Present Soil Chemical Status and Constraints for Rice-Based Cropping Systems in Vientiane Plain and Neighboring Areas, Lao PDR

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Abstract: Soil chemistry and nutrient status of soil were surveyed in an attempt to improve the productivity of rainfed lowlands—which would include crop diversification and improved rice yields—in the semi-mountainous areas near Nameuang village (NV) and in the Vientiane plain (VP), Lao PDR. The soil survey revealed soil acidity, deficiency in exchangeable Ca and Mg and in available P despite the its being in a calcareous zone. The nitrogen; phosphorus and potassium fertilities in NV were not notably unique to those in the neighboring districts. In addition, it became apparent that in NV there was a risk of aluminum toxicity. In order to determine appropriate soil management, the effects of liming on non-rice crops and on rice plants were studied in pot experiments using soils collected from NV. Liming was usually effective for enhancing the growth of the tested non-rice crops. Under submerged conditions, soil pH increased naturally despite the strong pre-flooding acidity. Although liming plus chemical fertilizer was effective for increasing rice yields, the effect of liming was not positive when only liming was applied. Although soil amendments are required to mitigate aluminum toxicity on non-rice crops in lowland double cropping systems, it was necessary to consider the influence on rice yields, particularly under a condition without fertilization.

Key words: Acrisols, Crop diversification, Deficiency in cations, Rainfed paddy, Rice, Soil acidity, Soil amendment.

Lao PDR is a landlocked, mountainous country covering 235,800 km² of which only 4.4% is arable. Sixty percent of its 6.7 million inhabitants live in rural areas in villages scattered throughout the lowland areas and practice subsistence farming. A land and forest allocation policy was introduced in the early 1990s: (a) to increase land tenure security (b) to encourage farmer involvement in intensive farming, and (c) to eliminate slash-and-burn agriculture to protect the environment (Ducourtieux et al., 2005). The cultivation of upland rice was dramatically decreased under this program as persons practicing shifting cultivation converted to sedentary agriculture. Although lowland agriculture with private ownership and intensive management tends to increase yield per unit area over against upland rice; Phoumphon et al. (2011) pointed out that an inherent problem with ownership is an accompanying shortage of land for cultivation due to an influx of population.

In response to population pressure and the decline in land for cultivation, it is necessary to raise productivity on the remaining land by increasing rice yields and/or diversification of cropping systems. In the semi-mountainous lowlands, the adoption of improved varieties, use of chemical fertilizers and mechanization has fallen behind the Mekong River corridor and other larger basins. Better soil fertility management will therefore be required for increasing productivity of montane rainfed paddy (Linquist et al., 2006b). Fukai and Ouk (2012) argued that in order to stabilize the livelihood of farmers two additional factors should be included: (a) the importance of crop intensification and (b) diversification. Cash crop production in rice-based cropping systems represents an option for improving livelihoods. Basnayake et al. (2006) reported that annual rainfall in Lao PDR is 1,506 mm in the north, 2,237 mm in the south and 1,795 mm in Vientiane province. Paddies in the mountainous valleys receive sufficient water throughout the year. Diversification with non-rice crops, however, is mostly restricted to the irrigated dry season relatively small scale (Haefele et al., 2006).
Our research aimed to improve livelihoods by overcoming the limitations of sedentary farming in the semi-mountainous areas (Saito, 2013). Nameuang village (NV) is a village in the semi-mountainous study area. Although the number of households is 110 and total paddy holding of villagers is ≤ 50 ha, there is scarcely any land that can be reclaimed. There is, therefore, a shortage of paddy land. Paddy yields in NV are less than the national average and crop production after the rainy season is nearly impossible despite there being relatively large reservoirs. Strong soil acidity and the death of maize plants in the preliminary experiment indicated a soil chemical problem as the main constraint for non-rice crops. Although there have been several reports on the chemical status of paddy fields in Lao PDR vis-à-vis paddy rice production (Egashira, 1996; SSLCC, 1996; Kotegawa et al., 2010), few have assessed rice-based cropping systems in the rainfed lowlands in the central region. In order to know the actual soil chemical conditions and clarify the constraints for rice and non-rice production, we conducted a comparative soil survey in the paddy fields of Nameuang village (NV) and in Vientiane plain & its neighboring areas (VP). We also carried out pot experiments to test the effect of empirical soil amendments and soil management.

