

NPK Removal from Maize Cultivation Fields in Kenethao and Paklai Districts, Xayabury Province, Lao PDR

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Abstract

The maize cultivation area in Lao PDR has increased since 2004, mostly without the use of fertilizer. For sustainable maize production, maintaining soil fertility is essential. This study aims to clarify nutrient removal by maize cultivation in fields located in the districts of Kenethao and Paklai in Xayabury Province—the main maize production area in Lao PDR. Field surveys were conducted at 27 plots in nine farmer fields in 2013 to measure maize production, collect plant samples for analyzing nutrient uptake and soil samples for analyzing nutrient stock in the soil, and interview farmers about cultivation practices and field history. N, P, and K removal by harvest from the fields totaled 51.7, 7.5, and 14.2 kg ha⁻¹, respectively. Nutrient stock in the soil surface layer at 0-20 cm deep was 2980 kg ha⁻¹ as total N, 10.1 kg ha⁻¹ as available P, and 233 kg ha⁻¹ as exchangeable K. N and K stocks in the soil were sufficient compared with N and K removal in maize at harvest, although available P in the soil was similar in amount compared to P removal by harvest. Most farmers did not apply any fertilizer for maize cultivation. The N, P, and K balances in the fields were estimated at -47.6, -7.4, and -14.3 kg ha⁻¹, respectively, without fertilizer input, and were improved to -25.6, +1.4, and +5.5 kg ha⁻¹, respectively, by applying chemical fertilizer.

Discipline: Agricultural Environment

Additional key words: Lao PDR, maize, nutrient balance, nutrient level in soil, nutrient removal

Introduction

The maize cultivation area in Lao PDR has increased since 2004, reaching a total harvest area of 200,000-220,000 ha with the production of 1.1-1.2 million tons of maize since 2008, and then stabilizing until 2017 (Ministry of Agriculture and Forestry 2001-2018). Lao farmers produce maize as a cash crop to earn income with promotion by the Lao government. Xayabury Province is the main maize production area with 60,000 ha of harvest area and 0.3-0.4 million tons of crop production (Ministry of Agriculture and Forestry, Lao PDR 2001-2018). Based on our preliminary survey and interviews with farmers in Xayabury Province in 2011, maize fields have been expanded by converting upland rice fields or clearing forest. Local farmers have cultivated maize without applying chemical fertilizer, resulting in lower maize yields in recent years (Fujisao et

al. 2018). And nutrients removed through maize crop harvest may lead to land degradation.

Nutrients are removed from the soil at crop harvests. The application of fertilizer supplies nutrients to support crop growth and replenish soil nutrient stocks. Tan et al. (2005) estimated global soil NPK budgets for major crop production in 2000, and suggested that soil nutrient depletion can be attributed to insufficient nutrient inputs in many developing countries and in all of the least developed countries. Analyzing the nutrient balance in farmland is useful for understanding nutrient depletion in farmland and reveals the effects of nutrient management practices in cropping systems on soil nutrient status (e.g., Frissel 1978). When a field has a lot of nutrients in the soil with no or low fertilizer input, the amount of nutrient uptake by the crop is higher than the amount of nutrient input to the farmland; hence, the nutrient balance becomes negative (Haileslassie et al. 2006, He et al.

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2013). Nutrient input through the application of chemical fertilizer and manure shifts the nutrient balance from negative to positive, so as to maintain soil fertility for increased crop production (Pinitpaitoon et al. 2011, Wang et al. 2007a, Yanai et al. 2007). Few studies have been made on the nutrient balance in farmland in Laos. The nutrient balance in rain-fed lowland rice fields was studied by Linquist et al. (2007), but the nutrient balance in maize fields has yet to be analyzed.

This study aims to clarify how much nutrient is absorbed by maize, returned to farmland, and input by fertilizer application, in order to estimate the nutrient balance in maize fields and evaluate nutrient removal by maize production on nutrient stocks in the soil of maize fields in Xayabury Province—the main maize production area in Lao PDR.

Materials and methods

1. Description of study sites

The study was conducted in the districts of Kenethao and Paklai in Xayabury Province (Fig. 1), which is located at N17°35' to N18°51' and E101°07' to E101°51'. Altitude at the study sites varies from 220 to 1175 m a.s.l. From 1982

to 2012, Xayabury recorded annual mean temperature of 25.4°C and annual precipitation of 1282 mm. The area is categorized as being mountainous with paddy fields in the lowlands, and forests and upland crop fields on sloping land. Upland rice, maize, and legume crops are cultivated in upland fields. The type of soil in the survey area is Orthic Acrisols (FAO/UNESCO, 1976).

2. Estimation of nutrient uptake by maize

We selected nine maize fields with typical maize growth in the area with guidance provided by officers of the District Agriculture and Forestry Office (DAFO) in the districts of Kenethao and Paklai. Maize production was measured at three points in plots of 3 m x 3 m in each field.

