CHAPTER II
THEORETICAL BACKGROUND AND
LITERATURE REVIEWS

2.1 Cadmium

Cadmium is a metal that belongs together with zinc and mercury to group IIB of the Periodic Table. It has atomic number of 48 and the relative atomic weight 122.40. Cadmium has no essential biological function. Moreover, it appears to be highly toxic to plants and animals. Cadmium is also recognized to produce toxic effects on humans. Long-term occupational exposure can cause adverse health effects on the lungs and kidneys. Cadmium has been found to occur in the natural environment typically in close association with zinc ores. It is a common impurity in zinc and most often isolated during the production of zinc. In the Mae Sot area, sulfide and nonsulfide zinc ores also possess remarkable amount of cadmium content with levels up to 1% in some analytical samples (Reynold et al., 2003).

2.1.1 Cadmium in soils

Cadmium concentrations in soil range from low in uncontaminated soils to high in soils receiving large quantities of cadmium through anthropogenic activities or in soils naturally rich in cadmium. In nature soils, cadmium concentration is largely influence by the amount of cadmium in the parent rock. The average contents of soil cadmium in soils lie between 0.06 and 1.1 mg/kg (Kabata-Pendias and Pendias, 2001). However, it is expected to be much less than this in most soils (Alloway, 1995). In soil solution, dissolved cadmium may also form several complex ion ($CdCl^+$, $CdOH^+$, $CdHCO_3^+$, $CdCl_3^-$, $CdCl_4^{2-}$, $Cd(OH)_3^-$, and $Cd(OH)_4^{2-}$). However, the most important factors valance state of cadmium in natural environment is Cd^{2+} (Kabata-Pendias and Pendias, 2001).

Cadmium in uncontaminated soil may have been derived in situ from the weathering of minerals in underlying parent rock or from precipitation or accumulation of transported fragments or particles via hydraulic or atmospheric media. Varying amounts of cadmium in soil depend much upon the lithology and

geography of the area where soil was formed. For example, the average cadmium concentrations in agricultural soils in remote locations in the USA (3054 samples) were found to be 0.27 mg/kg (Holmgren et al., 1993).

For the contamination of cadmium in soil, the present concentration of cadmium in top soils is reported to be very high in the vicinities of lead and zinc mine. Adriano (2001) reported that areas affected by smelting operations showed cadmium concentration ranging from 0.20 to 350 ppm in the surface soil. It has become apparently that cadmium from metallurgical activities (mining and smelting) is likely to be more bioavailable to organisms than cadmium from unimpacted soils (Asami et al., 1988; Chlopecka et al., 1996). Phosphorus fertilizers are one of the most ubiquitous sources of cadmium contamination in agricultural soils. It may contain cadmium from 10 to 300 mg/kg (Cook and Morrow 1995) whereas N and K fertilizers generally contain less than 9 mg/kg (Fergusson, 1990). The possibility of cadmium accumulating in soil as a result of applying phosphorus fertilizers is of concern because plant based foodstuffs are the largest sources of dietary cadmium

2.1.2 Cadmium in plants

Cadmium is a nonessential element in plant nutrition. Under normal condition, plants uptake only small quantities of cadmium from soil. When present in growth medium in higher than background concentration, cadmium is readily taken up by the roots and distributed throughout the plant (Adriano, 2001). In most every case, a linear relationship between cadmium in plant material and cadmium in growth medium is reported. Finding of Hornburg and Brümmer (1986), however, indicated that the cadmium concentration in wheat grains increase linearly with total cadmium content of soil. Also, a worldwide experiment carried out in 30 countries with young wheat (N = 1723) and young corn plants (N = 1892) indicates that plant-cadmium is a function of soil-cadmium (Sillanpää and Jansson, 1992).

The amount of cadmium uptake is tempered by soil factors such as pH, CEC, redox potential, organic matter, other metals, fertilization, and other factor (Adriano, 2001). Soil pH is list as the major soil factor controlling both total and relative uptake of cadmium. Kitagishi and Yamane (1981) reported results of their experiment, indicating that the relative uptake of cadmium by rice seedling was the greatest within the pH range of 4.5 to 5.5. Even at the high soil pH (7.2-7.8), cadmium uptake by

barley was a function of its content in soil. Moreover, McLaughlin and Singh (1999) stated that the availability of cadmium to plants decreases as the soil pH increases. Plant factor, such as species and genotype, also influence the total uptake. Cadmium is rather readily translocated throughout the plant following its uptake by the roots. Distribution between roots and shoots differs with plant species, rooting medium, and time of treatment.

In spite of the high bioavailability of cadmium to plants, only a small fraction of the cadmium pool in soil is recovered by plants. One reason is that cadmium is phytotoxic up to certain levels, which can drastically reduce plant yield (Adriano, 2001). Cadmium is not only bioavailable to plants from soil and other media but is also known to be toxic to them at much lower concentrations than other metals, Such as zinc, lead copper etc. Phytotoxicity has been observed to be dependent upon plant species as well as concentration of cadmium in medium. Plants grown in soil generally have a wide range of cadmium phytotoxicity than in nutrient culture. For 25% yield decrement, the total soil cadmium level ranged from 4 ppm for spinach to > 640 ppm for paddy rice. Root of subterranean clover was depressed by the addition of 1 ppm cadmium to soil, and at 5 ppm or higher, toxicity symptoms began to appear (William and David, 1977). Manicol and Backett (1985) established the upper critical level for cadmium that cadmium in plant tissues in the range of 10-20 ppm dry weight would cause 10% yield loss.