Materials and Methods

1. Soil survey

In the 2012 and 2013 dry seasons, two series of soil surveys were undertaken to determine the actual lowland soil conditions.

Survey 1: Between February and March, 2012, during the dry season, a soil survey was conducted on paddy fields in Nameuang village (NV) (Feuang district, Vientiane province, Lao PDR). The paddy fields run south to north and belong to 5 watersheds. In each, the slope (≤ 1%) runs from east to west and ends at the foot of steep limestone mountains on the west side of the village. Soil samples were collected from 87 fields (Fig. 1 B) divided into 5 clusters; one for each watershed (NV_A1, NV_A2, NV_B, NV_C, and NV_D). NV_A1 was divided into 2 sub-clusters according to the concentration of cations in each sample solution was determined by atomic absorbance spectrometry (AA200; PerkinElmer Inc.). Exchangeable Al was determined on 5.0 g of air-dried soil with 25 mL 1 M KCl suspensions of H_2O and 1 M KCl suspensions of 10 g air-dried soil. Exchangeable cations (exc. Ca; exc. K and exc. Mg) were determined from 2.5 g of air-dried soil with 50 mL of 1 M ammonium acetate (NH_4OAc: pH7.0) shaken for 1 h, and filtered through a 2-mm mesh sieve. Each processed soil sample was stored in a Ziploc® (AsahiKASEI) plastic bag until analyzed.

2. Soil analyses

Soil analyses included: pH_{H_2O}, pH_{KCl}, exchangeable (exc.) cations (exc. Ca; exc. K and exc. Mg); exchangeable aluminum (exc. Al); available phosphorus (avail. P); total carbon (TC) and total nitrogen (TN). Measurement of soil pH (using a LAQUA F-72, HORIBA Ltd. pH meter) was done on 25-mL suspensions of H_2O and 1 M KCl suspensions of 10 g air-dried soil. Exchangeable cations (exc. Ca; exc. K and exc. Mg) were determined from 2.5 g of air-dried soil with 50 mL of 1 M ammonium acetate (NH_4OAc: pH7.0) shaken for 1 h, and filtered through Analytical Filter No.2 (Toyo Roshi Kaisya, Ltd.). The concentration of cations in each sample solution was determined by atomic absorbance spectrometry (AA200; PerkinElmer Inc.). Exchangeable Al was determined on 5.0 g of air-dried soil with 25 mL 1 M KCl solution in a 100 mL polypropylene container shaken for 1 h then filtered. A nitrous oxide-acetylene flame was used for the atomic absorbance spectrometric analysis. Available P was
The first and second trials. Prior to sowing in the second trials, the residual roots of the previous crop were removed by sieving and the seeds sown in the pot received same crop in first trial. In addition, pots without any plants were prepared for soil analysis, which was conducted after harvesting the plant samples in the first trial.

Experiment II: The effects of liming in relation to chemical fertilizer on soil pH, growth and yield of rice were studied by pot experiment. The soil collected from paddy fields located at the toe slope position in NV A1 was air-dried and passed through a 5-mm sieve. In this experiment, 3 liming treatments (non-liming; lime at 6.3 g pot$^{-1}$ and lime at 11.7 g pot$^{-1}$; calculated from a lime requirement curve) were combined with non-fertilizer or chemical fertilizer (0.63 g pot$^{-1}$ of 15-15-15 compound fertilizer as basal fertilizer + 0.2 g pot$^{-1}$ of top-dressed urea). The lime used in this experiment was the same as that used in Experiment I. Lime was applied to 4.5 kg of air-dried soil in the plastic pot (26 cm in diameter; 20 cm in height) and stirred with water (23 June 2012). Pots were kept in a submerged condition until transplanting. Two rice cultivars (TDK-8 and Takied) were used; the former was developed by ARC, NAFRI and the latter is a popular local variety in NV. Three seedlings (age 28 days) were transplanted per pot on 6 July 2012—two weeks after liming. Compound fertilizer was applied the day after transplanting and urea top-dressed one month after transplanting (i.e., in the chemical fertilizer plots). Soil pH$_{H_2O}$ was monitored using a portable pH meter (PRN-41 (body)+ EL6550-EM (electrode); Fujiwara Seisakusyo Co. Ltd.) at 4-day intervals on 6 pots grown TDK-8 and Takied without chemical fertilizer. Harvesting was conducted on 28 October 2012 and the weights of ear and straw were determined. Samples of ear and straw were decomposed with nitric acid and perchloric acid for nutrient analysis. The respective nutrient content of each solution was determined in the same manner as the soil samples.

