Soil–water conditions and efficient fertilization strategies to increase rice grain yield in rainfed lowland fields in Savannakhet Province

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Abstract

Most lowland rice fields in Savannakhet Province, the main rice-producing region in Laos, are rainfed and cover both lowlands as well as gradual hilly terrain with sandy soils. The water and nutrient conditions of the lowland rice fields likely vary by location and geological conditions. Additionally, high risk of nutrient leaching from applied fertilizer is expected in such sandy rainfed fields. The objectives of this study are 1) to assess rice yield and water and soil conditions in the rainfed rice fields of Savannakhet Province, 2) to identify the determinants of variation in rice yield, and 3) to evaluate rice plant growth and nutrient leaching under different split chemical-fertilizer application patterns. The rice grain yield varied from 0.6 to 3.6 t ha^{-1}, and the yield in the lower position fields was significantly higher than in the upper position fields. Surface water in the observed fields was mostly maintained above ground level throughout the planting period. Total carbon, total nitrogen, available phosphorus, and exchangeable potassium were extremely low, while the exchangeable calcium and exchangeable magnesium were relatively high. Exchangeable calcium was selected as the highest influential factor to rice grain yield, followed by total carbon. The grain yield from six split fertilization was higher than from three split fertilization (standard) and basal fertilization only. The split fertilization is advantageous in that it supplies nitrogen for panicle initiation and maturing stages in sandy paddy fields.

Introduction

Rice is a staple food in the Lao People's Democratic Republic (hereinafter referred to as Laos). The net rice production, 0.54 million tons in 1961, has increased to 4.15 million tons in 2016 (Food and Agriculture Organization (FAO) 2018). The government of Laos aims to increase rice production for domestic consumption as well as export and plans to increase production to 4.7 million tons in 2020 and 5.0 million tons in 2025 (Ministry of Agriculture and Forestry, Laos (MAF) 2015). Only 4% of the total Laos land area is cultivated, with rice constituting 70% of the net cropped area (World Food Program (WFP) 2007). The irrigated areas in Laos constitute only 12% of the total agricultural land (FAO 2018), and most lowland rice is cultivated under rainfed conditions.

Savannakhet Province is the main rice-producing region in Laos; the province produced 25% of the country's total lowland rice (MAF 2016). Generally, the rice fields in the province are laid out on flat or almost flat land, with slopes ranging from 0–8% (Inthavong et al. 2011). Soils in most rainfed lowland areas in Laos are highly weathered, moderately acidic sandy loams, loams, and loamy sands; the soils in Savannakhet have low levels of nitrogen (N), phosphorus (P), and sometimes potassium (K). Low organic matter and cation exchange capacity (CEC) are also common (Lathvilayvong et al. 1994). When combined with sandy soil textures that have high permeability and low fertility, these geological conditions may affect water and nutrient conditions of each field. In addition, a considerable part of applied fertilizer may be lost by the leaching due to high permeability of the soil.

The objectives of this study are 1) to assess the rice yield and water and soil conditions in the sloped rainfed rice fields of Savannakhet Province, 2) to identify the factors affecting difference in rice yield among field positions, considering environmental factors, and 3) to evaluate rice plant growth and leaching loss of chemical-fertilizer from sandy soil by pot experiment.

Materials and methods

Field survey

Field surveys were conducted in Koudkher Village, Outhomphone District, Savannakhet Province, Laos (Fig. 1). The topography gently slopes downward from north to south at a 2.8% mean slope gradient. The elevation varies from 153 to 183 m above sea level from the lowest to the highest field (Fig. 2). Soil sampled from twenty fields in the village was classified as sand and loamy sand at the surface layer (0–20 cm), and sand, loamy sand and sandy loam at the subsurface layer (20–40 cm) according to the International Society of Soil Science Method. Saturated hydraulic conductivity was 10^{-3}–10^{-5} cm s^{-1}, and 10^{-4}–10^{-8} cm s^{-1} at the surface and subsurface layers, respectively. The annual precipitation in Seno meteorological station, 10 km away from the village, is 1,560 mm (average from 2001 to 2013); almost 85% of precipitation occurs between May and September (Ikeura et al. 2019). Weather data in the village was measured from 2014 to 2017.

Fig. 1. Location of survey site
This figure was modified to reference
Ikeura et al. (2019) and
http://www.freemapviewer.com.