The fresh weight of all maize ears and stover in each plot was measured to determine production. And to determine dry weight, the fresh weight of collected ear and stover samples was measured in each plot. The ear samples were dried in the sun for 4-5 days, and then separated between seeds and cobs. The seeds, cobs, and stover of samples were dried in an oven at 75°C for 48 h, and then weighed to obtain the dry weight. Dry matter production of seeds, cobs, and stover was calculated by

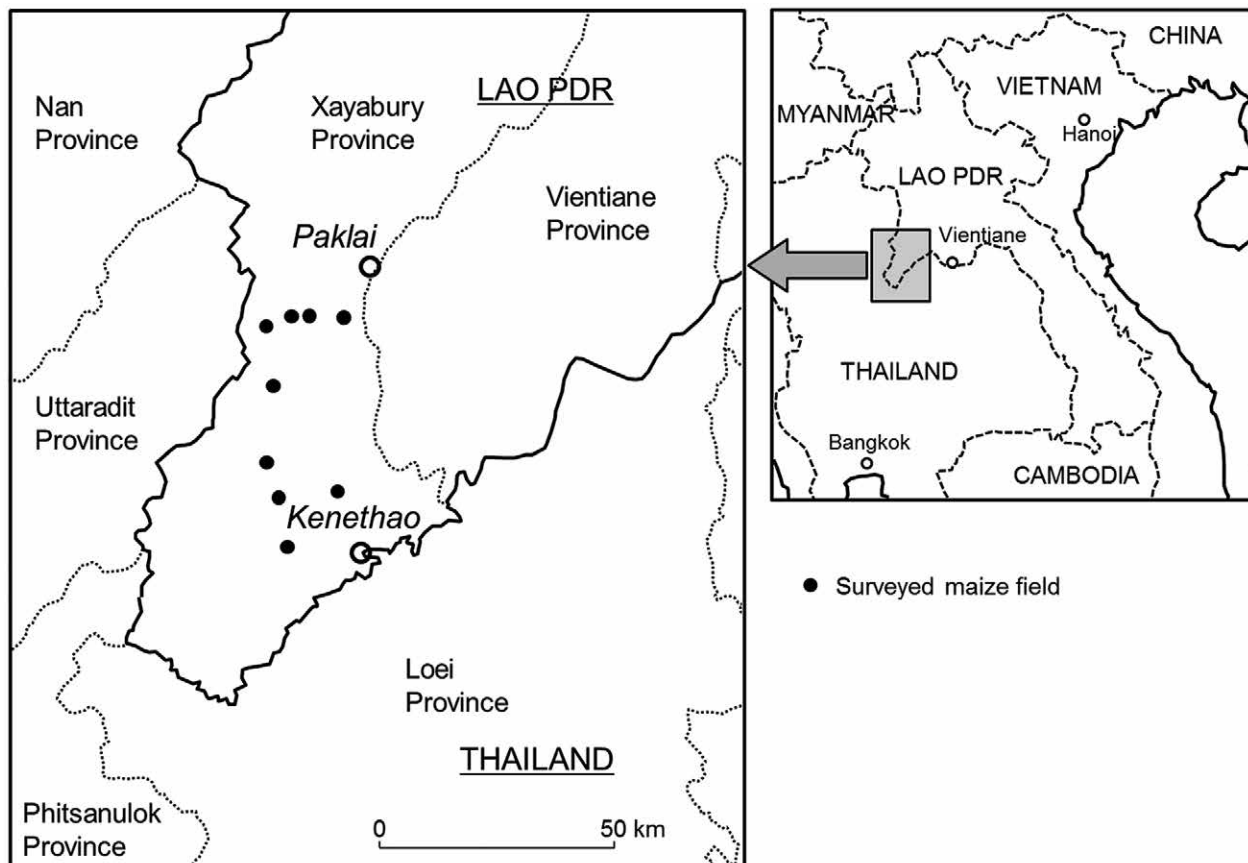


Fig. 1. Sites of the surveyed maize fields in Kenethao and Paklai districts, Xayabury Province in 2013

taking the ratio of dry weight per fresh weight of samples and the fresh weight of all ears and stover in each plot. Seed yield (15% moisture) was calculated by the dry matter production of seeds in the plots.

Samples of the oven-dried seeds, cobs, stover were ground for analysis of N, P, and K content. Total N content was determined by high-temperature combustion and subsequent gas analysis (Dumas processing) (JM-3000CN, J-Science Lab, Kyoto, Japan). Total P content and total K content were digested by nitric-perchloric acid (Miller 1998). The P content of the digested solution was determined by the molybdenum blue colorimetric method. The K content of the digested solution was determined on an atomic absorption spectrometer (AAAnalyst 200, PerkinElmer, Waltham, MA, USA).

N, P, and K uptake by seeds, cobs, and stover was calculated by multiplying dry matter production by the N, P, and K content in each part of each plot.

3. Analysis of soil chemical properties

Soil samples were collected from depths of 0-20 cm at three points and then mixed for each plot. Soil samples were air dried, crushed, and sieved through 2 mm. Total N content of the soil samples was determined by high-temperature combustion and subsequent gas analysis (Dumas processing) (JM-3000CN, J-Science Lab). The available P of the soil samples was extracted by the Bray-2 method and then determined by the molybdenum blue colorimetric method. Exchangeable K, Mg, and Ca of the soil samples were extracted by 1 N NH_4OAC , and then determined on an atomic absorption spectrometer (AAAnalyst 200, PerkinElmer).

4. Interviews with farmers and field observations

We conducted interviews with farmers about maize cultivation practices, such as variety, plowing, fertilizer application, weeding, and cultivation history of the maize fields. We observed the planting conditions of maize in the surveyed fields, such as hill space, the number of plants, and height of maize.