| Cluster | n  | pH$_{H_2O}$ | pH$i$ | Avail. P cmol(+)$^{-1}$ | Exc. Ca cmol(+)$^{-1}$ | Exc. K cmol(+)$^{-1}$ | Exc. Mg cmol(+)$^{-1}$ | Exc. Al cmol(+)$^{-1}$ | TC g kg$^{-1}$ | TN g kg$^{-1}$ |
|---------|----|-------------|-------|-----------------|----------------|----------------|----------------|----------------|--------------|--------------|
| NV A1  | 26 | 4.8 c       | 3.5 c | 11.3 c          | 0.74 b          | 0.21 b         | 0.50 a          | 0.56 a         | 13.2 b       | 1.37 ab      |
| NV A2  | 4  | 5.1 b       | 3.9 ab | 257.0 a         | 1.29 a          | 0.34 b         | 0.47 ab         | 0.16 c         | 12.1 bc      | 1.08 c       |
| NV A3  | 10 | 5.0 b       | 3.7 b | 10.4 c          | 0.56 bc         | 0.23 b         | 0.42 ab         | 0.56 a         | 10.8 c       | 1.10 bc      |
| NV A4  | 15 | 4.9 bc      | 3.6 bc | 19.4 bc         | 0.46 c          | 0.31 b         | 0.35 b          | 0.49 a         | 10.5 c       | 1.03 c       |
| NV A5  | 6  | 5.0 bc      | 3.6 bc | 13.0 bc         | 0.46 c          | 0.13 b         | 0.35 b          | 0.49 ab        | 11.6 bc      | 1.07 c       |
| NV A6  | 16 | 5.3 a       | 4.1 a | 4.9 c           | 1.11 a          | 0.15 b         | 0.53 a          | 0.10 c         | 12.1 bc      | 1.12 bc      |
| NV A7  | 10 | 4.8 c       | 3.8 b | 42.5 b          | 0.71 bc         | 0.89 a         | 0.48 ab         | 0.36 b         | 15.8 a       | 1.53 a       |

NV$_A$ was divided into 2 sub-clusters according to the level of available phosphorus (NV$_{A1}$ (< 60 mg kg$^{-1}$) and NV$_{A2}$ (> 60 mg kg$^{-1}$)), and the fields adjacent to small bodies of water at the toe of slopes were grouped as NV$_E$. *: Significance at $P < 0.05$ and $P < 0.01$, respectively. Different alphabetical letters in each trait show significant difference by Fisher's LSD test ($t = 0.05$).
Results

1. Chemical traits of paddy fields in NV and VP

The results of the soil survey for each cluster in NV are presented in Table 1. The average soil pH (H₂O and KCl) in NVₚ was higher than those in the other clusters. The avail. P was markedly high in NVₚ followed by NVₜ, while the average avail. P in the other clusters was < 20 mg kg⁻¹. There were significant differences in the exc. Ca among clusters. The average exc. Ca at NVₜ and NVₚ was relatively higher than that in the other clusters. Enrichment of exc. K was found in NVₚ. Although there were differences in exc. Mg and exc. Al among the clusters, the lowest average exc. Al and highest average exc. Mg were observed in NVₜ. In contrast to the low TC and TN at NVₚ and NVₜ, higher levels of TC and TN were found in NVₚ.

