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Maize Cannot Be Grown in Xiengkhouang Province?

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Abstract

During a 2005 visit with National Agricultural and Forestry Institute (NAFRI) Director, Dr. Kouang Doungsila issued a challenge to these authors to determine if it was true that crops could not be grown in the extensive uplands of Xiengkhouang Province, Laos PDR. In response, a two-phase series of experiments was proposed and implemented. The Phase I experiment was to bring soil from the Xiengkhouang province uplands to a NAFRI greenhouse near Vientiane to assess possible nutrient requirements using a nutrient omission experiment. Simultaneously, soils were collected and analyzed from seven recognized agricultural regions of Laos. The initial Vientiane greenhouse experiment indicated that maize did grow, but there were multiple issues of extreme soil acidity and clear deficiencies of phosphorus and other nutrients. Phase II of the study included field studies on the site of soil selected for the greenhouse study. Field experiments were carried out for two years at the site with yields of maize exceeding 5500 kg·ha^{-1} in the first year and exceeding 6250 kg·ha^{-1} in a subsequent year. Intense symptoms of nutrient zinc (Zn) deficiency were observed, however. In 2008 another experiment was designed and carried out that included a Zn variable. The results from that experiment confirmed that maize yields nearing 6000 kg·ha^{-1} were indeed possible. Substantial amounts of lime were needed to correct the strong soil acidity, and a series of other nutrients including N, P, K, and Zn were also required. Ongoing issues are where to obtain the extensive amounts of limestone needed as well as an evaluation of the residual effect of the limestone The finely ground, very reactive burnt lime residual effect was, as expected, short-lived. The results clearly demonstrated that, indeed, it was possible for maize to be produced in the extensive uplands of Xiengkhouang province, in answer to Director Khouang's challenging question.

Keywords

Lao Uplands, Food Security, Acid Soils of the Tropics

1. Introduction

According to the World Food Program's Comprehensive Food Security and Vulnerability Analysis of Laos, food insecurity is widespread throughout the country and alarmingly high in rural areas [1]. While Lao PDR has reduced the proportion of hungry poor to 23 percent, the 2015 Global Hunger Index still rates hunger levels as "serious". Climate change is expected to further worsen this situation [1]. The 2019 report further states that, 35.6% of children between 6 and 59 months suffer from chronic malnutrition and stunting [1]. One of the contributing factors is the insufficient production of food.

Local experience as of 2005 was that food crops such as maize could not be grown in the extensive highlands of the province of Xiengkhouang, Laos (Kouang Doungsila, 2005, personal communication). Director Doungsila personally challenged the authors of this study to examine that local opinion and conclusion and if true what solutions might be feasible. This manuscript describes the initial research studies carried out in response to Director Kouang's challenge. The study reports two phases. Phase 1 was a greenhouse investigation carried out by Konepany Dounphady [2] in controlled conditions in Vientiane. Phase 2, a field experiment was carried out by the senior author of this manuscript in Pek district, Xiengkhouang province in 2010. Both studies comprised Master's in Soil Science degrees at Kasetsart University, Bangkok, Thailand.

Other researchers in Laos have previously identified soil phosphorus (P) as being among the nutrients that most limiting growth of rice in both uplands soils of Laos [3] [4] as well as in lowland soils [5]. A subsequent study also carried out by the senior author of this manuscript confirmed and quantified the extensive P deficiency in Lao uplands [6].

The plains of Xiengkhouang province of Laos are located in the northeast part of Laos and represent high potential for production of food and industrial crops such as maize. As of 2005, only 5% of the plains were cultivated [7]. In the vicinity of the provincial capital of Xiengkhouang, it is estimated that more than 60,000 ha of acid, infertile savanna grassland was under-utilized by smallholders [8].

Limitations to food crop production by phosphorus are well-known in the tropics and a large number of technologies are available to diagnose and solve this pervasive problem [9].

2. Objectives

Phase 1. Greenhouse

- Was crop growth possible on soils of the uplands of Xiengkhouang Province, Lao PDR?
- What factors are most likely limiting crop growth on such upland soils?

Phase 2. Field

- Carry out confirmation studies in field conditions of the Lao uplands to confirm which nutrients or conditions were limiting crop growth in the extensive uplands of Xiengkhouang Province.
- Assess yield potential of maize in a site representative of upland soils and estimate amendments necessary to achieve maximum yield.

