under those condition, it effects on nutrient uptake, reduce transpiration and photosynthesis and growth rate, mainly root hairs diminishes, induce early and uneven maturity that lead to low yield (Yadava, 1991). Especially, in heavy soils, constant wetting of lower soil strata in soil creates bad aeration condition with soil compactness and superficial shallow root system. The problems of bad drainage within root zone stipulate in some changes of soil chemical properties. Such results of the changes like a production of hydrogen sulfide and accumulation of iron sulfide, which can cause depression in juice quality and plant growth, so call as toxicity.

Hunsigi (1993) had taken into account the facts that drawbacks of excessive moisture conditions affected on chemical and physical changes in soil system and sugarcane response to those respective conditions in term of physiologically and morphologically, as follows;

1- Yellowing and curling of young leaves.

2- Reduced gaseous diffusion (influx of air and out flow of CO_2).

3- Lowered soil temperature.

4- Stagnant and a fluctuating water table are harmful.

5- Adventitious roots are formed.

6-Restricted root system, flattened and distorted roots, and strangler roots seen. Hence, plants cannot stand drought condition after excessive water has drained away or after the water table recedes. Incidence of root rot and red rot accentuated.

7-Lower sprouting and poor plant stand.

8-Internal length drastically reduced.

9-Reduced microbial activity and higher nutrient loss, especially of N, but increased content of Fe, Mn and Al.

10-Poor juice quality with a high level of invert sugars, gums and free N.

11-Profuse flowering, pithiness, a high fiber content and cane does not ripen, leading to an eventual reduction in cane and sugar yield.

12-Trafficability is reduced which is of the utmost importance in cane haulage.

Carter *et.al.,* (1985 and 1987); Wang *et.al.,* (1987) found that Sugarcane responds to surface drainage through improved plant stand and increased cane and sugar yields.

2.5. Nitrogen nutrition in sugarcane

Nitrogen is one of essential major plant food element and a major component of many important organic compounds ranging from protein to nucleic acids since the protein synthesis is made by combination of N and carbohydrate. Protein and water, that protoplasm, the living part of cell is formed (Clements, 1980). Thus, Nitrogen is necessary for cell division and thus for the development of essential plant tissues and organs. The presence of nitrogen increases the volume of functional reactive cell plasma and contributes to increase the chlorophyll content, in order to ensure the assimilation potential of the plant (Husz, 1972). Moreover, N involves in many reactions and synthesis for ATP (adenosine triphosphate) which is capable of absorbing high levels of energy and which is active in all synthesis and respiratory area where high energy transformations at ordinary temperature (Clements, 1980). Alexander (1973) reviewed comprehensively on the role of N in sugarcane crop involving as important role in several physiological processes such as photosynthesis, photorespiration, sucrose assimilation, translocation and accumulation of assimilates interacting with external variables.

Commonly, plant uptakes both NH_4^+ and NO_3^- forms of nitrogen. The nitrate and the ammonical forms of nitrogen were equally effects in generating growth and yield of sugarcane (Husz, 1972). Nitrogen is the most important influencing on the initiation, development and maintenance of tillers, which is the most important yield component in sugarcane. Usually, with increase in nitrogen dose, there is an increase in tillering up to a limit beyond which the response is not significant (Yadava, 1991). Yadava (1981) reported that LAI increases with the increasing rate of N up to 150 kg N ha^{-1}. Further increased of N does to 225 kg N ha^{-1}, decreased in LAI. Because, whole N applied at planting hinders germination, there by affecting the plant population adversely. Lower plant population that causes lower LAI. Sugarcane responded to application of N but not to application of phosphorous and potassium (Htun Haling, 1968). Similarly, San Thein (1984) reported that both applied N and K significantly increased fresh cane tonnes ha^{-1} while applied P failed to be significant. However, sugar yield decreased as affected by increased cane yield due to increasing rate of N application. Htun Than and Tin Nyaunt (1984) found that stalk population and weight had increased with increasing rate of application. In addition, the synergetic positive effects with cow dung manure application, but combined application with P and K significant at higher N rate in their factorial experiments. Similarly, cane length increased with increasing N application. Therefore, nitrogen application is mainly contributing for increasing sugarcane yield since nitrogen promotes to vegetative growth via cell activities. However, the results indicated that it should consider for balance application when N application rate is higher at certain level under given circumstances indicating from numerous studies.