Exchangeable Al increased exponentially as soil pHKCl declined to pH 4.0. The frequency distributions of exc. Al in the soils in VP and NV are shown in Fig. 2. Except for one sample from Feuang district (0.94 cmol (+) kg⁻¹), exc. Al in VP ranged from 0 to 0.45 cmol (+) kg⁻¹. By contrast, exc. Al in NV ranged from 0 to 0.92 cmol (+) kg⁻¹: samples with an exc. Al > 0.4 cmol (+) kg⁻¹ comprised 60% of all samples of NV.

The soil chemical properties, including the potential of the nutrient supply of different areas, in VP and NV are shown in Table 2. In this comparison, the data for NVₚ and NVₜ were excluded from the data for NV because of their atypical values. Average soil pHH₂O was significantly higher in Vangvieng district than the other areas. There were significant differences in average soil pHKCl among the areas: it was highest in Vangvieng district (pH 4.5) and lowest in NVₚ (pH 3.5). Average exc. Ca in NV was 0.71 cmol (+) kg⁻¹, which was significantly lower than those in the Feuang, Vangvieng and Xaythany districts. There were wide variations in exc. K and the differences were not statistically significant; it was highest in Xaythany district.

![Fig. 2. Frequency distribution of exc. Al in the soils at VP and NV.](image)

### Table 2. Soil chemical traits of paddy fields in VP.

| Group            | n  | pHH₂O  | pHKCl | Avail. P  | Exc. Ca | Exc. K  | Exc. Mg | Exc. Al | TC  | TN  |
|------------------|----|--------|-------|-----------|---------|---------|---------|---------|-----|-----|
| Nameuang village | 73 | 5.0 b  | 3.7 c | 11.6      | 0.71 b  | 0.21 b  | 0.45 b  | 0.44 a  | 11.9 a | 1.18 a |
| Phonhong dist.   | 5  | 4.9 b  | 3.8 bc| 6.3       | 1.16 ab | 0.19 b  | 0.43 b  | 0.29 ab | 8.1 b  | 0.88 b |
| Feuang dist.     | 10 | 4.9 b  | 3.9 b | 10.1      | 2.03 a  | 0.19 b  | 0.71 a  | 0.22 b  | 9.6 b  | 1.07 a |
| Vangvieng dist.  | 6  | 5.5 a  | 4.4 a | 9.9       | 2.28 a  | 0.18 b  | 0.48 b  | 0.07 b  | 11.6 a | 1.20 a |
| Xaythany dist.   | 34 | 5.1 b  | 4.0 b | 11.9      | 1.75 a  | 0.44 a  | 0.50 b  | 0.13 b  | 10.3 ab | 0.94 ab |

The data of Nameuang village exclude NVₜ and NVₚ (see Table 1). *, **: Significance at P < 0.05 and P < 0.01, respectively. Different alphabetical letters in each trait show significant difference by Fisher’s LSD test (t = 0.05).

### Table 3. Effects of liming and animal feces application in early growth of non-rice crops.

| Trial  | Treatment  | Maize Shoot dry weight (g pot⁻¹) | Soybean Shoot dry weight (g pot⁻¹) | Mungbean Shoot dry weight (g pot⁻¹) | Tomato Shoot dry weight (g pot⁻¹) |
|--------|------------|----------------------------------|-----------------------------------|------------------------------------|----------------------------------|
|        | Lime       | 1.91 a                           | 1.62 a                            | 0.96 a                             | 0.20 a                           |
| First  | Animal Feces | 0.54 b                           | 1.57 a                            | 0.41 b                             | 0.08 b                           |
| First  | Non        | 1.03 b                           | 1.16 a                            | 0.45 b                             | 0.03 b                           |
| Second | Lime       | 1.41 d                           | 1.34 d                            | 0.77 d                             | 0.19 d                           |
| Second | Animal Feces | 1.50 d                           | 1.45 d                            | 0.80 d                             | 0.07 e                           |
| Second | Non        | 0.99 e                           | 1.45 d                            | 0.34 e                             | 0.04 e                           |