3. Materials and Methods

Phase 1. Greenhouse studies

Soils were collected, in 2006, from grasslands near Mee village, Pek district, Xiengkhouang Province Lao PDR (19˚24'21.01"N; 103˚06'38.48"E). Samples were taken from the 0 - 20 cm depth. Total N was determined by Kjeldahl analysis [10], available P was extracted by Bray 2 [11], Mehlich 1 [12], and by the Fe-strip Pi [13] methods. Exchangeable K, Ca, Mg, Na were extracted by NH_4OAc, pH 7 [14], and cation exchange capacity (CEC) was measured by NH_4OAc, pH 7 [14]. Organic matter (OM) was determined by the method of Walkley and Black [15]. Iron, Mn, and Zn were extracted by the DTPA pH 7.3 method [16]. Extractable Al and Fe were measured by two methods—acid ammonium oxalate pH 3 and the citrate bicarbonate dithionite method [17].

The taxonomic classification of the soils was determined using Soil Taxonomy [18].

Maize variety (*Zea mays*, L. "LVN10"), which was extensively grown in the Vientiane province was selected for the greenhouse study. The greenhouse study was conducted at the Dong Dok Station, Vientiane, during the late summer of 2006.

Phase 2. Field studies

A field experiment was begun in 2006 by Dounphady on the grasslands near Mee village, Pek district, Xiengkhouang Province [2]. The soil of this area was that used in the Phase 1 experiment at the Dong Dok Station, Vientiane. The soil was tentatively classified as a fine, kaolinitic, isohyperthermic, Typic Paleustult. Nutrient and chemical analysis is shown in **Table 1**. This soil was very acid, high in Al and Fe oxides and also extremely P deficient. Lime, 3500 $kg \cdot ha^{-1}$ of $Ca(OH)_2$, was applied two weeks prior to planting of the first crop (2006) and incorporated to a depth of 20 cm [2]. The field study of 2006 (data not shown) revealed that maize responded to P applications up to 56 $kg \cdot P_2O_5 \cdot ha^{-1}$ but plants still appeared P deficient and zinc (Zn) deficiency symptoms were also observed.

In 2007, an additional 300 $kg \cdot ha^{-1}$ of burnt limestone was added.

Table 1. Characteristics of the Pek soil from the field experiment site, Xiengkhoung province, Laos. The sample was selected for the nutrient omission experiment.

	Pek
Texture	SCL
Clay ($g \cdot kg^{-1}$)[1]	323
Soil pH[2]	4.5
OC ($g \cdot kg^{-1}$)[3]	22.4
CEC ($cmolc \cdot kg^{-1}$)[4]	12.1
Total N($g \cdot kg^{-1}$)[5]	1.00
Total P ($g \cdot kg^{-1}$)[6]	2.40
P ($mg \cdot kg^{-1}$)[7]	1.46
P ($mg \cdot kg^{-1}$)[8]	0.85
P ($mg \cdot kg^{-1}$)[9]	0.60
K ($cmolc \cdot kg^{-1}$)[10]	0.12
Ca ($cmolc \cdot kg^{-1}$)[10]	0.56
Mg ($cmolc \cdot kg^{-1}$)[10]	0.09
Na ($cmolc \cdot kg^{-1}$)[10]	0.33
Feo ($g \cdot kg^{-1}$)[11]	3.91
Fed ($g \cdot kg^{-1}$)[12]	21.8
Alo ($g \cdot kg^{-1}$)[11]	3.07
Ald ($g \cdot kg^{-1}$)[12]	7.65

[1]Pipette method [23]; [2]Glass electrode, 1:1 soil:water ratio; [3]Walkley Black titration [15]; [4]NH4OAc, pH 7 replacement method [16]; [5]Macro Kjeldhal methods [24]; [6]Conc. HNO_3-H_2SO_4-$HClO_4$, ratio 5:1:2 [14]; [7]Bray 2 method [11]; [8]Mehlich-1 extractable P [12]; [9]Pi-test [13]; [10]NH4OAc pH 7 [25]; [11]Ammonium oxalate pH 3 in darkness [17]; [12]Citrate bicarbonate dithionite method [17].