Twenty fields were selected to cover the entire lowland field area in the target village (Fig. 2). Located on five sequential slopes, the fields were classified into upper, middle, and lower groups by their toposequential locations. There were 5, 7, and 8 fields in the upper, middle, and lower groups, respectively. Three sampling quadrats (1 × 1 m) were set in each field in the middle of July 2017 (20 fields × 3 replicates = 60 quadrats). In one-quarter of fields only basal fertilizer was applied in low amounts (e.g., 4–5 kg N ha^{-1}, 1–3 kg P_2O_5 ha^{-1}, 0–2 kg K_2O ha^{-1}). In the other fields fertilizer was not applied, and the only manure was supplied by browsing cows and buffalos during the dry season. Transplanting began in mid-June and was completed before making the quadrats. Six cultivars were included in the samples. Rice samples were harvested from each quadrat at maturity, and grain weight and moisture content were measured after drying, threshing, and winnowing (Ikeura et al. 2019).

The surface water depth in each plot was measured using gauge rods on July 17, August 24, September 10, October 7 and 21 in 2017. To evaluate soil fertility, a topsoil sample (0–10 cm depth) was collected from each quadrat before flowering at the end of August 2017. Soil samples were air-dried and passed through a 2-mm mesh screen. Soil pH (1:2.5), total nitrogen (total N), total carbon (total C), available phosphorus (available P) and exchangeable cations [potassium (exchangeable K); magnesium (exchangeable Mg); calcium (exchangeable Ca)] were determined (Ikeura et al. 2019).

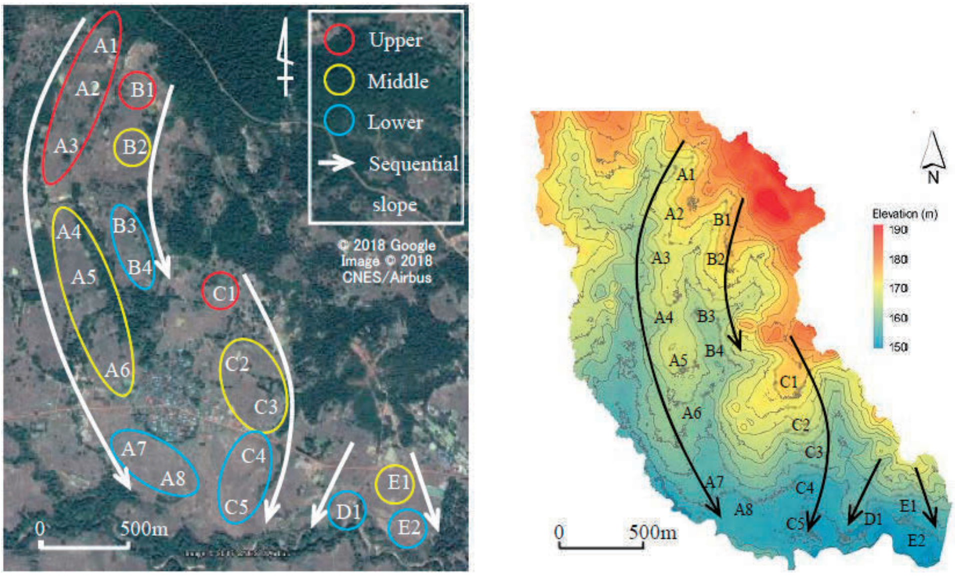


Fig. 2. Location of surveyed fields and topographic condition of survey site (Ikeura et al. 2019).

The difference in yield, water depth, and soil chemical properties among the upper, middle, and lower groups were analyzed by Tukey–Kramer HSD test using JMP 10 statistical software (SAS Institute Inc., Cary, NC, USA.). To investigate the factors affecting differences in rice grain yield, linear regression analyses were performed using R statistical software v. 3.4.1 (R Core Team 2016), as per the following steps (Ikeura et al. 2019):

Step 1: Multiple linear regression (MLR) analysis was conducted to determine the major factors as shown in **Eq. 1**; the response variable was rice grain yield (*GY*), and explanatory variables were environmental factors (*V*) such as average water depth in the rice growing period, soil chemical properties (pH, total N, total C, available P, exchangeable K, exchangeable Mg, and exchangeable Ca), and variety of rice.

$$GY = a + b_1V_1 + b_2V_2 + \ldots + b_nV_n \qquad \text{Eq. 1}$$

where GY is the rice grain yield, a is constant, V_1 to V_n are the explanatory variables selected by stepwise variable selection (here, V_n is the factor with the highest correlation to GY), n is the number of selected variables, and b_1 to b_n are coefficients of variables V_1 to V_n, respectively.

Step 2: To specify the determinants of difference in rice grain yield, a generalized linear mixed model (GLMM) incorporating location (upper, middle, and lower positions) as a fixed effect (L_i) was applied. The explanatory variables include the variables selected by Step 1 and the locational factor as continuous variables (i = 1 [lower] to 3 [upper]).

$$GY = a_{Li} + b_1V_1 + b_2V_2 + \ldots + b_{nLi}V_n + L_i \qquad \text{Eq. 2}$$

where a_i is constant based on the ith fixed effect of the locational factor (L_i).

