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Increasing Fertilizer Use Efficiency, Availability of Phosphorus and Crop yield in Furrow Cultivation for Sustainable Agriculture on Sloping Land

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Introduction

Soil and water conservative cultural practices are necessary to maintain soil and crop productivity on sloping cultivated land. Many strategies for soil and water conservation have been proved as efficient practices for several decades. However, a few have been adopted under the local conditions due to impractical and low cost of benefit return. During the last decade, Panomtaranichagul et al. (2010) had found that most effective methods for building a sustainable highland rainfed agriculture were the "*Integrated Water-harvest, Anti-erosion, and Multiple-cropping*, IWAM" techniques. The technique consisted of furrow cultivation, mulched with biodegradable materials and rotational crop growing in alley multiple cropping system. This field trial was a part of the research titled "*The improvement of anti-erosive and water harvesting practices in alley cropping to increase sustainable rainfed multiple crop production on sloping land*", under The Uplands Program (NRCT-DFG). Most representative soil in the study area or the experimental plot has low pH, available phosphorus (P) and zinc (Zn), particularly the high amount of extractable P (> 100 mg kg^{-1}) in this soil is not always available to plant. Therefore, it is necessary to improve soil pH, fertility and nutrient availability in order to increase soil and crop productivity. These may be achieved by applying lime, organic fertilizer and inorganic fertilizer including foliar Zn application, under the IWAM cultural practice.

This experiment aimed to study the effects of integrated cultural practice, zinc, lime, and fertilizer (organic and inorganic) applications on soil available phosphorus, crop growth, and yields, under contour conventional and furrow cultivation.

Materials and Methods

The experiment was conducted in Mae Chaem District (altitude 1,238 m, latitude 18° 31' 04.81" N, and longitude 98° 17' 29.46" E), Chiang Mai Province, Northern Thailand. The average annual rainfall during the last 10 years was approximately 1,500 mm. Dominant soil is Acrisols according to The World Reference Base for Soil Resources (WRB) classification.

The experiment was designed as a Split-split Plot in Completely Randomized Designed (Split-split Plot in CRD) with 3 replicates of the 6 combination-treatments. Main plots were two cultivated systems, conventional planting (CP) and furrow cultivation (CF). Sub plots were foliar zinc (Zn_1) and no-zinc (Zn_0) applications, and sub-sub plots were applications of lime (L), organic and inorganic fertilizers (OF and IF) including control (CP or CF only). The amounts and times of lime (L), organic fertilizer (OF), inorganic fertilizer (IF) and zinc (Zn) applications are described as follows.

Lime (L, Calcium carbonate, $CaCO_3$) was applied as dry powder by banding along the contour planting rows in order to reduce soil acidity. The lime application rate was 0.5 kg m^{-2} (5 t ha^{-1}), 2 weeks before crop sowing. The commercial products of organic fertilizer (OF, pH 7.1) (consisted of Total N, P and K 1.30, 2.04 and 1.19 g/100g respectively), and inorganic fertilizer (IF, ammonium phosphate, 16-20-0) were applied as planting-row-banding at the rates of 130 and 65 g/row (333 and 167 kg ha^{-1} respectively). The comercial grade of zinc sulphate ($ZnSO_4.7\ H_2O$, with 1 g l^{-1}-concentration) was applied as foliar spraying at 1 kg ha^{-1} rate for Zn application. All fertilizers were applied at seedling stage, 2 weeks after germination.

The crops were planted as multiple rotational relay cropping system, sweet corn (*Zea mays saccharata*) was the 1st crop, planted at the early-rainy season followed by peanut *(Arachis hypogaea L.)* as the 2nd crop in the mid- rainy season. Lablab bean *(Lablab perpureus Linn.)* was the 3rd crop, planted at the late-rainy season. Soil sampling and analysis were conducted before planting and monthly during seedling–harvesting period. The measured soil properties were bulk density (BD), particle density (PD), total porosity (TP), field capacity (FC), aeration porosity (AP), soil acidity (pH), organic matter (OM) and extractable phosphorus (Ext.P). Crop yield and biomass productions were measured as dry weight of seed yield and total dry matter above ground level per unit area. Total plant phosphorus (Total P) was analyzed at harvesting stage to measure plant uptake-phosphorus.