2.2 Zinc

Zinc is widely recognized as one of the most important microelements on plants and animals nutrition. However, it can be toxic whether presence in soils at high concentration. Zinc has atomic number of 30 and the relative atomic weight 65.38. Zinc belongs to group IIB with cadmium and mercury, which potentially most hazardous to the biosphere, in the Periodic Table. Most of the concern about excessive zinc concentration in soils relates to its possible uptake by crops and consequent adverse effects on crop, livestock and human diets (Alloway, 1990).

2.2.1 Zinc in soils

Total zinc content of soils is largely dependent on the composition of parent rock material. Swaine (1955) reported that the most quoted range for total zinc in normal soils is 10 to 300 mg/kg. However, grand mean zinc for worldwide soils may be calculated as 64 mg/kg (Kabata-Pendias and Pendias, 2001). The solubilization of zinc minerals during weathering produces mobile Zn^{2+}, especially in acid, oxidizing environments. Zinc is, however, also easily absorbed by mineral and organic components and thus, in most soil types, its accumulation in the surface horizons is observed (Kabata-Pendias and Pendias, 2001). Many studies of zinc adsorption and retention in soils were reviewed by Lindsay (1972) and it has been shown that clay and soil organic matter are capable of holding zinc quite strongly. Zinc also forms complexes with chloride, phosphate, nitrate and sulphate. The $ZnSO_4$ and $ZnHPO_4$ are the most important and may be contribute significantly to total zinc in soil solution. Compared to the average total zinc content in soils, the concentration of zinc in the soil solution is very low. Kabata-Pendias and Pendias (2001) reports values from the literature ranging from 4 to 270 µg/l, depending on the soil and techniques used for obtaining the solution.

In zinc-contaminated soils, concentrations of some 1,000 to 10,000 mg/kg of zinc have been found (Alloway, 1990). The uses of agrochemicals such as fertilizers and pesticides may also increase the zinc concentrations of soils. Zinc concentrations in inorganic phosphate fertilizers range from 50-1,450 mg/kg while in manure values from 15-250 mg/kg have been reported (Alloway, 1990).

2.2.2 Zinc in plants

Zinc is an essential element for plant nutrition. Unlike the major nutrients ordinarily supplied in mixed fertilizers it is required in only minute amounts (Adriano, 2001). Zinc is vary important in plant nutrition because it is involved in a number of metallo-enzymes, is essential in the stability of cytoplasmic ribosome and root cell plasma membrane, and the transformation of carbohydrates (Kochian, 1993; Romheld and Marchner, 1991).

Soluble forms of zinc are readily available to plant and uptake of zinc has been reported to be linear with concentration in the nutrient solution and in soils. Soil pH also affects the bioavailability of zinc to uptake by plants. Kabata-Pendias and Pendias (1999) reported that at a high pH value (7.2-7.8), zinc uptake by barley is also closely correlated with its content in soils. However, the deficiency of zinc to uptake by plant could occur. In most cases, the total quantity of zinc present is high but most of the zinc occurs in an unavailable form and the extractable zinc present is insufficient to sustain normal plant growth. This can be expected in high-pH, high-OM soil where zinc would be mostly in unavailable form. Adriano (2001) stated that zinc deficiency is caused primarily by three factors: 1) low content of zinc in the soils; 2) unavailability of zinc present in the soil to the plant; and 3) management practices that depress zinc bioavailability or its uptake. Zinc deficiencies have been reported in Nigeria and other countries mostly occurring in places where lime is used to increase soil pH from 4.5 to about 7.0 (Kang and Osiname, 1985). Jones (1972) stated that plants with zinc contents below 20 ppm in dry tissue can be suspected of zinc deficiency. The accordance value was reported by Kabata-Pendias and Pendias (2001) that the deficiency content of zinc was in the range of 10 to 20 ppm dry weight.

Potential zinc phytotoxicity from excess zinc input into soils exists because zinc is fairly immobile in soil. Occurrence of zinc toxicity has been associated with zinc smelting (Singh and Lag, 1976), naturally high localized zinc concentrations, or production practices that add extremely large quantities of zinc to soils. Zinc phytotoxicity is undesirable because of decreased crop yield and quality. Ichikura et al. (1970) reported that from 250 to 1000 ppm of total zinc in soil was harmful to rice plants and 10% reduction in yield occurred when extractable zinc was 460 ppm in paddy soils (Chino, 1981). A zinc tissue exceed the concentration of 400 mg/kg leaves, toxicities can be expected (Jones, 1972). The upper critical level for zinc was establish by Manicol and Backett (1985) revealed that zinc in plant tissues in the range of 100-500 ppm dry weight would cause 10% yield loss.