Different alphabetical letters in each trait show significant difference by Fisher’s LSD test (t = 0.05).
The yield response of rice, however, varied with the treatment combined liming and chemical fertilizer application (Table 5). Yield and nutrient uptake of rice tended to increase with liming accompanied by chemical fertilizer applications in both cultivars. By contrast, liming at 11.7 g⁻¹ was not effective in increasing the yield of TDK-8 but instead caused yield reductions regardless of larger foliage weight in Takied when chemical fertilizer was not applied. Unfilled spikelets were conspicuous particularly in Takied grown under the conditions with liming at 11.7 g⁻¹ pot⁻¹ and non-chemical fertilizer. There were no significant differences in nutrient uptake (excluding Mg) among the liming treatments without chemical fertilizer application. Mg uptake consistently increased with liming with or without chemical fertilizer application. The results of soil analysis after rice harvesting are shown in Table 6. Soil pH (H₂O) recovered to the level before submerging by drying the soil. In contrast to increases in exc. Ca and exc. Mg, significant reductions of exc. K with liming were observed.

**Table 4. Chemical traits of the soil received different treatments for soil amendments.**

| Treatment   | pH_{H_2O} | Avail. P (mg kg⁻¹) | Exc. Ca (cmol(+)/kg⁻¹) | Exc. K (cmol(+)/kg⁻¹) | Exc. Mg (cmol(+)/kg⁻¹) |
|-------------|-----------|-------------------|------------------------|-----------------------|------------------------|
| Liming      | 5.8 a     | 12.1 b            | 1.94 a                 | 0.05 b                | 0.27 a                 |
| Animal feces| 4.6 b     | 15.6 a            | 0.77 b                 | 0.26 a                | 0.17 b                 |
| Non         | 4.3 c     | 13.8 ab           | 0.68 b                 | 0.21 a                | 0.12 c                 |

Chemical traits were determined in the fallow pot after first trial. Different alphabetical letters in each trait show significant difference by Fisher's LSD test (t = 0.05).

Due to low soil pH_{H_2O} and low exc. Ca, average exc. Al at NV was higher than that in the other districts.

**2. Effects of soil amendments on growth of non-rice crops**

Table 3 shows the growth response of several crops to soil amendments. The effects of liming on crop growth were similar among the tested crops except for soybean, for which there was no significant difference between liming treatment and control. The most dramatic effect of liming was observed on tomato followed by mungbean. The dry weight of the top part that received the liming treatment compared to the control was 5 to 6 times for tomato and 2 to 3 times for mungbean. The effect of animal feces varied with crop and but its application decreased the growth of maize and mungbean in Trial 1 but increased it in Trial 2. The results of the soil analysis in the fallow pot experiment are presented in Table 4. Soil pH (H₂O), exc. Ca and exc. Mg noticeably increased with liming but only slightly with animal feces compared with non-treatment. By contrast, exc. K decreased significantly with liming. There was a significant increase in avail. P with animal feces application.

**3. Effects of liming and chemical fertilizer application on growth and yield of rice**

Changes in soil pH under submerged, rice cropping conditions are presented in Fig. 3. Although there was a large variation in soil pH_{H_2O} across the various liming treatments; just after submerging, pH values approximated the condition at six weeks. In contrast to the increase in pH from 4.5 to 5.5 in the non-treated pots, a gradual decrease in pH from 6.8 to 5.6 was observed in the pots that received liming at 11.7 g pot⁻¹. In spite of the differences in pH, there was no significant difference in the growth of rice one month after transplanting (data not shown). The yield response of rice, however, varied with the treatment combined liming and chemical fertilizer application (Table 5). Yield and nutrient uptake of rice tended to increase with liming accompanied by chemical fertilizer applications in both cultivars. By contrast, liming at 11.7 g⁻¹ was not effective in increasing the yield of TDK-8 but instead caused yield reductions regardless of larger foliage weight in Takied when chemical fertilizer was not applied. Unfilled spikelets were conspicuous particularly in Takied grown under the conditions with liming at 11.7 g⁻¹ pot⁻¹ and non-chemical fertilizer. There were no significant differences in nutrient uptake (excluding Mg) among the liming treatments without chemical fertilizer application. Mg uptake consistently increased with liming with or without chemical fertilizer application. The results of soil analysis after rice harvesting are shown in Table 6. Soil pH recovered to the level before submerging by drying the soil. In contrast to increases in exc. Ca and exc. Mg, significant reductions of exc. K with liming were observed.