5. Statistical analysis

Statistical analyses were conducted using JMP 10 (SAS Institute Inc., Cary, NC, USA). The effects of slope position and chemical fertilizer application on maize seed yield and soil chemical properties were examined using the Tukey-Kramer HSD test. The correlation between maize seed yield and soil chemical properties was also evaluated.

Results

1. Field conditions and cultivation practices

Table 1 lists the field conditions and cultivation practices of the surveyed maize fields. In Kenethao District and Parklai District, maize was cultivated on sloping land in mountainous areas. The surveyed fields were at 250-650 m a.s.l and had a slope degree of 1-18°. Land developed more than 25 years ago accounted for four of the nine surveyed fields, and land developed less than five years accounted for two of the nine fields. The maize cultivation period was longer than 10 years in four of the nine surveyed fields.

The most commonly grown maize variety was CP-888, a Thai commercial variety. The height of maize at harvest was mostly about 2 m, but some plots were at a height of 1 m. Fertilizer was applied in three of the nine surveyed fields, in which fertilizer was applied as a trial. In all nine fields, ears were removed and stover was left in the fields.

All farmers used big tractors with more than 60 HP for plowing. Sowing in 2013 was done in half of the fields by machine, with one seed being dropped at each point with 60 cm spacing between rows and 20-30 cm spacing between plants, while the other half was sown by hand where 1-3 seeds were dropped at each point with 50-60 cm spacing between plants. Maize seed yield was not different between using a machine and by hand. Farmers tried to introduce mechanized planters due to a labor shortage in Lao PDR. Plant density was higher when using mechanized planters as compared to sowing by hand. Weeding was mostly carried out by using herbicide.

2. Maize seed yield and soil chemical properties of surveyed maize fields

Maize seed yield (15% moisture) in the 27 plots was 5.32 t ha⁻¹ on average with standard deviation of 1.86 t ha⁻¹, a maximum of 9.61 t ha⁻¹, and a minimum of 0.83 t ha⁻¹ (Fig. 2). In 2013, the average maize yield was 5.27 t ha⁻¹ for Lao PDR, and 5.60 t ha⁻¹ in Xayabury Province (Ministry of Agriculture and Forestry, Lao PDR, 2014). Fujisao et al. (2018) reported that maize seed yield in 2014 and 2015 in Kenethao District was 1.1-6.0 t ha⁻¹. Maize seed yields in our surveyed fields were typical. In the maize fields in Xayabury Province, gully erosion was observed in some places. Fields with a low yield (< 2 t ha⁻¹) were located at the top of slopes where surface soil was shallow. However, the maize seed yield did not differ significantly at the upper, middle, and lower positions on slopes. And chemical fertilizer application did not significantly increase the maize seed yield.

Figure 3 shows the soil chemical properties of the

Table 1. Field conditions of survey in Kenethao and Paklai districts, Xayabury Province in 2013

Field No.	Date	Province	District	Land	Slope position	Slope degree	Altitude	Height of maize (cm)	Variety	Hill space	Number of plants per hill	Stover treatment
Field #1	1 Oct. 2013	Xayabury	Paklai	Mountainous	Lower-middle	5-11°	269-291 m	193-240 cm	CP-888	50 cm x 50 cm	3 plants	Left in field
Field #2	1 Oct. 2013	Xayabury	Paklai	Mountainous	Middle	4-6°	400-410 m	187-234 cm	unknown	60 cm x 30 cm	1 plant (machine)	Left in field
Field #3	1 Oct. 2013	Xayabury	Kenethao	Mountainous	Lower-middle	3-8°	625-635 m	155-237 cm	CP-888	60 cm x 30 cm	1 plant (machine)	Left in field
Field #4	2 Oct. 2013	Xayabury	Paklai	Mountainous	Middle	1-3°	380-390 m	172-226 cm	CP-888	60 cm x 20 cm	1 plant (machine)	Left in field
Field #5	2 Oct. 2013	Xayabury	Paklai	Mountainous	Middle-top	4°	475-480 m	118-231 cm	VT-10	60 cm x 20 cm	1 plant (machine)	Left in field
Field #6	3 Oct. 2013	Xayabury	Kenethao	Mountainous	Middle-top	12-18°	505-515 m	157-204 cm	CP-888	50 cm x 60 cm	1-2 plants	Left in field
Field #7	3 Oct. 2013	Xayabury	Kenethao	Mountainous	Middle-top	6-12°	445-455 m	112-190 cm	CP-888	50 cm x 60 cm	1-2 plants	Left in field
Field #8	3 Oct. 2013	Xayabury	Kenethao	Mountainous	Middle-top	6-8°	470-480 m	145-218 cm	CP-888	50 cm x 60 cm	1-2 plants	Left in field
Field #9	4 Oct. 2013	Xayabury	Kenethao	Mountainous	Lower-top	13-18°	325-345 m	96-217 cm	CP-888	50 cm x 60 cm	1-2 plants	Left in field