2.3 Bioavailability

Bioavailability is defined as the proportion of total metals that are available for incorporation into biota or taken up into plants (John and Leventhal, 1995). It is a dynamic and mobile system acting as a chemically reacting system. Generally, the uptake of trace metals by plants is closely related to the concentration of those elements in the soil solution (Kashem and Singh, 2002). However, not all the metals content in soil is available for plant uptake, only the dissolved in soil solution is moveable enough for plant to absorb around its rhizosphere. Metal bioavailability is largely dependent on the partition of the metals between the solid and solution phases. It is widely acknowledged for the importance of the metal content in soil solution that it was a major controlling factor in the bioavailability of metals (Alloway et al., 1988; Boekhold et al., 1993; Kabata-Pendias, 1999; Lee et al., 1996). A soil solution composition provides an important index of the available of different ions to plants (Manz et al., 1999).

The availability of heavy metal in soil to plants is depend on the physical, chemical, and biological processes that control the solubility and from of heavy metal in soil solution, especially in rhizosphere. Different chemical, physical and biological processes acting on soil media control the fate of heavy metals in soil (Kashem and Singh, 2002). The major factor governing metal behavior to plants in soils is the solubility of the metal associated with the solid phase (Cataldo and Wildung, 1978). The factor influencing solubility and the distribution of metals between the specific forms varies widely according to the individual metal and the characteristics of soils (Sparks, 1995). Bioavailability is complex function of many factor including total concentration and speciation of metals, mineralogy, pH, redox potial, temperature, total organic content and suspended particulate conteny. These factors vary seasonally and temporally. Most factors are interrelated as changing one factor may affect others (John and Leventhal, 1995), as this influence the kinetics of sorption reaction, metal concentration in solution and the form of soluble and insoluble chemical species (Cataldo and Wildung, 1978). There are many factors in which can affect the availability such as pH, redox potential, soil texture, clay content, organic matter and the presence of cations and anions in soil solution (Rieuwerts et al., 1998). Among factor affecting the solubility of metal in soil, pH is likely to be the most easily managed and changing. There are significant effects of addition fertilizer on soil pH.

The following selected soil pH factor affecting metal bioavailability were focused in this study

Soil pH is generally acknowledge to be the principal factor governing concentrations of soluble and plant available metals (Brallier et al., 1996) and also considered as the most important factor affecting metal speciation (Selim and Kingery, 2003) and behavior in soil systems both directly and indirectly. The influence of soil pH on metal availability is due mainly to its effect on the reactions controlling concentrations of metal in the soil solution (Sparks, 1995). Metal speciation changes with pH, affecting metal sorption/desorption on solid surfaces as well as the solubility of metal hydroxide minerals. Metals tend to be adsorbed at different pH values. This results in precipitation of different metals over a large range of pH units. Metal solubility tends to increase at lower pH and decrease at higher pH values (Sanchez-Camazano et al., 1994; Chuan et al., 1996). Adriano (2001) stated that the solubility and phytoavailability of metals are inversely related to soil pH. At soil pH above 7.0 the bioavailability of zinc is substantially reduced. Moreover, Levi-Minzi and Petruzzelli (1984) observed a pH decrease with the application of monoammonium phosphate and an increase with diammonium phosphate.

2.4 Phosphorus

Phosphorus (P) is an essential element classified as a micronutrient necessary for plant growth because of the relatively large amounts of phosphorus required by plants and was discovered to be one of limiting element. The total phosphorus content of the surface six inches may be ranging from 200 to 2,500 lb/acre (Tisdale et al., 1985) (approximately 36 to 450 kg/rai). However, only a small fraction of this total phosphorus is in a form that is readily available to plants.

2.4.1 Forms of phosphorus in soils

Phosphorus in soils can be generalized into three pools including: solution phosphorus, active phosphorus and fixed phosphorus.

1) Solution phosphorus

The solution phosphorus pool is very small. The solution phosphorus will usually be in the orthophosphate form ($H_2PO_4^-$, HPO_4^{2-}), but small amounts of organic phosphorus may exist as well. The solution phosphorus pool is important because it is the pool from which plants take up phosphorus and is the only pool that has any measurable mobility. Most of the phosphorus taken up by a crop during a growing season will probably have moved only an inch or less through the soil to the roots. A growing crop would quickly deplete the phosphorus in the soluble phosphorus pool if the pool was not being continuously replenished.
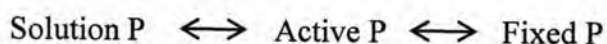
2) Active phosphorus

The active phosphorus pool is phosphorus in the solid phase which is relatively easily released to the soil solution, the water surrounding soil particles. As plants take up phosphate, the concentration of phosphate in solution is decreased and some phosphate from the active phosphorus pool is released. Because the solution phosphorus pool is very small, the active phosphorus pool is the main source of available phosphorus for crops. The ability of the active phosphorus pool to replenish the soil solution phosphorus pool in a soil is what makes a soil fertile with respect to phosphate. The active phosphorus pool will contain inorganic phosphate that is attached (or adsorbed) to small particles in the soil, phosphate that reacted with elements such as calcium or aluminum to form somewhat soluble solids, and organic phosphorus that is easily mineralized. Adsorbed phosphate ions are held on active sites on the surfaces of soil particles. The amount of phosphate adsorbed by soil increases as the amount of phosphate in solution increases. Soil particles can act either as a source or a sink of phosphate to the surrounding water depending on conditions. Soil particles with low levels of adsorbed phosphorus that are eroded into a body of water with relatively high levels of dissolved phosphate may adsorb phosphate from the water, and vice versa.