Prior to planting the 2008 crop, the experimental plot was tilled as in years 2006 and 2007, N and K were applied at the same rate as previously by Dounphady, specifically 110 $kg \cdot N \cdot ha^{-1}$ was applied as urea, 82 $kg \cdot K \cdot ha^{-1}$ was applied as muriate of potash [2]. The N was split-applied two times, at 10 days as a basal dressing and at 30 days after planting as a top dressing. Phosphorus was applied as triple super phosphate as previously. In 2006 and 2007 the P application was 0, 7, 14, 28, and 56 kg P_2O_5 ha^{-1}, incorporated. In 2008, P was re-applied in the same plot as 0, 16, 32, 64, and 128 kg P_2O_5 ha^{-1}. The same variety of maize (*Zea mays*, L. "LVN10") was planted as in 2006 and 2007. This variety is adapted to growing conditions in other zones of the Lao PDR. A soil sample was composited from cores taken between the rows in each plot including 20 samples in 20 cm depth, and P was extracted by Bray 2, Mehlich 1 and the Fe-strip Pi.

The 2008 field experiment was laid out using an RCB design. The main plot size was 6 m long × 5 m wide with 8 rows and 200 plants. The plant spacing was 25 cm within the row × 75 cm between rows. Each main plot was divided into two subplots comprised of 4 rows. Each subplot either received or did not receive seed-applied Zn as a factor stripped over the entire experiment. Zinc sulfate (4.78 kg·Zn·ha^{-1} as $ZnSO_4·7H_2O$) was applied as a coating of the maize seed using a gum arabic solution as the adhesive. The solution was prepared by dissolving 75 g of gum arabic in 250 ml boiling, deionized water. After cooling, the $ZnSO_4·7H_2O$ was added to the gum arabic solution and 937.5 g of maize seed (30 kg·ha^{-1}) was put into the solution and mixed thoroughly [19].

3.1. Grain and Stover Yield Collection

Grain and Stover data were collected from the middle two rows in subplots of Zn and without Zn applied treatments. The two rows of plants and two plants of the beginning and the end of row were used as guard plants. The harvest area of grain and stover was 6 m^2.

3.2. Statistical Analysis

Grain yields as affected by levels of P and Zn were analyzed using a strip-plot analysis with SAS [20] since the Zn was applied as a stripped factor. Yields of grain in 2008 were plotted versus P applied in 2008 to assess whether maximum response to added P had been obtained.

Grain yields for 2008 versus P additions in 2008 were also analyzed using a linear—plateau model [21], which is an implementation of the linear response model presented by Anderson and Nelson [22].

4. Results

Phase 1. Soil Analysis and exploratory Greenhouse evaluation of nutrient limitations using a nutrient omission experiment at the Dong Dok experiment station, Vientiane.

Phase 2. Field study at Pek District, 2008 yields harvested (included Zn).

5. Discussion

Phase 1. Results from both the soil analyses (**Table 1**) and the nutrient omission experiment (**Table 2** and **Figure 1**), indicate that both soil pH and nutrient levels were extremely low and clearly were growth limiting for most food crops. The nutrient omission experiment clearly demonstrated that among nutrient limitations, the P deficiency limitation was one of the most growth limiting. At the same time, the experiment clearly demonstrated that maize could grow well if the soil constraints were alleviated in the soil from Xiengkhouang province and that there was a possibility of excellent maize growth in the extensive, un-cropped plains. These two results indicated that while extremely nutrient poor and extremely acidic, there was no other apparent reason for crops could not grow well in the extensive uplands of the province.

Table 2. Response of maize in the Dong Dok greenhouse nutrient omission experiment. Measurements taken 55 days after planting (see also Figure 1).

Fertilizer rates: (N-P_2O_5-K_2O-$ZnSO_4$)	Dry weight (g/pot)
Lime applied (8.70 g/pot)	
T1:0-0-0-0	29.3c[1]
T2:-N	73.3b
T3:-P	28.2c
T4:-K	75.9ab
T5:-Zn	88.9ab
T6:+N, +P, +K, +Zn	96.2a

[1]Dry weights with the same letter did not differ at the P = 0.01.