Nitrogen deficiency is characterized by the poor growth rate. The plants remain small, the stem has spindly appearance, the leaves are small and pale green, the older ones often fall prematurely. Nitrogen deficiency results in the collapse of chloroplast and also disturbance of chloroplast development (Husz, 1972). Humbert (1968) briefly described about the sugarcane features that suffering from nitrogen deficiency – exhibiting yellow-green color of all leaves and a retardation of growth. Cane stalks are small in diameter and premature drying and dying of old leaves take places and roots attain in greater length but smaller in diameter, but sugar accumulation takes fast.

Nitrogen, a major essential element required by plant in substantial quantities. When supply of water is adequate, N is the most common limiting factor for crop production. Thus, as an average, considerably more N than any other element is supplied to crops as fertilizer. It is removed from agricultural lands in harvested crops (Olson and Kurtz, 1982), especially, the crop likes sugarcane has considerable amount of nutrient removal from soil (IFAS, 1996; Zende, 1990; Barnes, 1974).

2.6. Nitrogen transformation in soil system

In most agricultural soils, approximately 97-99% of total N presents as organic forms of N. They are not readily available for the plants since some of these slowly have become to be available mineral forms of N through microbial decomposition processes (Haynes, 1986b; Goh and Haynes, 1986). Moreover, the crop removal in harvesting is also considerable high. To do so, nitrogen nutrition becomes as the most common limiting factor in the crop production. It leads to additional inorganic N fertilizations to achieve certain productivity (Olson and Kurtz, 1982), and the most demanding management skills (Loomis and Connor, 1992).

Since one of the energy sources for decomposer is organic matter in soil, therefore, its quality and constituents determine the rate or decomposition and mineralization of organic N. Haynes (1986b) discussed in detail that the rate of decompostion process is determined by organic substrate itself. The quality of substrate or organic matter, C:N ratio, lignin and polyphenol (organic compound with polyphenol structure) contents, elemental concentration and concentration of various classes of organic compounds, the proportion of each different organic constituent varies according to plant species, part, and age, are affecting on its decomposition.

The major groups of decomposer are: bacteria, actinomycetes, fungi, protozoa, nematodes, microarthropods, enchytraeid worms, and lumbricid worm in mineralization process. The following particular microbes play important roles: Microflora (e.g., fungi, bacteria), their role is decomposing and releasing NH_4^+ and NO_3^-, fauna (animals especially invertebrates) and their role: redistribution of biomass, accelerate nutrient cycling through chemical reactions of metabolism (Haynes, 1986b).

N decomposition constitutes the means by which N held in plant tissue is released into the soils for the reuse by plants. Organic N in the soil is made available (mineralized) as inorganic forms; NH_4^+ and NO_3^-. Other essential nutrients appear in plant available forms through decomposition by soil microorganism using the carbon and nitrogenous compounds from soil organic matter and atmospheric carbondioxide during the process as well. Mainly, mineralization and ammonification processes, nitrfication process and denitrification process have been involved in the nitrogen transformation process. Nitrogen mineralization is defined as the release of NH_4^+ and NO_3^- from organic forms through microbial process. Then, the NH_4^+ is oxidized and transformed into nitrate through microbial process, called as nitrification (Loomis and Connor, 1992). The certain amount of soil nitrogen is turned into microbial biomass for their building called as immobilization. These two processes: mineralization and immobilization occur simultaneously turnover from one state to another in soil system interacting with its environment (Jansson and Presson, 1982; Haynes, 1986c). Moreover, some of soil nitrogen is returned from soil to atmosphere in gaseous forms through microbial denitrification process and chemical reactions called chemodenitrification (Haynes and Sherlock, 1986).

As the most available N comes out through the decomposition process, it is a very important link in the natural ecosystems and many agricultural ecosystems (Floate, 1981, *cited in* Haynes, 1986b). The decomposition of soil organic matter is also important, in terms of N availability to crop plants in cultivated ecosystems (Agroecsystems). Particularly, the rapid microbial immobilization of added nitrogen fertilizer is followed by a slow net remineralization provide available nitrogen to plant over a period of year (Loomis and Connor, 1992).

2.7. Nitrogen losses in the soils

The soil nitrogen losses occur through crop removal, volatilization, denitrification, leaching, dissolving in surface runoff water and erosion, lost as ammonia from foliage and burning of natural vegetation and crop residues and become as pollutant to environment (Conway, 1997). Experiments involving the use of N labeled fertilizers confirmed that a significant proportion of applied N is lost from the soil during the cropping season (Hauck and Bremner, 1976).

2.7.1. Gaseous losses

A numbers of processes contributing to gaseous loss of soil N include ammonia volatilization, biological nitrification, biological denitrification, and reaction of nitrite with soil solution (Haynes and Sherlock, 1986).