3) Fixed phosphorus

The fixed phosphorus pool of phosphate will contain inorganic phosphate compounds that are very insoluble and organic compounds that are resistant to mineralization by microorganisms in the soil. Phosphate in this pool may remain in soils for years without being made available to plants and may have very little impact on the fertility of a soil. The inorganic phosphate compounds in this fixed phosphorus pool are more crystalline in their structure and less soluble than those compounds considered to be in the active phosphorus pool. Some slow conversion between the fixed phosphorus pool and the active phosphorus pool does occur in soils.

From of phosphorus in soils can be simplified to the following relationship:

$$\text{Solution P} \longleftrightarrow \text{Active P} \longleftrightarrow \text{Fixed P}$$

Where active phosphorus and fixed phosphorus represent both inorganic and organic fractions. Active phosphorus is the readily available portion of the quantity factor that exhibits a high dissociation rate and rapidly replenishes solution phosphorus. Depletion of active phosphorus causes some fixed phosphorus to become active, but at a slow rate. Thus, the quantity factor of phosphorus in soils comprises both active and fixed phosphorus fractions (Havlin et al., 1999).

2.4.2 Phosphorus cycle

The phosphorus cycle in soil is a dynamic system involving soil, plants and microorganisms. Major processes include uptake of soil phosphorus by plants, recycling through return of plant and animal residues, biological turnover through mineralization-immobilization, fixation reactions at clay and oxide surfaces, and solubilization and formation of mineral phosphates through chemical reactions and activities of microorganisms. In natural systems, essentially all of the phosphorus utilized by plants is returned to the soil in plant and animal residues; under cultivation, some phosphorus is removed in the harvest and only part is returned. Most losses of soil phosphorus arise through erosion; smaller losses occur as a result of leaching (Stevenson and Cole, 1999).

The interrelationships between the various forms of phosphorus in soils were illustrated in Figure 2.1. The decrease in soil solution phosphorus concentration with absorption by plant roots is buffered by both inorganic and organic phosphorus fractions in soils. Primary and secondary phosphorus minerals dissolve to resupply $H_2PO_4^-/HPO_4^{2-}$ in solution. Inorganic phosphorus absorbed on mineral and clay surfaces as $H_2PO_4^-$ or HPO_4^{2-} (labile inorganic phosphorus) can also desorb to buffer decreases in solution phosphorus. Numerous soil microorganisms digest plant residues containing phosphorus and produce many organic phosphorus compounds in soil that are mineralized through microbial activity to supply solution phosphorus.

In addition to phosphorus uptake by roots, solution phosphorus can be absorbed on mineral surfaces and precipitated as secondary phosphorus minerals. Soil microbes immobilize solution phosphorus as microbial phosphorus, eventually producing readily mineralizable phosphorus compounds (labile organic phosphorus) and organic phosphorus compounds more resistant to microbial degradation. Maintenance of solution phosphorus concentration (intensity) for adequate phosphorus nutrient in the plant depends on the ability of labile phosphorus (quantity) to replace soil solution phosphorus taken up by the plant. The ratio of quantity of the soil to intensity factors is called the buffer capacity, which expresses the relative ability of the soil to buffer changes in soil solution phosphorus.
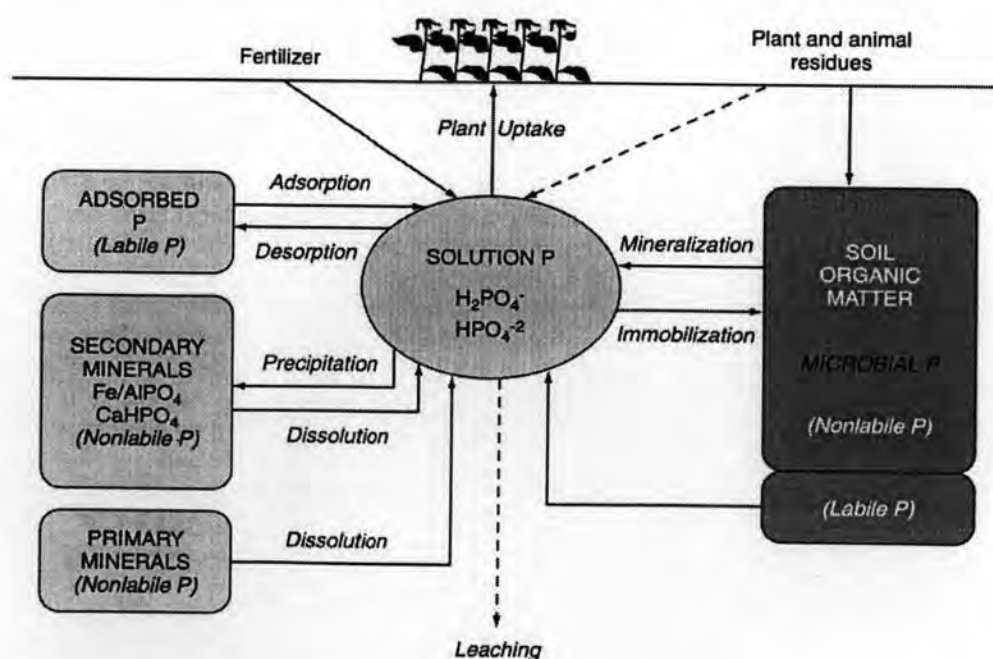