**Discussion**

Development in Lao PDR includes migration from mountainous areas to lowland villages and improvements to the living environment at the village level. A consequence of increasing population density in the lowlands has been a reduction in the cropping area per family and declining food self-sufficiency. New cultivation technologies for improving rice yields and more efficient utilization of current lands are urgently needed to help address these
socio-economic challenges. The predominant lowland soils in the central and southern regions of Lao PDR are Acrisols—strongly weathered soils with a lower soil pH and a clay-enriched subsoil (FAO, 1998). Interestingly, Vientiane province—including Nameuang village—abounds in limestone (United Nations, 1990); its landscape being dotted with steep limestone mountains rising from the lowlands. We, therefore, expected adequate soil pH owing to its being in a calcareous zone; however, the soil survey indicated otherwise. There was a large variation in the soil chemical properties among the clusters in NV (Table 1). A relatively high level of avail. P was observed at NV_{A2} followed by NV_{P}. The fields of NV_{A2} were located near village houses and commonly received waste water. Enrichment of avail. P and exc. K were observed in the fields of NV_{P}, which are located in a lower slope position, were terminals of plot-to-plot irrigation and popular marshlands for water buffalo. The boundary between low and medium nutrient classes of paddy soil are: < 1 g kg\(^{-1}\) of TN, 15 mg kg\(^{-1}\) of available P (Bray II) and 0.2 cmol kg\(^{-1}\) of exc. K (Nwilene et al., 2008). Accordingly, with the exception of the NV_{A2} and NV_{P} clusters, the nutrient level of NV was classified as medium for N, low to medium for P and low to medium for K. Inthapanya et al. (2005) reported that the use of K fertilizer for rice was much less than that of N or P, although the use of chemical fertilizer was altogether rare in Lao PDR. Linquist and Sengxia (2001) reported that the rank of importance of nutrients in paddy rice production was N>P>K while Inthavong et al. (2011) suggested that exc. K was not an important factor in determining yields in the Savanakett province, Lao PDR. Although use of fertilizer is rare in NV, soil fertility in VP and NV is generally such that fertilizer application would be required to increase rice yields.

The mountainous areas of Lao PDR belong to the Asian monsoon climate zone and have an annual precipitation >1,500 mm despite, concentrated during the 6-month rainy season (Basnayake et al., 2006). The extensive forest

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### Table 5. Effects of liming on the yield and nutrient uptake of rice.

| Cultivar | Chemical Fertilizer | Liming g pot\(^{-1}\) | Air-dried weight (g pot\(^{-1}\)) | Nutrient uptake (mg pot\(^{-1}\)) |
|----------|---------------------|-----------------------|---------------------------------|---------------------------------|
|          |                     |                       | Foliage | Ear | Total | N | P | K | Ca | Mg |
| TDK-8    | No                  | 0                     | 45.8 bc | 17.7 b | 63.5 c | 402 b | 119 b | 712 b | 214 b | 85 d |
|          | 6.3                 | 4.47 c                | 23.5 ab | 68.1 bc | 462 ab | 119 b | 648 b | 229 b | 108 c |
|          | 11.7                | 47.6 bc               | 20.6 ab | 68.2 bc | 472 ab | 104 c | 690 b | 220 b | 128 b |
|          | Yes                 | 0                     | 46.8 bc | 29.9 a | 76.6 bc | 503 ab | 140 a | 754 b | 289 b | 100 c |
|          | 6.3                 | 50.0 b                | 28.1 ab | 78.0 ab | 563 ab | 141 a | 750 b | 261 b | 132 b |
|          | 11.7                | 60.6 a                | 30.4 a | 91.1 a | 629 b | 149 a | 853 a | 280 b | 155 a |