Losses through Ammonia volatilization

Soil nitrogen is lost to the atmosphere as NH_3 gas, which is called as ammonia volatilization. Gaseous N losses like NH_3 and NO_2 volatilization, probably account for a substantial portion of the soil N deficit observed in many experiments (Nelson, 1982). The quantity of ammonia losses, are highly variable depending on such factors as rate, type and method of fertilizer application, soil pH and environmental factors including temperature, moisture, and wind (Black and Sherlock, 1985). In sugarcane field, ammonia volatilization is paramount importance when urea is applied to the surface of cane residue left on the soil surface (Freney *et.al.,* 1992). A necessary prerequisite for ammonia volatilization is a supply of free ammonia near the soil surface. The source of ammonia is usually soil ammonium, supplied from organic nitrogenous sources such as urine or feces of animals, plant residues, or native soil organic matter, all of which decomposed to release ammonium N, moreover, a wide variety of ammonium fertilizers (Haynes and Sherlock, 1986).

Soil type, soil pH, temperature, soil moisture, soil aeration, status of concentration of NH_4^+ in the soil surface solution, soil Cation Exchange Capacity (CEC), contents and type of organic matter in soil, addition of ammonical formed fertilizers etc., are the major factors affecting ammonia volatilization process from soils (Loomis and Conner, 1992; Haynes and Sherlock, 1986; Nelson, 1982)

Losses through biological Nitrification and Denitrification Processes

Available form of soil N-NO_3 is transformed, by diverse soil micro-organisms, to N_2O or N_2 gaseous form and lost to the atmosphere. This process is known as denitrification. Denitrification is a major biological process through which N from the soil is turned to atmosphere (Firestones, 1982). Moreover, since the gaseous forms of N are not only the by-product of denitrification process but also the intermediate product of nitrification process itself or through chemical reactions while these processes too often simultaneously occur in the field conditions, therefore soil N can loss as gaseous form during nitrification under field circumstances (Haynes and Sherlock, 1986; Nelson, 1982; Schmidt, 1982; Firestones, 1982).

Soil factors that strongly influences on denitrification are oxygen (control primarily by soil water contents), nitrate concentration, soil pH, soil temperature, and the soil organic carbon (Peoples *et.al.,* 1995). The conditions—poor drainage, temperature at 25°C and above, soil reaction near neutral, good supply of readily decomposable organic matter, and high rate of fertilizer application--are leading to gaseous loss of soil nitrogen by denitrifying bacteria (Firestones, 1982). Factors such as addition of ammonical formed fertilizers, soil pH, soil temperature, soil moisture, soil types and its characteristics, aeration, are affecting on the equilibrium of soil N pools (Haynes and Sherlock, 1986; Nelson, 1982; Schmidt, 1982; Firestones, 1982).

Commonly, however, gaseous emission of N via ammonia volatilization, and denitrification has been identified as dominating mechanisms of Fertilizer N loss in many different agricultural systems (Peoples *et.al.,* 1995).

2.7.2. Losses through Leaching

Soil nitrogen is also lost through a process called leaching, mainly as NO_3^-. Also, NH_4^+ may be lost in sandy soils (Stevenson, 1982). NH_4^+ ions are strongly adsorbed by soil colloids. Whereas the an-ions exchange capacity of soils is weak and NO_3^- moves down rather freely with soil water. Nitrate originated from the mineralization of soil organic matter, crop and plant residue, fertilizer N that was not used by plants with rainfall input generate the leaching process (Canmeron and Haynes, 1986). Climate and season; especially, amount and intensity of rainfall and its distribution pattern, quantity and frequency of irrigation, drainage, evaporation rate, temperature effects, soil properties (particularly, texture and structure), the type of land use, cropping and tillage practices, and applied nitrogen fertilizer amount and form are determining the extent of leaching losses (Loomis and Conner, 1992; Canmeron and Haynes, 1986).

2.7.3. Losses through surface runoff water and soil erosion

N loss through runoff does not exceed 5% of added fertilizer input and are often less than rainfall inputs (Barker, 1980). However, in sloping cultivable land, losses of N in sediment are main considerable. Significant nitrate loss occurs when high rate of fertilizer (above the rate of greatest economic return) are applied. Soil nitrogen can also loss through erosion, which effected by rainfall, soil texture, slope, vegetation or cropping, land management including conservation practices, irrigation, and, fertilizer and organic waste application factors (Canmeron and Haynes, 1986).