Figure 2.1 Schematic representation of phosphorus cycle in soils
Source: Havlin et al. (1999)

2.5 Fertilizer

The phosphorus in fertilizers is initially quite soluble and available. As a particle of fertilizer comes in contact with the soil, moisture from the soil will begin dissolving the particle. Dissolving of the fertilizer increases the soluble phosphate in the soil solution around the particle and allows the dissolved phosphate to move a short distance away from the fertilizer particle. Havlin et al. (1999) state that water-soluble fertilizer phosphorus applied to soil readily dissolves and increases the concentration of soil solution phosphorus. The chemical form of phosphorus in fertilizer materials is phosphate ions ($H_2PO_4^-$ and HPO_4^{2-}) in which available for plants uptake (Busman et al., 1998). Growing crops generally need more phosphorus than is normally dissolved in the soil solution for optimum and also quickly deplete the available phosphorus in soil. Therefore, the available phosphorus fertilizer must be replenished many times during the growing season.

Adequate phosphorus availability for plants stimulates early plant growth and hastens maturity. Phosphorus generally stimulates root and shoot growth, promoting vigorous seedling growth and advancing maturity. Thus, application of chemical fertilizer, manures or agriculture and municipal wastes is necessary on many soils to meet plant phosphorus needs (Whitney, 1988). To correct the deficiency, phosphorus generally added to soils in the form of fertilizers.

In sugarcane cultivated fields in Mae Sot district, Tak province, farmers always apply phosphorus to the soils in form of granular commercial fertilizer 16-16-8 NPK formulation to increase the quantity and quality of sugarcane production. The 16-16-8 NPK fertilizer is the composition of urea fertilizer, diammonium phosphate (DAP), KCl and some additives such as lime, dolomite and silica. Many researchers investigated that soluble phosphates chemical fertilizer have often included liming materials to buffer against drastic decreases in pH (Brown et al., 1999; Hettiarachchi et al., 1997; Hettiarachchi and Pierzynski, 1999). The additions of liming materials with soluble phosphate chemical fertilizer are crucial for maintaining desirable pH and controlling metal solubility (McGowen et al., 2001).

2.6 Effect of added fertilizers on cadmium-zinc-phosphorus interactions

In general, commercial fertilizers always contain some heavy metals and trace elements as an impurity such as cadmium and zinc. The effect of contaminated fertilizers on metal solubility is mixed. First, cadmium contaminated fertilizers also contain zinc as an impurity. The competition between both metals for adsorption on soil surfaces or plant uptake then depends on the relative proportion of both elements in the soil, in the soil solution and in the fertilizer. In addition, the fertilizer itself can influence metal solubility (Lambert et al., 2007). In the soils fertilized with phosphorus fertilizers, many interactions between elements can occurred. The orthophosphate ion can forms sparingly soluble solids with several toxic metals such as cadmium, zinc and lead. Much research has explored the utility of using phosphates to reduce the mobility and bioavailability of these metals in contaminated environments (Chen et al., 1997; Ma and Rao, 1997; Cotter-Howells and Capron, 1996; McGowen et al., 2001).

2.6.1 Cadmium-Phosphorus interactions

Many investigators stated the interaction between cadmium and phosphorus that phosphate added to soil immobilizes the cadmium. As Hettiarachchi et al. (1997) reported, the mobility of cadmium in phosphorus amended soil is significantly reduced. The exchangeable fraction of cadmium decreases with the presence of phosphate in soils, while carbonate and oxide fractions increase. Krishnamurti et al. (1999) reported the reduction of cadmium adsorption in the presence of phosphate in soils and attributed to the formation of cadmium-phosphorus complexes in solution. Cadmium-Phosphorus interaction is exhibited in the phosphorus effect on cadmium uptake by plants. Apparently, these reactions take place in the root media, and thus, the influence of the phosphorus supply on soil may differ for various soils and crops (Kabata-Pendias, 2001).