### Table 6. Effect of liming and chemical fertilization on the status of chemical traits.

| Fertilizer | Liming g pot\(^{-1}\) | pH\(_{H2O}\) | pH\(_{KCl}\) | Avail. P mg kg\(^{-1}\) | Exc. Ca cmol(+) kg\(^{-1}\) | Exc. K cmol(+) kg\(^{-1}\) | Exc. Mg cmol(+) kg\(^{-1}\) |
|------------|-----------------------|-------------|-------------|--------------------------|-----------------------------|-----------------------------|-----------------------------|
| No         | 0                     | 4.6 c       | 3.7 c       | 99.0 b                   | 1.38 c                      | 0.14 a                      | 0.34 b                      |
|            | 6.3                   | 5.2 b       | 4.2 b       | 95.3 b                   | 2.38 b                      | 0.12 b                      | 0.79 ab                     |
|            | 11.7                  | 6.0 a       | 4.9 a       | 93.5 b                   | 2.83 a                      | 0.10 c                      | 1.06 a                      |
| Yes        | 0                     | 4.7 c       | 3.8 c       | 100.0 b                  | 1.65 c                      | 0.14 a                      | 0.42 b                      |
|            | 6.3                   | 5.2 b       | 4.2 b       | 96.8 b                   | 2.92 a                      | 0.12 b                      | 0.75 ab                     |
|            | 11.7                  | 5.8 a       | 5.0 a       | 127.4 a                  | 2.96 a                      | 0.10 c                      | 1.11 a                      |

Different alphabetical letters in each trait show significant difference by Fisher’s LSD test (\(t = 0.05\)) on each cultivar.
cover and mountains catch and stock this rainwater, which supply the downstream paddy fields. Linquist et al. (2006b) mentioned the opportunities for crop diversification where water supplies are ample albeit inadequate for lowland rice. Fukai and Ouk (2012) emphasized the importance of crop intensification and diversification in addition to improvement of rice yields as a means of stabilizing farmer income. Notwithstanding, the lowland of NV is un-cropped and used for grazing during the dry season except for small-scale vegetable production. In addition to the shortage of water, the soil survey indicates soil chemistry would also be a reason for unused fields during the dry season.

Although pH is an important factor affecting nutrient supply (Janssen et al., 1990), soil acidity has not been recognized as a critical constraint in rice mono cropping because of its high tolerance to soil acidity (Fageria and Zimmermann, 1998) and due to increasing soil pH under submerged conditions (Ponnamperuma, 1972; Morales et al., 2002). The soil in NV is classified into strongly or extremely acidic with low base saturation. After rice cropping began in NV, 30 years ago, paddy fields spread from the south to the north. By comparison, the rice cropping in NV began around 10 years ago. The variation in soil pH with the cluster seems to be related to the history of rice cropping, with accompanying nutrient losses due to uptake and leaching. Linquist and Sengxua (2001) reported that irrigation water from the river supplied considerable amounts of K, Ca and Mg to the field. By contrast, in NV the amount of exc. cations was small and soil pH was low, suggesting a limited nutrient supply as a consequence of rainfed paddy plot-to-plot irrigation. Although there are limestone mountains west of paddies in NV, there is no limestone in the gentle hills on the east side which is the source of water supply, indicating little supply of Ca with water. Although pHKCl is used for determining major soil characteristics, pHKCl is more adequate to estimate exchangeable acidity and to know the status of Exc. Al associated with acid soil infertility. The lowest average pHKCl in NV (pH = 3.5) among surveyed areas suggests the aluminum problem in this village. Fig. 2 also illustrates that the risk of aluminum injury in NV is higher than in VP and that it is necessary to take measures to amend soil acidity. Such acidic conditions would be detrimental to some kinds of non-rice crops, and indeed we observed the death of maize plants at an early stage. In particular, the effect of liming was prominent on tomato followed by mungbean. The application of animal feces was also effective in the growth of tested crops, except for maize and mungbean: in Trial 1, a reduction of growth was observed but not in Trial 2. The reduction might have been due to the immobilization of inorganic N caused by animal feces with a high C/N ratio. Animal feces usually enhance growth of non-rice crops despite slight changes in soil pH. For example, the addition of green manure and animal waste to acid soil was effective in alleviation of aluminum toxicity and increased crop yields (Berek et al., 1995; Duruigbo et al., 2007). It is well-known that excessive application of Ca and Mg in lime causes an antagonistic effect against K (Fageria et al., 1995; Ding et al., 2006); consequently, the effects of animal feces on soil chemistry are more moderate than liming.