Results and Discussion

Effects of Cultivation, Lime and Fertilizers Applications on Soil Properties

Soil physical properties under conventional planting (CP) and furrow cultivation (CF) were not significantly different. However CF plot tended to have better soil physical properties than CP plot. CF tended to give lower BD, higher TP and AP (1.12 Mg m^{-3}, 0.54 m^3 m^{-3} and 0.20 m^3 m^{-3} respectively) compared to CP (1.23 Mg m^{-3}, 0.48 m^3 m^{-3} and 0.12 m^3 m^{-3} respectively). This might be due to soil loss and runoff including rainfall energy impact occurring in CF plot less than in CP plot. Figure 1 shows that the improvement of soil pH and OM content were found under CF more than CP. Particularly, substantially higher value soil pH and OM were obtained in CF plot (5.53 and 3.6 g/100g respectively) after lime and organic fertilizer applications compared to CP plot (4.67 and 3.3 g/100g respectively).

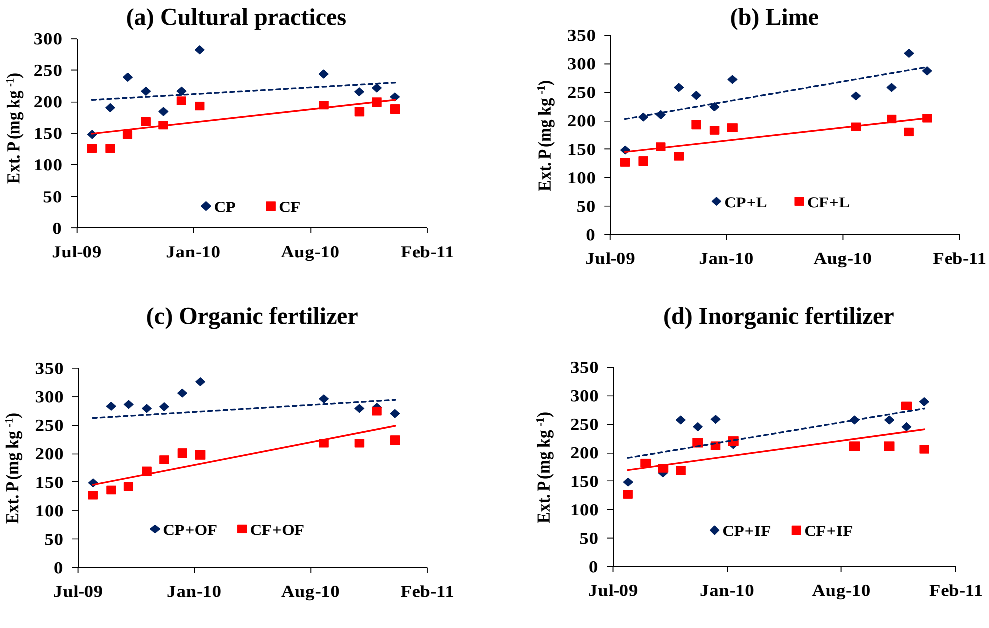

Figure 1. *Variation of Extractable phosphorus (Ext.P) within 0-20 cm soil depth under conventional planting (CP) and furrow cultivation (CF)with applications of **(a)** no lime and no fertilizers (CP or CF only) **(b)** lime (L), **(c)** organic fertilizer (OF), and **(d)** inorganic fertilizer (IF) during Aug 2009- Jan 2011.*

However, CP tended to result in higher amount of Ext.P than CF (Figure 1). This might be caused by the lower crop development and less phosphorus consumption under CP than CF. Both CF and CP tended to increase the Ext.P after applying lime, organic and inorganic fertilizers as shown in Figure 1 (a-d). OF applied in CP plot tended to give the highest residual amount of Ext.P compared to L, IF and CP only. Figure 1 (a-d) also shows that, lime and fertilizers applied in CP plot tended to give largely varied amounts of Ext.P during the two experimental years. Conversely, the applications of lime and fertilizers tended to give little variations and similar amounts of Ext.P in CF plot. In general, the residual amounts of Ext.P under each single effect of the studied treatments were not significantly different. This might have resulted from interactive effects of different treatments (cultivation methods, liming and fertilizers applications), the amount and distributions of rainfall including crop developments during different growing stages (Panomtoranichagul and Narubarn, 2008, Tisdale and Nelson, 1966).