Field No.	Plow	Fertilizer application	Weeding	Cultivation history
Field #1	Big tractor	None	Herbicide at maize height of 50 cm	18 years after clearing forest, maize cultivation since 2010.
Field #2	Big tractor	None	Herbicide at maize height of 1 m	10 years after clearing forest.
Field #3	Big tractor, after cutting/burning weeds	Compound (15-15-15) 150 kg/ha	Herbicide at maize height of 1 m	Forest cleared in 1975, upland rice 1975-2007, maize since 2008.
Field #4	Big tractor incorporating weeds	Urea 100 kg/ha at 15 DAS	Herbicide at maize height of 50 cm	Forest cleared in 1995, maize-peanuts since 2nd year.
Field #5	Big tractor incorporating weeds	None	Herbicide at sowing	5 years after clearing forest.
Field #6	Big tractor, after cutting/burning weeds	Urea 75 kg/ha at 1 MAS	By hand at maize height of 70-80 cm	4 years after clearing forest, red bean in 1st year, maize since 2nd.
Field #7	Big tractor incorporating weeds	None	Once by hand	Parents cut forest long ago, maize since 1999, cassava in 2012.
Field #8	Big tractor incorporating weeds	None	Herbicide 3-4 DAS and 1 MAS*	Forest cleared in 1987, maize since 1990.
Field #9	Big tractor incorporating weeds	None	Herbicide at 20 cm height	Forest cleared in 1975, upland rice 1975-2003, maize since 2003.

* DAS: day after sowing; MAS: month after sowing

27 plots. Soil pH (H₂O) was typically 5.6 to 6.8. Total C and total N in the soil were 7 to 25 g C kg⁻¹ (17.3 g C kg⁻¹ on average) and 0.5 to 2.0 g N kg⁻¹ (1.35 g N kg⁻¹ on average), respectively. Most fields had high C and N content, but some fields had relatively low content. Available P ranged mostly from 1 to 6 mg P kg⁻¹ (4.6 mg

P kg⁻¹ on average) and was higher than 10 mg P kg⁻¹ in Field #5, where fertilizer was likely applied in the past. Exchangeable K, Mg, and Ca ranged from 0.15 to 0.54 cmolc K kg⁻¹ (0.27 cmolc K kg⁻¹ on average), 1.6 to 17.0 cmolc Mg kg⁻¹ (7.18 cmolc Mg kg⁻¹ on average), and 6 to 22 cmolc Ca kg⁻¹ (13.4 cmolc Ca kg⁻¹ on average), respectively. The fields had high cation content in soil. Soil chemical properties did not differ significantly between with and without chemical fertilizer.

Based on linear regression analysis between the maize yield and soil chemistry properties in the 27 plots (Fig. 4), the maize yield increased significantly through an increase of total C, total N, and exchangeable Ca with $r^2 = 0.33, 0.38, \text{ and } 0.16$, respectively. These coefficients of determination (r^2) were not as high as expected, likely because soil fertility degradation was not so severe. In contrast, soil pH, available P, exchangeable K, and exchangeable Mg did not affect the maize yield.

The seed yield and soil chemical properties did not differ significantly on the slope positions (upper, middle, and lower), except for exchangeable Mg with lower content at the upper position than at the lower position.

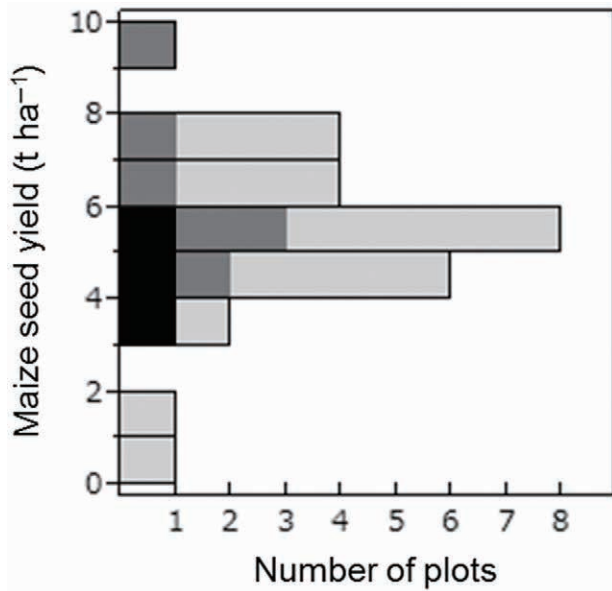


Fig. 2. Histogram of maize seed yield in the surveyed maize fields (27 plots) in Kenethao and Paklai districts, Xayabury Province in 2013
 ■ NPK application plots, ■ N application plots, □ No application plots