2.6.2 Zinc- Phosphorus interactions

Zinc-Phosphorus interaction has been widely observed and reported for many crops, especially after phosphate and lime applications (Loneragan et al., 1979). Although phosphorus interacts with many nutrients, the most commonly observed and studied antagonistic interaction is with zinc. Zinc is taken up by plants as a cation

(Zn^{2+}) and phosphorus is taken up by plants as a species of the phosphate (PO_4^{3-}) anion. Positively and negatively charged ions have an electrical attraction to one another, facilitating the formation of a chemical bond that can form in either the soil or the plant tissue. The relative strength of the phosphorus-zinc bond is strong and does not readily break without dramatic changes in the physical or chemical environment. If excess phosphorus binds a large amount of the zinc normally used by the plant, the result can be a phosphorus-induced zinc deficiency (Hopkins and Ellsworth, 2003). High phosphorus availability can induce zinc deficiency, commonly in soils that are marginally zinc deficient. Several reports stated that high levels of phosphate fertilization are known to reduce zinc concentrations in plant tissues (Lindsay, 1972; Racz and Haluschak, 1974; Moraghan, 1984). Norvell et al. (1987) studied Zinc-Phosphorus interaction in alkaline soils and stated that the specific effects of phosphorus on the concentration of Zn^{2+} in the solution were observed only when the Zn^{2+} contents was raised previously by zinc fertilizers and found that the addition of phosphorus also caused decreases in the concentrations of other divalent cations in the solution.

2.7 Sugarcane

Sugarcane (*Saccarum officinarum* L.) is a tall perennial tropical grass which tillers at the base to produce unbranched stems, 3-4 m or more tall and about 5 cm in diameter. It has been introduced as an old energy source for human beings and more recently replacement of fuel for motor vehicles. Sugarcane is propagated by cutting piece of mature cane stems called setts. The sett should be fresh and juicy, free from pest and diseases and eye buds should be fully developed. Each sett contains one or more buds and a circle of small dots above node which are the root primordia. While germination the buds develop into primary shoot and the primadia develop into sett roots. The sett root initiation and extension requires continuous presence of moisture in the top soil. During the first month after germination the young plant lives at the expense of reserves present in the stem piece (setts) (Jain irrigation system Ltd., 2002). Kuyper (1952) stated that sugarcane has essentially four growth phases include: Germination phase, Tillering phase, Grand growth phase and Maturation and ripening phase (Figure 2.2).

1) Germination Phase

Commercial sugarcane is propagated by cutting pieces of the mature cane stem (setts) containing usually two or more nodes with buds. The bud, a miniature stem with its growing point and root and leaf primordia, forms the new shoot. In addition, a sett contains root primordia within its root band, which develop into set roots which function until the young shoot develops its own roots. The transition from the dormant into the active stage constitutes a complex phenomenon characterized by changes in the activity of enzymes and growth regulating substances (hormones, auxins). Maximum germination and shoot vigor will result when both internal and external factors are optimal. 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 1 month.

2) Tillering Phase

Tillering, or development of secondary shoots, is a beneficial characteristic of a variety because it provides the plants with the appropriate number of stalks for a good yield. Varieties differ greatly in their tillering capability and the ultimate number of tillers present at harvest. Besides variety differences, numerous other factors influence tillering. Ultimately, tillering is related to the phenomenon of apical dominance and therefore plant hormones are involved in the process of tillering. The most important external factors influencing tillering are nutrition, light, temperature, moisture and the spacing of the plantings. Tillering phase starts from around 2 months after planting and may last up to 4 months.

3) Grand Growth Phase

The growth of the cane plant does not proceed at a uniform rate. Development starts slowly in the germinating bud and it increases gradually until a maximum is reached which is followed by a gradual decrease (Figure 2.3). The time period in which the plant is growing rapidly is called the grand growth period. Grand growth phase is the most important phase of the crop wherein the actual cane formation and elongation and thus yield build up take place. This phase starts from 4 months after planting and last ups to 9 months in a 12-month crop.

4) Maturation and Ripening Phase

The storage of sucrose in the stalk is known as ripening. Ripening is a joint to joint process and the degree of maturity of the individual joints depends on their age. In young plants, the sucrose content exhibits a distinct maximum which is located approximately at soil level. The sucrose content in these plants decreases through the stalk toward the top of the stalk. As the plant matures, more uniform sucrose content is found throughout the stalk except for the top few internodes and the below-ground stool.
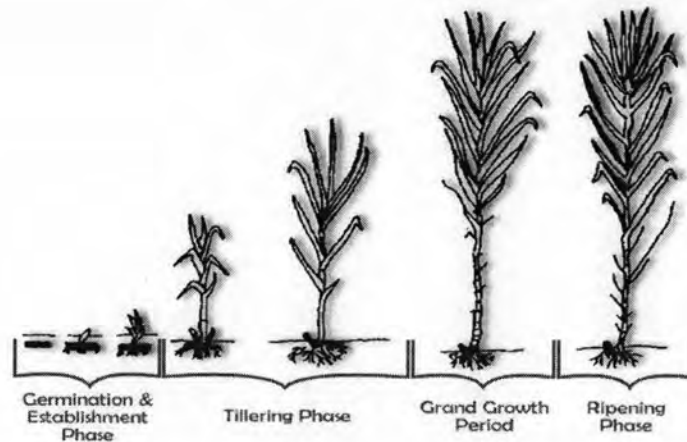