The growth response to treatment among tested crops was least in soybeans, which agrees with a report on the insensitivity of soybeans to aluminum toxicity (Tanaka et al., 1984) and suggests its suitability for the acidic soil condition of the target village. The soil used for this experiment was collected from a field where the death of maize was observed, but such severe symptoms in the maize plants were not observed in the pot experiment. The inhibition of root growth with aluminum toxicity exacerbates drought stress through a reduction in the ability to take up water and nutrients (Bernel and Clark, 1998; Zhong-Bao et al., 2013). Our pots were watered almost every day, which might have mitigated any drought stress and aluminum toxicity. Nevertheless, liming was effective in enhancing the growth of non-rice crops and it is also necessary for non-rice crop cultivation in the lowlands of NV. In particular, enhancement of early growth by soil amendments is required for cultivation of non-rice crops after the rice harvest in order to take advantage of the remaining limited, soil water. The soil analysis in the fallow pot indicated a reduction of exc. K with liming. Bekker et al. (1994) reported loss of K through displacement of exc. K with applied Ca ions and subsequent leaching. A similar reduction in exc. K with liming was also observed in Experiment II (Table 6).

Ponnamperuma (1972) reported that the overall effects of submergence are (a) to increase the pH of acid soils and (b) to depress the pH of sodic and calcareous soil. Similarly, under submerged conditions we observed an increase in soil pHKCl from 4.5 to 5.3 in the pots without liming and a decrease of soil pH from 6.5 to 5.5 in the pots.
with liming at 11.7 g pot$^{-1}$. No significant difference in the growth of rice was observed one month after transplanting regardless of the large difference in soil pH, suggesting that low soil pH was not necessarily detrimental for rice plant development. However, the effect of liming in the yield of rice varied with chemical fertilizer application. Suressh (2001) reported the effect of liming in increasing the yield and nutrient uptake by rice, but negative aspects of liming are also known. Fageria and Zimmermann (1998) reported a decrease in K uptake due to the antagonistic effects of Ca and Mg, while Magdoff and Barlett (1980) reported that liming to a pH > 5.5 often resulted in no increase in crop yields and caused decreases due to cation imbalances—with K deficiency symptoms in the crop.

Although liming with chemical fertilizer tended to increase rice yield, liming alone without chemical fertilizer was ineffective in the yield of rice in our experiment with two rice cultivars. Except for the consistent increase in Mg uptake with liming, there was no significant difference in nutrient uptake among the liming treatments without chemical fertilizer. Such imbalance if nutrient uptake might have been a reason for stagnancy in increasing rice yield, suggesting the risk of yield loss with liming under low-input condition. Moreover, the reduction in exc. K with increasing liming rates was observed after rice cropping, which was not due to any increase in K uptake (Table 5). Bekker et al. (1994) reported an increase in leaching of K with liming; we observed a similar reduction in fallow pots in Experiment I. Although the data are not shown, we observed an increase in water soluble K after liming, which suggests that the displacement of exc. K by exc. Ca or Mg contained in the lime. The reduction of the exc. K seems to be due to the loss through overflowing after a heavy rain; as we conducted the pot experiment under outdoor conditions in the wet season.

Except for the areas along the Mekong River—the so-called “Mekong River corridor” or big basins—most rice production in Lao PDR is practiced with little chemical fertilizer application. Bekker et al. (1994) reported an increase in leaching of K with liming; we observed a similar reduction in fallow pots in Experiment I. Although the data are not shown, we observed an increase in water soluble K after liming, which suggests that the displacement of exc. K by exc. Ca or Mg contained in the lime. The reduction of the exc. K seems to be due to the loss through overflowing after a heavy rain; as we conducted the pot experiment under outdoor conditions in the wet season.

We thank (a) the Agriculture Research Center (ARC), National Agriculture and Forestry Research Institute (NAFRI), Lao PDR, the Japan International Research Center for Agricultural Sciences and Rakuno Gakuen University for support (b) the farmers and villagers for their cooperation and (c) Mr. Bryan Roderick Hamman for assistance with the English-language presentation of the manuscript.

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