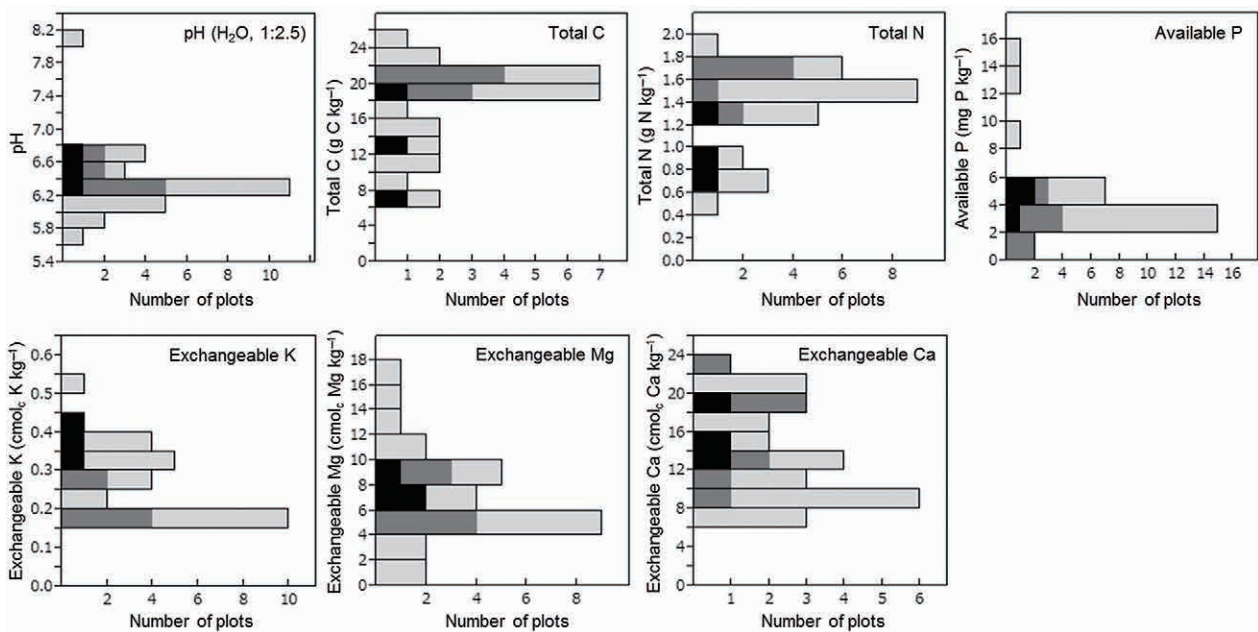


Fig. 3. Histogram of soil chemical properties in the surveyed maize fields (27 plots) in Kenethao and Paklai districts, Xayabury Province in 2013
 ■ NPK application plots, ■ N application plots, □ No application plots

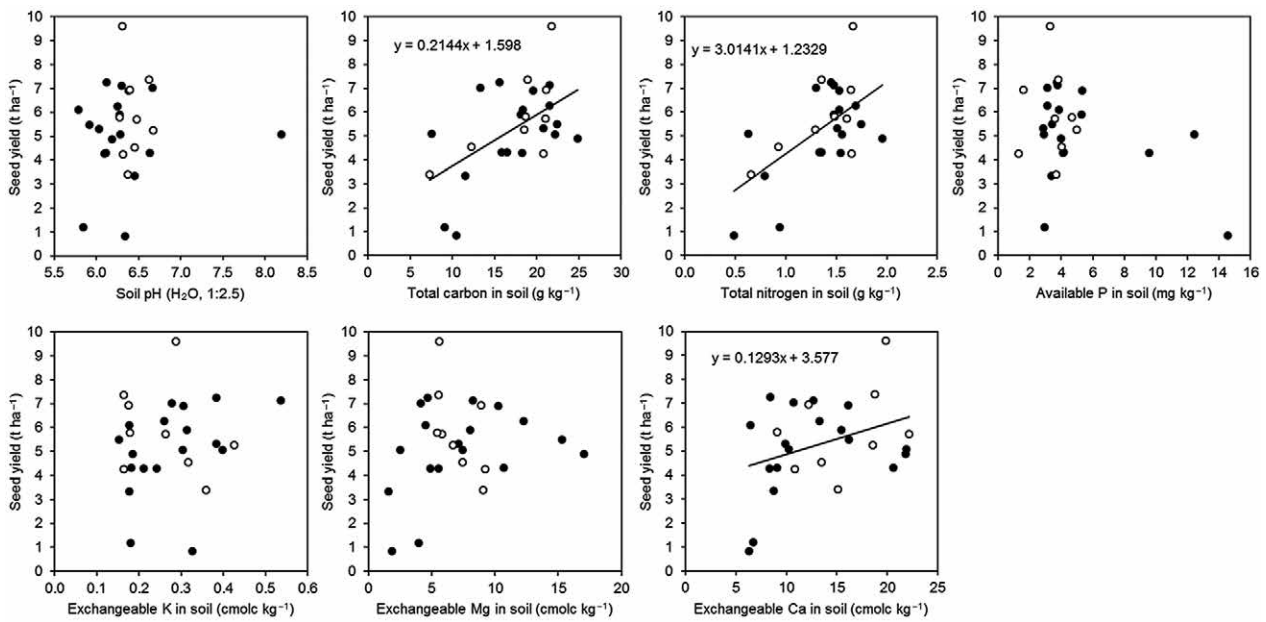


Fig. 4. Relationship between maize seed yield and soil chemical properties in the surveyed maize fields (27 plots) in Kenethao and Paklai districts, Xayabury Province in 2013
 ● Plots without chemical fertilizer application, ○ Plots with chemical fertilizer application