Figure 2.2 Sugarcane growth phases

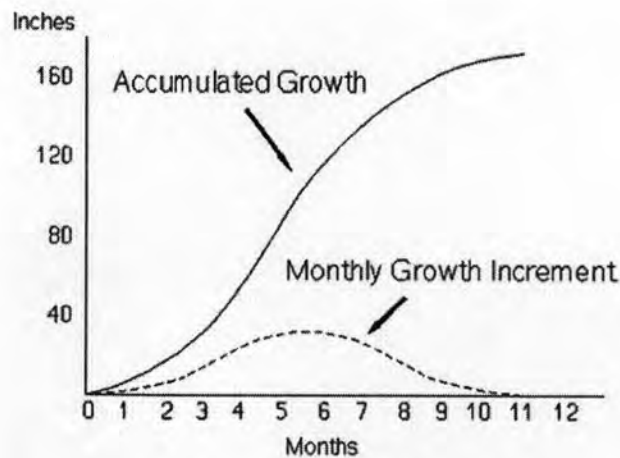Source: http://www.sugarcanecrops.com/crop_growth_phases/

Figure 2.3 Hypothetical growth curves for sugarcane

Source: Miller and Gilbert (2006)

2.8 Literature reviews

The effect of fertilizer application on the soil pH has been reported by Leviminzi and Petruzzelli (1984) who investigated the influence of monoammonium phosphate (MAP) and diammonium phosphate (DAP) on the adsorption process of cadmium. Their results showed that the phosphate induced variations in the pH values of soil-Cd suspensions, drastically influenced the solubility of the heavy metal. MAP decreased the amount adsorbed while DAP increased the quantity fixed by the soil.

He and Singh (1994) investigated the effect of different phosphorus fertilizers on the yields and cadmium contents of oat, ryegrass, carrot and spinach. These crops were grown in the greenhouse using soil treated with lime to achieve three pHs. The sources of phosphorus including a low cadmium NPK fertilizer, a high cadmium NPK fertilizer, a phosphate rock and a mixture of analytical grade $CaH_4(PO_4)_2H_2O$ and $CdCl_2H_2O$. The results showed that application of cadmium containing fertilizers in all cases tended to increase the cadmium concentrations in crops. Cadmium concentrations in crops in most cases decreased with increasing soil pH. Both DTPA and NH_4NO_3 extractable cadmium decreased with the increases in soil pH. The cadmium concentrations and total cadmium uptake of plants were significantly correlated with the soil cadmium extracted by DTPA and NH_4NO_3.

McLaughlin et al. (1995) studied the effect of potassic and phosphatic fertilizer type, fertilizer cadmium concentration and zinc rate on cadmium uptake by potato (*Solanum tuberosum L.*). The field experiment were therefore conducted in various regions of Australia to determine if cadmium uptake by potatoes could be minimized by changes in either phosphorus, potassium or zinc fertilizer management. The results indicated that changing the chemical form in which either phosphatic fertilizer (MAP, DAP, SSP and reactive phosphate) or potassic fertilizer (KCl, KSO₄) were added to the crops had little effect on tuber cadmium. Fertilizer cadmium concentrations also had little effect on tuber cadmium, suggesting that residual cadmium in the soil was major contributor to cadmium uptake by crops on these soils. However, the addition of zinc fertilizer up to 100 kg Zn/ ha significantly reduced tuber cadmium concentrations.

Loganathan and Hedley (1996) studied the effect of over ten years annual application (30 kg phosphorus/ha/yr) of four forms of phosphorus fertilizers on soil and herbage cadmium concentration. Four forms of phosphorus fertilizers different in

solubility and cadmium contents include 41, 32, 10 and 5 µg cadmium/g for North Carolina phosphate rock (NCPR), Single superphosphate (SSP), Diammonium phosphate (DAP), and Jordan phosphate rock (JPR) respectively. Herbages used in this study are grass and clover. Soil samples were collected in 2 levels of soil depth (0-30 and 30-75 mm). The results of the study indicated that ten years of fertilizers application caused a noticeable increase in surface soil cadmium concentrations. Total soil cadmium was significantly higher in SSP and NCPR treatments compared to control (no phosphorus fertilizer), JPR and DAP treatments in the 0-30 and 30-75 mm soil depths. Plant available cadmium was higher in SSP treatments. Chemical analysis of herbage samples showed that there was no significant difference in cadmium concentration in pasture grasses between treatments in the second year of the trial but in the eighth and tenth year, plots fertilized with SSP and NCPR had significantly higher cadmium in pasture grasses in most of the seasonal cuts compared to control, JPR and DAP.

Agbenin (1998) tested the hypothesis of phosphorus-induced zinc retention in soils. Phosphorus fertilizer at various rates (0, 500, 1,000 and 2,000 mg/kg) were mixed to soil added with zinc level ranging from 0 to 200 mg/kg. The results showed that the phosphorus-treated soil retained 93±2% of added zinc compared with 52±2% of the control soil. Moreover, the resulted revealed that at 2000 mg P/kg, up to 90% of zinc retained by soil was bound in solid form as $ZnHPO_4$.