2.7.4. Losses through Ammonium Fixation

In soils, with ability to bind K^+ and NH_4^+ in such a manner that they can't readily to replace by other cations. This ammonium binding processes known as ammonium fixation. Fixed Ammonium content in soil and in the root zone varies greatly from nil in sandy soil and considerable amount in clay sub soils (Young and Aldag, 1982). Factors— types and structure of clay and its content, humic substance content, amount of ammonium in soil, added organic matter, soil water content, temperature, presence of other ions (especially, K^+)—are effecting on ammonium fixation and releasing phenomenon (Canmeron and Haynes, 1986). Moreover, Nitrifiers (Nitrobacter) are major inter-mediators in making fixed NH_4^+ available to plant, especially when soluble and exchangeable concentration is low (Nommik and Vahtras, 1982). However, ammonium fixation should consider as a desirable factor when such condition need to prevent N loss through leaching and ensuring more even supply of N through out the growing season (Nommik and Vahtras, 1982). Fixed N is available in term of time than biologically immobilized into organic forms (Jansson and Presson, 1982). By understanding of these N transformation processes and ammonium fixation processes, allow one to justify a well-managed nitrogen application in crop production.

2.8. Fertilizer use efficiencies

Soil nitrogen is dynamic and interacting with physical and biological factors in agricultural and natural ecosystems (Loomis and Conner, 1992). In most agricultural soils, approximately 97-99% of total N presents as organic forms. These are not readily available for the plants since some of this slowly become available to plants through microbial decomposition of soil organic matter and the release of available mineral forms of N (Goh and Haynes, 1986). Moreover, crop removal in harvesting is always considerable high at the same time so that it becomes as the most common limiting factors in the crop production (Olson and Kurtz, 1982). To do so, Nitrogen has become demand of additional N fertilizers to achieve certain productivity in many intensive-farming systems, inevitably. When applied the fertilizers in the crop production, problems arise. Like rice, cotton, and sugarcane crops which receive large application of N, but which also lose large amount of N by denitrification, ammonia volatilization and leaching and become as pollutant and adverse effects on the environment (Peoples *et.al.,* 1995).

Commonly, farmers do not concern about applying excess amount of N, not only the environmental consequences but also in term of economic benefits of this wasteful practices need to be considered. Responsible management aimed at increasing fertilizers use efficiency will ensure greater return to the farmers and provide incentive for reducing any adverse impacts on the environment. Although much work had done to achieve greater efficiency in sugarcane cultivation, but the efficiency of nitrogen use is commonly reported as being less the 50% of total amount applied (Prammanee *et.al.,* 1999). Nevertheless, in Fiji, increasing sugarcane per unit area is closely related to the tasks of increasing fertilizer use efficiency per unit area (Sewak, 1995).

Definitions of nutrient efficiency

Several points of view assists in defining the term "nutrient efficiency". Fageria (1992) collected some of these views as follows:

- The amount of product produced per resource used. It means, amount of dry matter produced per unit of nutrient applied or absorbed.
- Relative yield of a genotype on different soils, compare with its yield at optimum nutrition.
- The increased yield of the harvested fraction of the crop per unit of nutrient supply by fertilizer. The highest efficiency usually obtained with the first increment of fertilizer; additional increment provides smaller increases.
- Traditionally, efficiency nutrient of utilization has been defined as the ratio of biomass to the total amount of nutrition on the biomass.
- Nutrient efficiency should also take into account nutrient concentration.

Maximum nutrient use efficiency is obtained when the nutrient concentration is near to the critical level, near maximum yield occurs at this point without excessive nutrient levels in the plant. The Nitrogen Use Efficiency (NUE) is defined as biomass produced or carbondioxide fixed per unit of N in the plant. It can be estimated by several methods. Fageria (1992) categorized nutrient efficiency into three groups and called them agronomic efficiency, physiological efficiency, and apparent recovery efficiency. NUE is paramount important due to escalating costs and the hazards of environmental pollution. The efficiency of nitrogen fertilizer usage is much dependent on factors such as water supply and the presence of other plant nutrients in soil (Mengel and Kirkby, 1987). Moreover, in sugarcane, nitrogen content, organic matter contents (Moberly *et.al.,* 1984), particular crop variety, form of nitrogen fertilizer, timing and placement (Vallis and Keating, 1994), has to be considered for NUE.

2.9. System, Simulation and Modeling in agriculture

Many definitions have been defined for the term "system", however, system can also be defined as the limited part of reality that contained related components that function together for some purposes to support the existence of such reality. Hence, such reality cannot exist or function normally if the system contained is malfunction (de Wit and Penning de Vries, 1982).