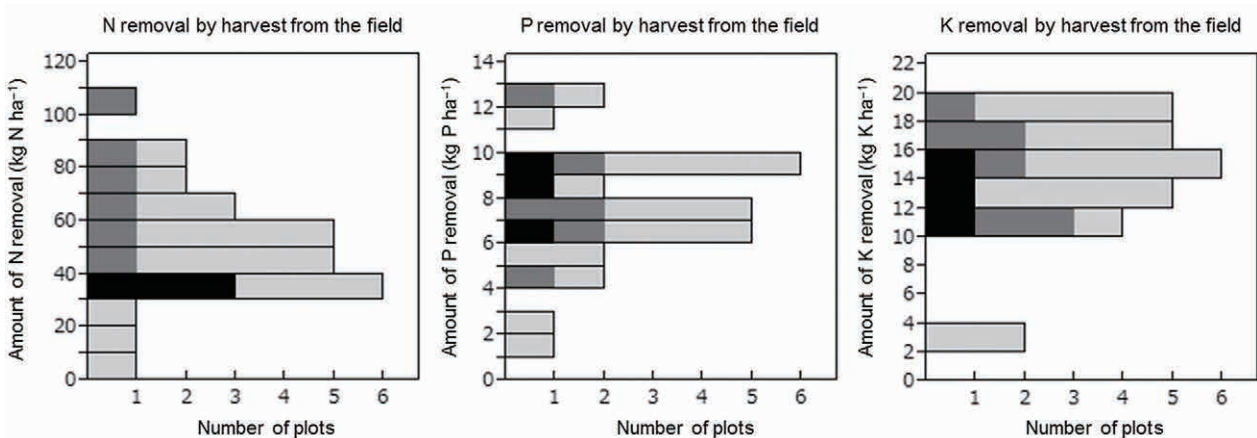


Fig. 5. Histogram of the amount of NPK removal by harvest from the surveyed maize fields (27 plots) in Kenethao and Paklai districts, Xayabury Province in 2013
 ■ NPK application plots, ▒ N application plots, □ No application plots

3. NPK uptake, removal, and return to field

Seeds and cobs were removed from the fields at harvest, while stover was left in all surveyed fields. Most of the N and P uptake was in the seeds, and most of the K uptake was in the stover. N, P, and K removal was on average 51.7, 7.5, and 14.2 kg ha⁻¹, respectively (Table 2), and the removal amount showed wide variation (Fig. 5) depending on yield.

Discussion

1. Nutrient removal by maize harvest and nutrient level in soil

Nutrient removal by crop harvest to total nutrient output (harvest, leaching, erosion, runoff, burning, gaseous loss) from the soil is as large as 34-72% for N, 28-87% for P, and 22-92% for K in case of low erosion loss or without taking erosion into account (Dechert et al. 2005, Frissel 1978, Nkonya et al. 2005, van der Pol & Traore 1993). Even in case of high erosion loss, the ratio is not so small (Bahr et al. 2015, Dung et al. 2008) at

Table 2. NPK uptake, removal, and return by maize and soil chemical properties in each surveyed maize field in Kenethao and Paklai districts, Xayabury Province in 2013

	N (kg N ha ⁻¹)						P (kg P ha ⁻¹)						K (kg K ha ⁻¹)						
	Uptake			Removal			Return			Uptake			Removal			Return			
	Seed	Cob	Stover	Total	Seed	Cob	Stover	Total	Seed	Cob	Stover	Total	Seed	Cob	Stover	Total	Seed	Cob	Stover
Field #1	48.5	2.0	12.0	62.5	50.5	12.0	6.6	0.1	0.6	7.3	6.7	0.6	10.8	3.1	11.2	25.1	13.9	11.2	11.2
Field #2	54.2	2.2	13.3	69.7	56.4	13.3	9.4	0.2	1.0	10.5	9.5	1.0	13.1	3.6	28.7	45.4	16.7	28.7	28.7
Field #3	36.1	1.6	13.1	50.9	37.7	13.1	8.3	0.1	1.4	9.8	8.4	1.4	10.5	2.6	70.8	84.0	13.1	70.8	70.8
Field #4	80.1	2.8	18.7	101.7	83.0	18.7	9.4	0.1	1.1	10.6	9.5	1.1	14.0	4.3	12.5	29.4	16.9	12.5	12.5
Field #5	22.0	1.0	10.4	33.3	23.0	10.4	5.1	0.1	2.1	7.4	5.3	2.1	8.0	2.3	57.7	68.0	10.3	57.7	57.7
Field #6	56.9	2.1	15.4	74.4	59.0	15.4	6.0	0.1	0.9	7.0	6.1	0.9	10.8	2.6	37.8	51.2	13.3	37.8	37.8
Field #7	43.8	2.1	10.3	56.2	45.9	10.3	6.2	0.2	0.9	7.3	6.3	0.9	11.1	2.6	31.5	45.2	13.7	31.5	31.5
Field #8	54.7	2.4	13.1	70.2	57.0	13.1	7.2	0.2	4.2	11.6	7.4	4.2	12.3	3.3	24.7	40.3	15.7	24.7	24.7
Field #9	50.8	2.0	14.7	67.5	52.8	14.7	7.7	0.2	2.6	10.5	7.9	2.6	11.6	2.6	36.5	50.8	14.2	36.5	36.5