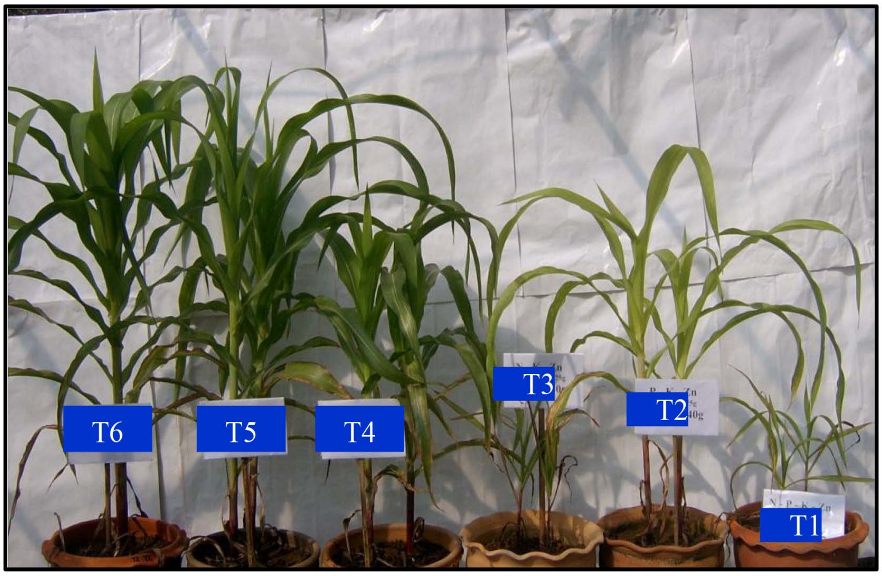

Figure 1. Maize growth at 55 days after planting in the nutrient omission experiment, Dong Dok Station, Vientiane.

Phase 2. The second phase of the response to the challenge delivered by Director Doungsila was to carry out field experiments in Xiengkhouang province. This was begun by student Konepany Dounphady in 2006 and 2007 and demonstrated that soil of the Pek district could support a complete growth cycle of maize. Two initial crops of maize carried out in 2006 and 2007 indicating that initial estimates of required levels of P were too low. This was confirmed in a country-wide survey of the seven major agricultural provinces of Laos: Champasak, Luang Prabang, Salavanh, Sekong, Vientiane, Xayaboury, and Xiengkhuang [6]. During the 2006 and 2007 maize experiments, a severe Zn deficiency was observed and thus the 2008 experiment included a strip plot application of Zn.

The results of the 2008 experiment confirmed that maize could be grown very successfully on the upland soils of Pek district and likely in other districts of the extensive Xiengkhouang uplands (**Table 3**). Of particular interest was the result that yields increased with the additional application of P (**Figure 2**). The application of Zn confirming earlier observations that it might be limiting. It was also interesting that the response to the addition of Zn was even greater at high levels of applied P. Maize response as measured by stover yields also increased markedly as well.

A soil analysis taken subsequent to the 2008 harvest pointed out several additional issues with growing crops on such acid soils (**Table 4**). The limestone initially added was burnt limestone, CaO, and as such it was extremely fine powder, which neutralized the soil acidity very rapidly, but does not typically have a long residual effectiveness. A slight decrease in soil pH was observed after the 2006 crop and some 300 kg was additionally applied prior to the 2007 crop. Soil pH after the 2008 crop was again in the very low ranging of 4.5 to 4.7. This soil pH is again too low and suggests additional liming is surely needed. This result is not surprising, because the initially applied burnt lime is ideal for quick acting, but does not have a long residual effectiveness. Consequently, it seems imperative that alternative sources of agricultural limestone are needed and a strong suggestion is to explore local reserves of naturally occurring limestone for a low-cost, locally available material. The use of the expensive burnt limestone, likely is financially profitable only for the extremely high value crops. If other soils are similarly deficient in Zn, then the provision of Zn as part of a foundation fertilization may be warranted.

Table 3. Grain and stover yield, Pek District, Xiengkhouang, Laos in 2008.

P rates (kg·ha^{-1}·P_2O_5)	Grain yield (kg·ha^{-1})		Stover yield (kg·ha^{-1})	
	Zn	No Zn	Zn	No Zn
0	1382	1302	2593	1893
16	3382	2945	5276	5078
32	4169	3246	6732	6189
64	4991	4213	10,462	9577
128	5735	4418	12,197	11,063
Zn applied	**		*	
P applied	**		**	
Zn applied*P applied	NS		NS	
CV%	15.26		14.31	
F-test	67.02	17.78	94.67	100.81
Intercept	1584.80	1302.01	2921.00	2489.90
Slope	199.1	234.74	273.1	260.8
Node	18.98	11.33	33.97	32.87

Note* = Significantly different at 95%; ** = Significantly different at 99%; NS = Not significant.

Table 4. Soil chemical analysis after harvest in 2008.

