CHAPTER 2

LITERATURE REVIEW

Many researches on mountainous area have been conducted to improve a sustainable agricultural system on sloping land, particularly based on the improvement of fertilizer use efficiency to increase nutrient availability under several soil conservative cultural practices. However, in this research, studies on the effects of conservative cultivation, liming for improvement of soil acidity and phosphorus availability including soil amendments applications on nutrient availability and crop productivity are reviewed as follows.

2.1 Effects of cultivation practices on sustainable highland rainfed agriculture

Shifting cultivation is the most popular and practical agriculture on sloping highland in northern Thailand. Intensive cropping is also widely practiced in the mountainous area, based on the industrial crop such as maize. These highland agricultural systems have been leading to degradations of natural resources (soil, water, and forest) and agrological systems for several decades. Therefore, sustainable cultural practice should be considered to ameliorate, alleviate the problems and increase the highland crop productions.

During the last 5 years, Panomtaranichagul et al. (2008) has found that contour furrow cultivation with mulching was the most effective method for building sustainable highland rainfed agriculture when compared to many other types of conservative contour cultural practices. The more specific IWAM (*Integrated Water-harvest, Anti-erosion, and Multiple-cropping)* technique consisted of furrow cultivation, mulched with biodegradable materials and rotational crop growing in alley multiple cropping systems, which had led to significantly increasing water and nutrient use efficiencies in the highland rainfed agricultural systems. However, accumulation of organic mulching materials in the cultivated furrow may lead to increasing soil acidity, hence, management of soil reaction and nutrient availability in the furrow are necessary to maintain crop yield in the long-run.

2.2 Effect of liming on nutrient availability

Soil acidity is indicated by the values of soil pH lower than 7. Soil pH is the product of parent materials and the environment. Rainfall and temperature control the processes that determine soil pH. Under high rainfall areas, rain slowly dissolves minerals containing exchangeable bases (calcium, magnesium, potassium and sodium). As the bases are dissolved, rainfall leaches them from the soil and replaces them with hydrogen from rainwater, leading to increased soil acidity (pH < 7.00) (Horneck et al., 2007).

Soil pH is the most important factor limiting plant nutrient availability, particularly phosphorus. This plant nutrient has the highest availability under the neutral soil pH (pH = 7). In fact, most cultivated soil in mountainous areas in northern Thailand is acidic with quite low amount of phosphorus availability, due to acidic parent materials and mineral containing exchangeable bases lost through soil erosion and leaching to the subsoil. Therefore, the required minerals must be replaced by decreasing soil acidity using liming method which is most popular strategy to improve soil pH.

2.2.1 Liming materials and benefits of lime application

The materials commonly used for liming are Ca and Mg oxide, hydroxides, carbonate, and silicate. Liming reactions begin with the neutralization of H^+ in the soil solution by either OH^- or HCO_3^- originated from the liming material. For example, calcium carbonate ($CaCO_3$) behaves as follows:

$$CaCO_3 + H_2O \longrightarrow Ca^{2+} + HCO_3^- + OH^-$$

The rate of the reaction is directly dependant on the rate at which the OH^- ions are removed from solution. As long as sufficient H^+ ions are in the soil solution, Ca^{2+} and HCO_3^- continue increasing in the solution ($CaCO_3$ dissolves). When H^+ in soil solution are removed, the precipitation of Al^{3+} and Fe^{3+} as $Al(OH)_3$ and $Fe(OH)_3$ and their replacement in the CEC, with Ca^{2+} and/or Mg^{2+} , are ultimately formed (Halvin et al.,1999).

The benefit to using lime is the reduction of Al^{3+} and Fe^{3+} activities by precipitating as $Al(OH)_3$ and $Fe(OH)_3$ respectively, leading to reducing P fixation by Al and Fe. Liming also increases N_2 fixation, improve the structure of fine-texture soils and controls certain plant pathogen, leading to improvement of plant growth and crop yield. However, the most interesting benefits of limes are increasing availability of phosphorus and crop yield. Several studies found that liming significantly increased crop yields, decreased soil acidity, increased plant vigor and practically eliminated physiological leaf necrosis (Launghlin et al. 1974; Fageria et al., 1995; Meng et al., 2004). In addition, they found that the increased crop yield was dependent not only on reduction of soil acidity, but also on the improvement of soil quality. Lime applications also helped increase the uptake of N, P, K, Ca, Mg, and Na.