Soil chemical properties						
pH (H ₂ O)	Total C (g C kg ⁻¹)	Total N (g N kg ⁻¹)	Available P (mg P kg ⁻¹)	Exchangeable K (cmolc K kg ⁻¹)	Exchangeable Mg (cmolc Mg kg ⁻¹)	Exchangeable Ca (cmolc Ca kg ⁻¹)
Field #1	6.1	22.9	1.80	3.5	0.20	14.9
Field #2	6.2	21.5	1.51	3.2	0.41	7.6
Field #3	6.5	12.7	0.96	4.2	0.37	7.7
Field #4	6.5	20.6	1.54	3.6	0.24	5.7
Field #5	7.0	9.9	0.64	10.1	0.30	2.0
Field #6	6.3	20.2	1.59	2.5	0.17	7.9
Field #7	6.0	17.7	1.47	5.8	0.21	5.0
Field #8	6.4	17.8	1.45	4.9	0.27	9.6
Field #9	6.2	12.7	1.23	3.3	0.28	4.3

11-17% for N, 9-22% for P, and 2-8% for K.

We estimated the ratio of NPK removal by maize harvest to NPK stock in the soil. In our surveyed maize fields in Xayabury Province, total NPK in the soil (0-20 cm deep and bulk density of 1.1 g cm⁻³) was estimated to be 2,980 kg N ha⁻¹ as total N, 10.1 kg P ha⁻¹ as available P, and 233 kg K ha⁻¹ as exchangeable K. The ratio of NPK removal by maize harvest to NPK in the soil was estimated to be 1.7% of total N, 74% of available P, and 6.1% of exchangeable K (Table 3). We calculated the ratio of NPK removal by maize harvest to NPK in the soil using data from previous studies on maize fields in tropical areas (Bahr et al. 2015, Bedada et al. 2016, Bekunda & Manzi 2003, Dechert et al. 2005, Yanai et al. 2007). As a result, said ratio accounted for 0.3-2.4% of total N, 2-87% of available P, and 2-14% of exchangeable K in the soil. The ratio in our study was within the ranges of previous studies. In fields with low available P content in the soil, the ratio of P was relatively high such as in our surveyed fields.

The ratio of N removal by maize harvest to N stock in the soil was small at 1.7%. However, assuming that N removal continues for 15 years without replenishment through fertilization, N stock in the soil decreases from 2,980 to 2,205 kg N ha⁻¹, and total N content in the soil decreases from 1.35 to 1.00 g N kg⁻¹. In previous studies, total N content in soil was higher than 1 g N kg⁻¹ and the maize seed yield was higher than 3 t ha⁻¹ without any fertilizer input (Adamtey et al. 2016, Bedada et al. 2016, Hartmann et al. 2014, Liu et al. 2003, Pinitpaitoon et al. 2011, Qiao et al. 2014, Wang et al. 2007b, Yan et al. 2016). In our surveyed fields in Xayabury Province, when total N content in the soil was higher than 1 g N kg⁻¹, the maize seed yield exceeded 4 t ha⁻¹ (Fig. 4). In these fields, the ratio of N removal by maize harvest (40.3 kg N ha⁻¹ by simple calculation) to N stock in soil (2,200 kg N ha⁻¹) is estimated to be about 1.8%. This ratio may reflect the N supply ability of soil.

In case of available P in soil of less than 5 mg P kg⁻¹ (our study, Bedada et al. 2016), the ratio of P removal by maize harvest to available P in soil was higher than 50%. Maize might have some mechanisms to absorb unavailable P in soil, such as root exudates and arbuscular mycorrhizal fungi to enhance P uptake (Bolan 1991, Hinsinger 2001). In Xayabury Province, maize cultivation has continued for 3-24 years after the switch from upland rice or clearing of the forest. For effective P replenishment and sustainable crop production, it is necessary to clarify how much P stock that can be absorbed by plants is contained in the soil.

In our surveyed fields, the amount of exchangeable K in the soil was sufficient to support the maize harvest, but it will become depleted in 16.4 years (= 233 kg ex-K ha⁻¹ / 14.2 kg K ha⁻¹). At the same time, however, exchangeable K is supplied by the weathering of minerals in the soil. Fertilizers recommended for maize in Thailand generally include no K application in clay and loam soil.

2. NPK balance in the maize fields

We defined the NPK balance as being calculated simply as inputs of maize residue returned to the field and chemical fertilizer application, and outputs of maize harvest removed from the field and maize residue. In fields without chemical fertilizer, the NPK balance became negative in fields as -47.6, -7.4, and -14.3 kg ha⁻¹ for N, P, and K, respectively. However, in fields with applied chemical fertilizer, the NPK balance improved as -25.6, +1.4, and +5.5 kg ha⁻¹ for N, P, and K, respectively (Table 4).

Based on the data in previous studies, the nutrient balance in maize cultivation fields ranged from negative to slightly positive (N: -160 to 0 kg ha⁻¹, P: -24 to +10 kg ha⁻¹, K: -90 to +20 kg ha⁻¹) with no or low fertilizer input (Adamtey et al. 2016, Bedada et al. 2016, Dechert et al. 2005, Hartmann et al. 2014, He et al. 2013, Lesschen et al. 2007, Liu et al. 2003, Nagumo & Nakamura 2013,

Table 3. NPK amount and removal in soil of the surveyed maize fields in Kenethao and Paklai districts, Xayabury Province in 2013

	N	P	K
NPK contents in soil*	1.35 g N kg ⁻¹	4.6 mg ava-P kg ⁻¹	106 mg ex-K kg ⁻¹
NPK amount in soil**	2,980 kg N ha ⁻¹	10.1 kg ava-P ha ⁻¹	233 kg ex-K ha ⁻¹
NPK removal by maize harvest	51.7 kg N ha ⁻¹	7.5 kg P ha ⁻¹	14.2 kg K ha ⁻¹
NPK removal by maize harvest / NPK amount in soil	1.7%	74%	6.1%

* Average of 27 plots in the surveyed maize fields. P is available P. K is exchangeable K.