P rates	$ZnSO_4 \cdot 7H_2O$	pH	Zn (DTPA)	P_{Bray2}	$P_{Mehlich1}$	$P_{Fe\text{-}strip\ Pi}$
($kg \cdot P_2O_5 \cdot ha^{-1}$)	($kg \cdot ha^{-1}$)	(1:1)	($mg \cdot kg^{-1}$)	----------------($mg \cdot kg^{-1}$)-------------		
0	4.72	4.5	0.52	3.12	2.86	1.33
16	4.72	4.7	0.63	5.44	3.85	1.89
32	4.72	4.6	0.36	12.88	8.24	5.55
64	4.72	4.6	0.20	25.32	21.05	16.24
128	4.72	4.7	0.64	32.25	28.20	22.45
0	0	4.6	0.23	3.34	3.19	1.45
16	0	4.9	0.21	5.94	3.96	2.04
32	0	4.4	0.23	13.45	4.81	5.34
64	0	4.8	0.38	29.23	15.24	13.55
128	0	4.8	0.17	37.52	32.00	22.86

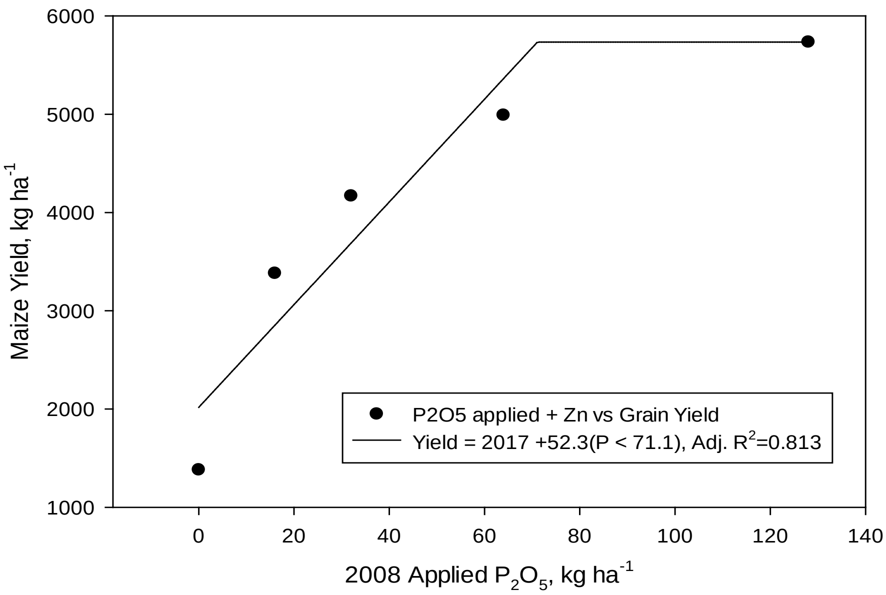

Figure 2. Maize grain yield 2008. Phosphate applied in 2008.

These results clearly provide a strong affirmative answer to Director Doungsila's challenge question as to what does it take to grow crops in the extensive Xiengkhoung uplands. We profoundly thank Director Khouang for his valuable, foresighted challenge.

6. Conclusions and Recommendations

The utility of classifying the soils can be illustrated by pointing out that the soil at the site of the experiment; Pek, was classified as a Typic Paleustult, indicating a highly weathered, acid, low nutrient capacity soil as well as low nutrient containing. The results show that these soils were both infertile and acid and will require substantial lime and fertilizer inputs, but can become highly productive if properly managed. Similar soils are highly productive elsewhere in the tropics.

It was observed that the soils had become acid again (pH 4.6) suggesting that the quick-acting burnt lime had a residual effect of approximately 2 to 3 years.

The expected productivity of LVN10 variety of maize was about 6 - 7 $t \cdot ha^{-1}$. The field experiment results suggested that the P requirement of this area was 71 $kg \cdot P_2O_5 \cdot ha^{-1}$. Besides the lime and P applications, it was shown that Zn was necessary for maize production in Xiengkhouang province.

The results of this study indicate that high yields of food crops were possible with proper management. The soil pH should be increased to be 5.5 - 6 with local liming materials and adequate amounts of P and Zn fertilizer applied. Moreover, planting with native legumes or other acid tolerant plants during the dry season and the incorporation of the residues into the soil is also recommended, especially when maize is to be grown. Gradually, the soil will be improved to better physical and chemical properties. These results suggest that the region has enormous potential to support food crops and to improve food security of the region.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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