2.2.2 Soil acidity and phosphorus availability

In acidic soil inorganic P precipitates as iron-phosphates/aluminum-phosphates (Fe/Al-P) secondary mineral and/or is adsorbed to the surface of Fe/Al oxide and clay mineral. In neutral and calcareous soil, inorganic P precipitates as calcium-phosphate (Ca-P) secondary mineral and/or is adsorbed to surface of clay mineral and calcite ($CaCO_3$). The high amounts of total soil P do not always represent the high amount of available P to the plant. $H_2PO_4^-$ and HPO_4^{2-} are the form of soluble-P in soil solution, which is readily available for plant consumption. The amount of $H_2PO_4^-$ and HPO_4^{2-} present in the soil solution depends on soil solution pH. Approximately equal amount of $H_2PO_4^-$ and HPO_4^{2-}in soil solution at pH is 7.2. $H_2PO_4^-$ is the major form in soil solution at pH lower than 7.2 whilst $HPO_4^{2-}$is the dominant form at pH higher than 7.2 (Halvin et al., 1999).

However, old soil which has been cultivated for a long time becomes acidic soil because of removal of alkaline nutrients together with crop harvesting, leaching of nitrates from nitrogenous inappropriate application, and organic matter accumulation from crop residues. This old cultivated soil required liming to increase the soil pH to increase plant nutrient availability, particularly phosphorus, and crop yields.

2.2.3 Effects of liming on phosphorus availability

Duncan (2002) reported that there was some relationship between P-availability and lime under a pasture and grazing system in the Northern Tablelands. Where P was not added, liming increased the availability and plant uptake of P in acid soils where aluminum and manganese toxicities were presented. Liming increased P uptake, probably due to improvement of root growth (increasing root elongation and root length density). Furthermore, the increased mineralization and subsequent supply of P from organic matter might have also contributed in increasing P-uptake. Similarly, Oluwatoyinbo (2005) found that liming had a significant positive effect on P concentration in plant and actually reduced the amount of P-fertilizer required for optimum yield. In addition, lime application rates should be targeted to achieve pH levels of approximately 5.2 - 5.5.

2.3 Effect of organic matter on soil properties and nutrient availability

Soil organic matter (OM) is organic materials that have decomposed and completed the process of humification; process of transforming and converting organic residues to humus (Brady and Weil, 1999). OM is an essential component of soil (contributing to soil biological, chemical, and physical properties).

2.3.1 Effect of organic matter on soil physical properties

OM influences the physical conditions of soil in several ways. Plant residues that cover the soil surface protect the soil from sealing and crusting by raindrop impact, thereby enhancing rainwater infiltration and reducing runoff. Surface infiltration depends on a number of factors including soil structure (aggregation and stability), pore continuity and stability, the existence of cracks, and the soil surface conditions. Increased OM contributes indirectly to soil porosity (via increased soil faunal activity) (Wang et al., 2001; FAO, 2005). Improving of soil pore leads to improvement of rainwater harvesting and increased crop-water use efficiency. However, in sloping areas, soil conservation practices are needed to conserve soil and water together with improving soil OM to build a sustainable agriculture.

2.3.2 Effect of organic matter on nutrient availability

Using of OM provides many direct and indirect benefits. OM can improve nutrient use efficiency. The benefits of OM are related to the cycling of plant nutrients and the ability of the soil to supply nutrients for plant growth. OM retains plant nutrients and prevents nutrient loss, leaching to deeper soil layers. Microorganisms are responsible for the mineralization and immobilization of N, P and S through the decomposition of OM. Use of OM can reduce the soil P-sorption capacity when compared with the soil without OM application, more rapidly increasing soil pH when applied together with lime and at the same time increased the CEC (FAO, 2005; Cooperband, 2002). Moreover the SOM increased the soil's CEC, provided chelates, and increased the solubility of certain nutrients in the soil solution (Cooperband, 2002; McCauley et al., 2009). Therefore, in the soil with low availability of phosphorus, SOM is an important component to the availability of phosphorus, particularly phosphorus fertilizer.

2.3.3 Relationships of organic matter, phosphorus fertilizer and phosphorus availability

Organic phosphorus represents about 50% of total P in soil, the same as organic matter (OM), soil organic P decreases with depth. The P content of SOM ranges from about 1 to 3%. Generally organic P increases with increasing organic C and/ or N. Most organic P compound is an ester of orthophosphoric acid ($H_2PO_4^-$) and has been identified primarily as an inositol phosphate, phospholipids, and nucleic acids (Halvin et al., 1999).

Plants use only 10 - 20% of phosphorus in chemical fertilizers as water-soluble P after application in the first growing season. Approximately 30 - 40% of the rest becomes available to the plant over the next few years. In most soils the remaining 50% becomes fixed, and may not be available, at least in the short to medium term, until P from OM gradually moves back into soil solution (Duncan, 2002).

The turn-over process of organic P in soil is P mineralization and immobilization. Organic P is produced after degradation of plant and animal residues by soil microorganism. Then, organic P is mineralized by phosphatase enzymes. Phosphatase activity in soil is not only increased with increasing organic C content but also is affected by pH, moisture, temperature, and aeration of soil, cultivation intensity and P fertilization. The effect of the increased soil pH on P-availability is related to (1) OH^- competing with $H_2PO_4^-$ or HPO_4^{2-} for bonding site (2) greater microbial activity at neutral pH level and (3) increased precipitation of Ca-P minerals at pH level above 7 (Halvin et al., 1999).