** Calculated by NPK contents in soil, soil depth (assumed as 200 mm which is the plow layer, by our observation) and bulk density (assumed as 1.1 g cm⁻³ from private information). P is available P. K is exchangeable K.

Table 4. NPK balance in the surveyed maize fields with/without chemical fertilizer applied in Kenethao and Paklai districts, Xayabury Province in 2013

	N	P	K
Number of fields without chemical fertilizer	6 fields	8 fields	8 fields
NPK removal by maize harvest (kg ha ⁻¹)	47.6	7.4	14.3
NPK balance in fields without chemical fertilizer (kg ha ⁻¹)	-47.6	-7.4	-14.3
Number of fields with chemical fertilizer applied	3 fields	1 field	1 field
NPK removal by maize harvest (kg ha ⁻¹)	59.9	8.4	13.1
NPK input by chemical fertilizer (kg ha ⁻¹)	34.3	9.8	18.7
NPK balance in fields with chemical fertilizer applied (kg ha ⁻¹)	-25.6	+1.4	+5.5

Nkonya et al. 2005, Qiao et al. 2014, Saïdou et al. 2003, Tovihoudji et al. 2017, Tully et al. 2015, van Beek et al. 2016, Yan et al. 2016, Zingore et al. 2007), and was slightly negative to highly positive (N: -60 to +300 kg ha⁻¹, P: -1 to +80 kg ha⁻¹, K: -65 to +130 kg ha⁻¹) with high and sufficient input of chemical fertilizer and manure (Adamtey et al. 2016, Bedada et al. 2016, Hartmann et al. 2014, He et al. 2013, Liu et al. 2003, Nagumo & Nakamura 2013, Qiao et al. 2014, Saïdou et al. 2003, Tully et al. 2015, van Beek et al. 2016, Yan et al. 2016, Zingore et al. 2007).

In tropical areas, Bedada et al. (2016), Tovihoudji et al. (2017), and Tully et al. (2015) analyzed the N balance for maize cultivation in Kenya, Benin, and Ethiopia, respectively. The N balance was -73 to -20 kg N ha⁻¹ under no or low rate fertilizer application (24-33 kg N ha⁻¹). In contrast, under a low to sufficient rate of fertilizer application (45-76 kg N ha⁻¹), the maize yield was increased by 0.3-2.2 t ha⁻¹ and the N balance improved to -60 to +11 kg ha⁻¹.

The P and K balances were -24 to -3 kg P ha⁻¹ and -90 to -6 kg K ha⁻¹ under no or low rate (4-13 kg P ha⁻¹ and 12-25 kg K ha⁻¹) fertilizer application, respectively (Bedada et al. 2016, Dechert et al. 2005, Saïdou et al. 2003, Tovihoudji et al. 2017). Chemical fertilizer application with 24-40 kg P ha⁻¹ and 50 kg K ha⁻¹ improved the P balance to +13 to +37 kg P ha⁻¹ and the K balance to +24 kg K ha⁻¹, respectively (Bedada et al. 2016, Dechert et al. 2005, Saïdou et al. 2003).

The NPK negative balance in maize fields in Xayabury Province follows the findings of previous studies and was attributed to having no fertilizer input. Reduction of the NPK negative balance also follows the pattern of previous studies. The low rate of chemical fertilizer application reduced the negative balance of N to -25.6 kg N ha⁻¹, and slightly improved both P and K to a slightly positive balance.

Changing the NPK balance from negative to positive increases NPK in the soil (Pinitpaitoon et al. 2011, Qiao

et al. 2014, Wang et al. 2007b). Further studies on changes of the NPK amount in soil as related to the NPK balance will contribute to clarifying the nutrient dynamics in soil, especially in tropical areas.

Conclusion

In the maize fields of farmers in Kenethao and Parklai districts, Xayabury Province, Lao PDR, N, P, and K removal by harvest from the field was 51.7, 7.5, and 14.2 kg ha⁻¹, respectively. Nutrient stock in the soil surface layer (0-20 cm deep) was 2980 kg ha⁻¹ as total N, 10.1 kg ha⁻¹ as available P, and 233 kg ha⁻¹ as exchangeable K. Most farmers did not apply any fertilizer for maize cultivation. Assuming that N removal by maize harvest continues for 15 years without replenishment through fertilization, it was estimated that total N content in the soil decreases from 1.35 to 1.00 g N kg⁻¹, and the maize seed yield decreases from 5 t ha⁻¹ to 4 t ha⁻¹. The N, P, and K balances in the field without fertilizer input were estimated to be -47.6, -7.4, and -14.3 kg ha⁻¹, respectively, and were improved with chemical fertilizer application to -25.6, +1.4, and +5.5 kg ha⁻¹, respectively, in which soil fertility was sustained.

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