Effects of Cultivations and Zinc Application on Crop Growth

Furrow cultivation (CF) resulted in better growth (height) of lablab bean in dry season than conventional planting (CP, Figure 2a), as well as foliar zinc application (Zn_1) tended to give better crop height than no zinc application (Zn_0, Figure 2b). These result were due to better rain harvesting, more soil water storage, less surface runoff and soil loss including nutrient loss under CF than CP. More fertilizer use efficiency was found in CF plot than CP plot. Foliar Zn application (Zn_1) promoted better crop development than Zn_0 because the natural Zn content in soil was very low and insufficient for plant growth.

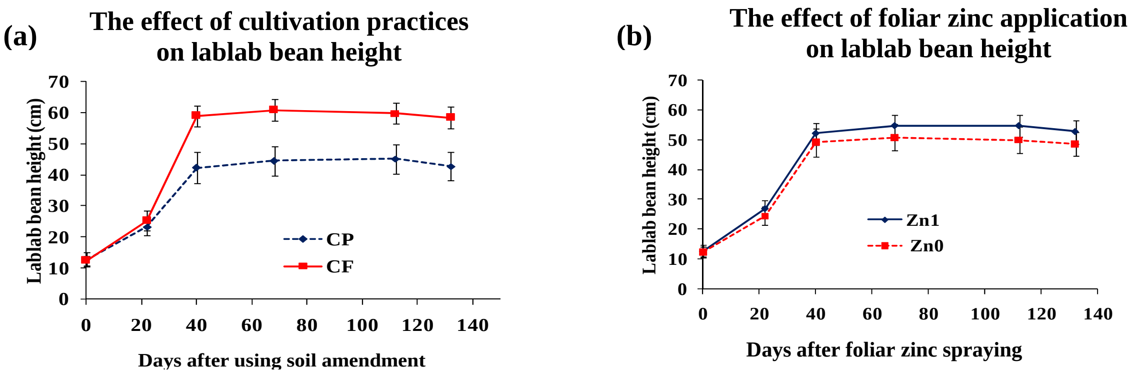

Figure 2. *Lablab bean growths (height) under (a) Conventional planting (CP) and Furrow cultivation (CF), and (b) foliar zinc (Zn_1) and no-zinc (Zn_0) application*

Effects of Cultivations and Applications of Zinc, Lime and Fertilizers on Total Phosphorus Uptake by Plant

Table 1 shows that furrow cultivation (CF) gave phosphorus uptake (Total P) of crop more than conventional planting (CP). Foliar zinc spraying (Zn_1) also gave higher Total P consumption than no-zinc (Zn_0) application.

Table 1. *The amount of total phosphorus (kg P ha^{-1}) in plant (lablab bean) under different treatments, cultivation methods (CP and CF), foliar zinc (Zn_1) and no-zinc (Zn_0) applications, control (CP or CF only), lime (L), organic (OF) and inorganic (IF) fertilizer applications.*

Treatments	20-Feb-10	14-Jan-11
Conventional planting (CP)	2.44	0.39
Furrow cultivation (CF)	5.15	0.90
Foliar zinc application (Zn_1)	4.64	0.86
No zinc application (Zn_0)	2.55	0.42
Control (CP or CF only)	1.90	0.25
Lime application (L)	2.62	0.65
Organic fertilizer application (OF)	3.61	0.75
Inorganic fertilizer application (IF)	6.72	0.92

Inorganic fertilizer (IF) gave the highest P-uptake of lablab bean compared with organic fertilizer (OF), lime (L), and control (CP or CF only), which gave the 2nd, 3rd and 4th high P-uptake respectively. The amount of P- uptake in 2011 (14-Jan-11) was very low due to the long drought period during the late rainy season, after lablab bean planting, leading to pour crop development caused by the low water and nutrient use efficiency.