The boundary of such system can vary from cell level to solar system level (Jongkaewwattana, 1995). Thus its components and variables also can be varied depending on its scope or boundary (Rabbinge and de Wit, 1989). In many agricultural systems or agroecosystems, since, components of such system interact altogether that render dynamic behavior and changes over time itself, moreover they interact with exogenous variables or external factors so becomes more complex.

System analysis is concerned with the resolution of any complex system into a number of simpler components and the identification of important linkages between them. In system analysis, as first, formulized set of logical statement and mathematical formulae on the real observed system. The second, developing the stage to mimic the behavior of the complex system. Finally, an experiment can be performed using the model. Using a model called as simulation. The possible consequences (ecological, agronomic, economic) of introducing a new technology can be examined using simulation techniques and appropriate field experiments designed to test the model predictions and application (Nix, 1986 *cited in* Jintrawet, 1995b).

In agriculture, crop growth process is determined by availability level of resources. So, production levels are classified as four levels based on this sense.

Production level 1 is classified when the limitation of weather, especially, solar radiation determined on crop growth. Level 2 is classified as the crop growth is limited by soil water availability. Production level 3 is classified as when crop growth is limited by available soil nitrogen, and when crop growth is limited by phosphorous availability and other minerals as well, classified as production level 4 (de Wit and Penning de Vries, 1982).

At present, there are number of crop models have been developed under different boundaries of production levels. Since such models have developed through processes; formulation, validation and sensitivity analysis (Dent and Blackie, 1979) thus, they are widely used in agriculture such as CERES models (Ritchie *et.al.,* 1998), CROPGRO models (Boote *et.al.,* 1998), APSIM, etc.,

2.10. Simulation, modeling in Agricultural research and Agro-technology transfer

The development of modeling and simulation through computer is very useful as a tool in modern agriculture with several perspectives such as testing of hypothetical statement, generating hypothesis, designing experiment treatments, simulate research results which is not possible or difficult to conduct in the real life i.e., climate changes (Jongkaewwattana, 1995) from farm level to policy level (Jintrawet,1995). Therefore, it is beneficial as a tool for agriculture research and development. Moreover, agro technology transfer as well by reducing time and finance while simple technology transfer methods; trial and error, analogy take such a long time with high spatial and temporal variability (Nix, 1986 *cited in* Jintrawet, 1995b).

Under the IBSNAT project, DSSAT was developed to integrate the crop models with databases to provide users with convenient access to the functions required to implement, test and apply the crop models to site-specific conditions (IBSNAT, 1989). The minimum data sets—site, weather (daily solar radiation, maximum and minimum temperatures and precipitation), soil layer (classification and analyzed results of surface, i.e., bulk density, organic carbon, organic nitrogen, pH, P and K), initial conditions (water, ammonium and nitrate by soil layer, and previous crop, root, nodules amount and rhizobia effectiveness), management practices—are needed to specify for DSSAT application by user (Hunt and Boote, 1998). DSSAT provides soil, crop, and weather information to various users. DSSAT provides crop models and application programs to simulate, analyze, and display outcomes, not only biophysical but also economic variables of alternative management strategy specified by user (Tsuji *et.al.,* 1994). Therefore, the users can be able to simulate the risks and consequences of alternatives, so, can optimize for management in crop production (Jones *et.al.,* 1998). Moreover, user can simulate and analyze in both seasonally and sequentially for many years (Tsuji *et.al.,* 1994). Nowadays, DSSAT can be applied, integrating with GIS, RS that can be accessed to spatial analysis with several aspects such as land evaluation, potential crop production (Jongkaewattana, 1995; Jintrawet, 1995b; Beinorth *et.al.,* 1998; Promburom *et.al.,* 2001). There are fifteen crop-models currently available under the DSSATv3.5 package including sugarcane crop model: CANEGRO-DSSAT. The model is a hybrid between CERES and CROPGRO models. CERES crop models can simulate soil water balance (Ritchie, 1998) and dynamism of nitrogen in soil plant system (Godwin and Singh, 1998) so that simulation is useful as a tool for improving nitrogen management (Bowen and Baethgen, 1998). CANEGRO-DSSAT simulates sugarcane physiology, population dynamics and water relations. However, currently, CANEGRO-DSSAT does not simulate the soil nitrogen balance and organic carbon. The model predicts the only vegetative-growth as the reproductive stages, which are not economically critical for farmers (Tsuji *et.al.,* 1994). Nevertheless, it has being undertaken to develop by incorporating with such nitrogen sub-model (O'leary *et.al.,* 2000).