Borie and Zunino (1983) and Wang et al. (2005), reported that the increased organic C and organic P were found in most cultivated soil which have used phosphorus fertilizer more than 10 years. It can be conclude that inorganic fertilizer P can be immobilized to organic P by microorganism. Continued fertilizer P application increases the organic P content and subsequently increases P mineralization. Organic P mineralization is clearly demonstrated by the gradual decreasing of organic P after decreasing of OM-content in soil. Extractable inorganic P initially increased but then decreased in a few years after continued cultivation (Halvin et al., 1999).

2.4 The source of zinc and effect of foliar zinc application on crop growth and yield

Zinc (Zn) is the trace element essential for promotion of crop growth, production of biomass and reproduction. Unfortunately, Zn deficiency was found in the crops grown in eroded soil and intensively cultivated soil.

Halvin et al. (1999) stated that Zn in soil solution is very low, ranging from 2 - 70 ppb, with more than half of the Zn^{2+} in the soil solution was complex by organic matter. Zn solubility is highly dependent on pH and increasing 100-fold for each decreased pH unit. Most Zn deficiency occurs at neutral pH and precipitates as insoluble amorphous soil Zn, $ZnSO_4$ and/or $ZnSiO_4$, which reduce availability of Zn (Zn^{2+}) in soil. Liming acidic soil, which is low in Zn content, will reduce uptake of Zn^{2+} which is related to the pH effect on Zn^{2+} solubility. Zn adsorption on the surface of calcite ($CaCO_3$) could also reduce soluble Zn^{2+}. Adsorption of Zn^{2+} by clay minerals, Al/Fe oxides, OM and $CaCO_3$, is increased with increasing pH.

As above mentioned, Zn easily changes to an unavailable form under liming and high organic matter content. The soil application of Zn fertilizer may not give high efficiency; foliar Zn application is an optional to solve the Zn deficiency (Broadley, 2007; Halvin et al., 1999).

2.4.1 Source of available zinc in soil

Most animal waste is known as an organic Zn source containing small quantities of plant-available Zn, typically ranging from 0.01-0.05 % (100 to 500 g/t) hence, a large manure application rate was used to provide sufficient plant-available Zn. On the other hand, zinc sulfate ($ZnSO_4$) is the common source of inorganic Zn or chemical fertilizer containing 35% Zn. It is more soluble in soil water and gives much more available Zn than organic fertilizer (Halvin et al., 1999).

2.4.2 Effect of foliar zinc application on crop growth and yield

Many investigators reported that foliar zinc application increased crop growth, quantity and quality of yield (Breman, 2005; Wang et al., 2005; Gobarah et al., 2006; Movahhedy-Dehnavy et al., 2009, Potarzycki and Grzebisz, 2009; Habib, 2009). Movahhedy-Dehnavy et al. (2009) studied the effect of foliar zinc application on the growth and development of safflower under water deficient conditions. They found that foliar Zn spray increased protein in seed, rate and percentage of germination, seedling emergence and dry weight under normal conditions. However, under drought stress, Zn had negative impacts on most of these parameters. Increasing zinc level from 0.50 to 1.00 gm l^{-1} significantly increased the above-ground biomass (Breman, 2005). Furthermore, Potarzycki and Grzebisz (2009) found that zinc foliar spray at the 5^{th} leaf growing stage of maize, with Zn application rate of 0.5 and 1.0 kg Zn ha^{-1}, could increase maize grain yield by 16% and 27% respectively. Such responses due to several plant enzymes and biosynthesis of growth substances controlled by Zn activity in plant. The Zn-deficient plant causes the shortening of internodes and smaller-than-normal leaves (Halvin et al., 1999).

In addition, foliar zinc application increased fertilizer use efficiency. Gobarah et al. (2006) observed that interaction between phosphorus fertilizer and foliar spraying with zinc significantly increased dry weight of stem, phosphorus and oil percentages and gave the highest peanut seed yields. Therefore, application of combined phosphorus and zinc may increase plant productivity much more efficiently than single application of either phosphorus or zinc only.

The overall reviewed studied research on the effects of conservative cultivation for sustainable rainfed sloping land agriculture and effects of liming including fertilizers applications on the improvement of soil acidity, nutrient availability, particularly based on phosphorus availability were mainly conducted in a green house or under controlled conditions. These studied results clearly showed that each single effects of each factor such as liming and fertilizers (phosphorus and zinc) applications on improvement of soil acidity and nutrients availability were significantly. However, under field conditions with variations of uncontrolled environment factors, such as soil moisture content, surface runoff and rainfall, etc., the results of those studies may be different from those under controlled conditions, particularly the study on sloping highland agricultural area. Furthermore, interactive effects of liming, organic/inorganic fertilizers application may be significantly different from single effect of either liming or fertilizer applications.