Effects of Cultivations, Lime, Fertilizers and Zinc Applications on Total Dry Matter and Yields

The effect of foliar zinc application under different treatments on total dry matter and yield of lablab bean during dry period are shown in Figure 3. The amounts of total dry matter and seed yield of lablab bean in CF plot were significantly higher than in CP plot (Figures 3a, 3b). This was caused by higher rain harvest, more stored soil water, lower amounts of runoff and soil loss, less amount of nutrients loss, leading to higher water and nutrient use efficiency in CF plot compared to CP plot.

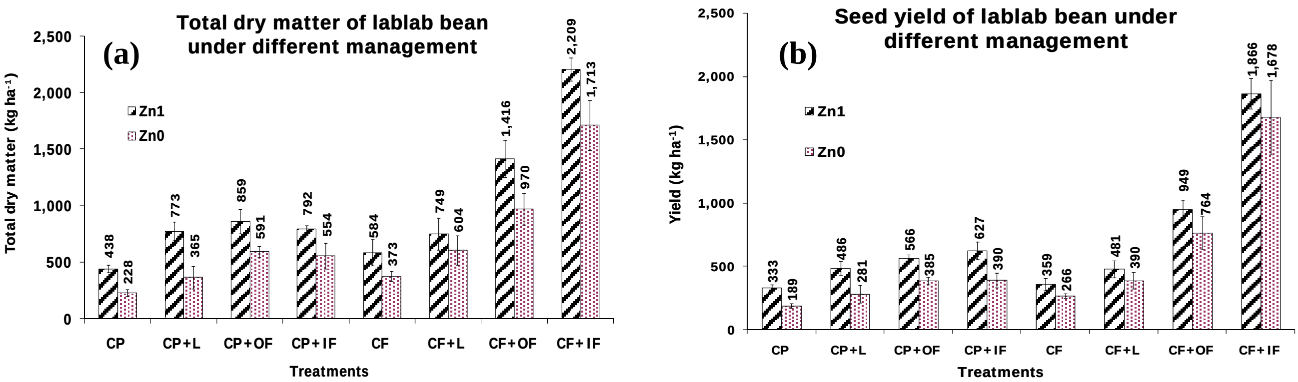

Figure 3. *Total dry matter (a) and seed yield (b) of lablab bean different soil amendments; control (CP or CF only), lime (L), organic (OF) and inorganic (IF) fertilizer, and influence by foliar zinc (Zn_1) and no-zinc (Zn_0) applications under conventional planting (CP) and furrow cultivation (CF).*

This results was supported by Panomtaranichagul et al. (2010) which reported that crop growth and yield productions in cultivated furrow (CF) were significantly higher than those in conventional planting (CP), on sloping highland under rainfed cultivation.

Figure 3 also shows that IF gave the highest values of total dry matter and seed yield compared to the other treatments. Whilst OF, L, and control gave the 2nd, 3rd, and 4th high amount of total dry matter and seed yield of lablab bean respectively. Foliar zinc application (Zn_1), also gave higher crop productions (total dry matter and seed yield) than no-zinc application (Zn_0). These results were corresponded to Movahhedy-Dehnanavy et al. (2009), which reported that foliar Zn spraying improve the seed yield and quality of oil plant grown under the drought stress. The reasons were that zinc promotes nitrogen and phosphorus uptakes, it is important in the synthesis of tryptophane, a component of some proteins and a compound needed for the production of growth hormone (auxin) and seed forming (Broadley et al., 2007). Further more, inorganic fertilizer applied with zinc foliar application, gave the highest amount of total dry biomass and seed yield of lablab bean, in CF plot (2,209 and 1,866 kg ha^{-1} respectively) which were three times higher than those given in CP plot (749 and 627 kg ha^{-1} respectively).

Conclusions

Furrow cultivation (CF) was the most efficient in conserving nutrients and water, leading to higher crop growth and yield than conventional planting (CP). Lower Ext.P remained in CF plot due to better crop growth with more nutrient consumption compared to CP plot. Applying lime and organic fertilizer under both cultivation practices (CP-L, CP-OF, CF-L and CF-OF) promoted more available phosphorus leading to higher crop growth and yield production compared to either CP or CF only. Foliar zinc application had promoted on crop growth, total dry matter, and seed yield significantly. Furthermore, combination of foliar zinc spray and inorganic fertilizer application under CF gave the highest crop growth, total dry matter and seed yield compared to the other treatments.

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