Panwar et al. (1999) determine the interactive effects of cadmium and phosphorus on dry matter yield of cowpea and mungbean and uptake of cadmium and phosphorus. Application of cadmium to soil decreased the dry matter yield of both the crops at each level of applied phosphorus. Phosphorus application, on the other hand, increased the dry matter yield of both crops at each level of cadmium additions. Cadmium concentration in plant tissue increased markedly with the increasing rates of cadmium in the soil. The magnitude of increase in tissue cadmium concentration, however, was higher in the absence than in the presence of added phosphorus. Consequently, the concentration of cadmium in plants decreased with increasing levels of phosphorus application to the soil.

McGowen et al. (2001) investigated the potential solids controlling metal solubility in DAP-amended in soil contaminated with cadmium, lead, zinc and arsenic collected from a former smelter site. The DAP was applied to soil in various rates (460, 920 and 2300 mgP/kg). The results of the study indicated that increasing of

DAP decreased total metal transported and also showed that application of 2,300 mgP/kg was the most effective for immobilizing cadmium, lead and zinc eluted from the contaminated soil. Moreover, the activity-ratio diagrams indicated that DAP decreased solution cadmium, lead and zinc by forming of metal-phosphate precipitated in low solubility products. Thus, they concluded that DAP may have potential for protecting water resources from heavy metal contamination near smelting and mining site.

Modaihsh et al. (2001) studied the changes of soil total and exchangeable phosphorus and total cadmium and the effect of phosphorus fertilization on the buildup of soil phosphorus and cadmium. The results revealed a positive significant relationship between total phosphorus and total cadmium in soil was obtained. Nonetheless, the results indicated that, a comparatively long-term application of phosphorus fertilizers only slightly elevated cadmium content of the soil surface layer. The data made clear that cadmium accumulation is associated with phosphorus accumulation.

Bolan et al. (2003) determined the effect of phosphate (KH_2PO_4) on the immobilization and phytoavailability of cadmium in soil treated with various levels of cadmium (0-10 mg Cd/kg soil) by using mustard (*Brassica juncea L.*) as a tested plant. Their results showed that increasing addition of cadmium enhanced cadmium concentration in plants in which resulting in the decreased plant growth (i.e., phytotoxicity). There was a significant inverse relationship between dry matter yield and cadmium concentration in soil solution. On the other hand, the results indicated that addition of phosphate effectively reduced the phytotoxicity of cadmium and also found that the addition of phosphate decreased the concentration of the soluble+exchangeable cadmium fraction but increased the concentration of inorganic-bond cadmium fraction in soil.

Zwonitzer et al. (2003) investigated the influence of phosphorus sources (rock phosphate and KH_2PO_4) and rates on bioavailabilities of lead, cadmium and zinc in a contaminated soil using plant sorghum-sudangrass (*Sorghum bicolor L. Moench*). The results showed that the addition of phosphorus did not influence lead concentration in plant tissue and had little effect on cadmium. However, the interaction was found for zinc concentration in plant tissues that the zinc concentrations increased with increasing amounts of phosphorus from KH_2PO_4 and decreased with increasing amounts of phosphorus from rock phosphate.

Basta and McGowen (2004) determined the ability of three chemical immobilization materials includes: agricultural lime stone (AL), mineral rock phosphate (RP) and diammonium phosphate (DAP) to reduced subsurface heavy metal transport in a smelter contaminated soil using solute transport experiments. Their result showed that DAP treatments were superior to all other materials for reducing cadmium and zinc elution. The result also found that DAP at 10 g/kg was the most effective treatment for immobilizing the combination of cadmium, lead and zinc with reductions of 94.6, 98.9 and 95.8%, respectively.

Osztoics et al. (2005) studied the effects of various rates of single superphosphate on soil pH, the available trace element concentrations in soil and in red clover. The results show that at increasing phosphorus application rate, the soil pH decreased when superphosphate was added but increased when the phosphorus was applied in the form of rock phosphate. The trace elements concentration in plants was lower on slightly acidic than on strongly acidic soils.

Chen et al. (2006) examine the influence of phosphate levels on phytoavailability and speciation distribution of cadmium, lead in soil. Spring wheat (*Triticum aestivum* L.) was selected as the tested plant. Various levels of phosphate fertilizer ($Ca(H_2PO_4)_2$) including 0, 50, 100, 200 and 400 mg P_2O_5/kg soil were added to the soil mixed with the mixture of $CdCl_2 \cdot 2.5\ H_2O$ and $Pb(NO_3)_2$ at different levels. The results showed that phosphorus fertilizers promoted dry weight of wheat in all treatments and alleviated the contamination induced by cadmium and lead. With increasing levels of the additional phosphorus fertilizers, cadmium concentration in the different parts (root, haulm, chaff and grain) of wheat decreased when applied 50 mg P_2O_5/kg soil. The result also indicated that the moderate phosphorus fertilizers reduced the phytoavailability of cadmium.