Pot experiment

A pot experiment was conducted at the Rice Research Center, National Agriculture and Forestry Research Institute, Laos from January to April 2018. The soil used in the experiment was topsoil (0 to 20 cm depth) collected in the dry season (March 2017) from a field in Koudkher Village (near Field E2). Fifteen (15) kg of air-dried soil were placed in 20 Wagner pots (surface area = 1/2,000 a). The soil was loamy sand composed of 4% clay, 4% silt, and 92% sand. It contained 141 mg N kg^{-1} of total N, 6.04 mg P kg^{-1} of available P and 6.93 mg K kg^{-1} of exchangeable K. At the beginning of the experiment the soil had an estimated 2,115 mg N of total N, 90.6 mg P of available P and 104 mg K of exchangeable K in each pot (Phongchanmixay et al. 2019). A glutinous rice variety (cv. TSN-7) used in this study was developed for sandy paddy fields in Savannakhet Province. One hill (three seedlings) of 30-day-old seedlings was transplanted in each pot on January 9, 2018. Linquist and Sengxua (2001) proposed supplying 60 kg N ha^{-1}, 20 kg P_2O_5 ha^{-1}, and 20 kg K_2O ha^{-1} to rice planted in rainfed fields with sandy soil. They also suggested three-split fertilization, with 20 kg N–20 kg P_2O_5–20 kg K_2O ha^{-1} basal fertilization at transplanting and 20 kg N ha^{-1} applied prior to active tillering and panicle initiation stages as topdressings. This was defined as the standard fertilization (control: C). Three more treatments were set as follows: 6-split fertilization applied at 12-day intervals (SF); basal fertilization in which all fertilizer was applied at transplanting (BF), and no fertilization (NF). The contents of application for each treatment are shown in **Table 1**. The four treatments were tested with five replicates.

Table 1. Fertilizer treatments in the pot experiments

	0 DAT	12 DAT	24 DAT	36 DAT	48 DAT	60 DAT
C	0.1 g N 0.1 g P_2O_5 0.1 g K_2O	–	0.1 g N	–	0.1 g N	–
SF	0.05 g N 0.05 g P_2O_5 0.05 g K_2O	0.05 g N 0.05 g P_2O_5 0.05 g K_2O	0.05 g N	0.05 g N	0.05 g N	0.05 g N
BF	0.3 g N 0.1 g P_2O_5 0.1 g K_2O	–	–	–	–	–
NF	–	–	–	–	–	–

DAT: Days after transplanting

Total applied fertilizer amount of each C, SF and BF were equal to 60 kg N–20 kg P_2O_5–20 kg K_2O ha^{-1}.

Compound fertilizer (N-P_2O_5-K_2O:15-15-15%) and urea ($CO(NH_2)_2$, N:46%) was applied for basal (0 and 12 DAT) and topdressings (24 - 60 DAT), respectively.

This table was modified to reference Phongchanmixay et al. (2019).

To simulate rainfed conditions, pots were placed under a roof and irrigation was conducted as controlled rainfall. The irrigation amounts and intervals were determined based on rainfall patterns from the 2016 rainy season in Koudkher Village; 27 mm of water was applied at 3-day intervals until 81 DAT, then 12 mm of water was applied at 10-day intervals until harvest. The drain plug of each pot was opened 24 hours before the next irrigation to measure the drainage amount and collect samples.

Plant height and number of tillers were measured every 6 days after transplanting until harvest. After harvesting, the air-dried weights of grain and rice straw were measured. Total N, total P and dissolved potassium (dissolved K) were measured in the drainage and irrigation water and drained N, P and K were calculated from the concentrations of total N, total P, dissolved K and drained water volume (Phongchanmixay et al. 2019).

Results and Discussion

1. Field survey of the factors affecting yield differences

Precipitation during the observed period

Table 2 shows monthly and annual precipitation. The annual precipitation in 2017 was 1,847 mm; 300 mm more than the 2001 to 2013 average and 500 mm more than the 2014 and 2016 average observed in the target village; particularly, the precipitation doubled in July 2017.

Table 2. Monthly precipitation (mm) in the field survey site

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Growing period*1	Annual
2001-2013*2	3	17	43	69	201	242	324	330	239	81	9	3	1,416	1,560
2014*3	0	0	0	62	86	342	439	355	231	6	0	0	1,460	1,521
2016*3	6	0	0	14	181	191	205	194	286	60	25	1	1,115	1,161
2017*3	0	1	136	27	195	246	644	185	313	83	14	3	1,667	1,847

This table was modified to reference Ikeura et al. (2019).
*1: Rice growing period from May to October (including a seedling period in nursery) (drawn as green color).
*2: Average data observed at Seno meteorological station (obtained from Department of Meteorology and Hydrology).
*3: Observed at Koudkher Village (data in 2015 was missing).

Rice grain yield

The rice grain yield in 2017 varied from 0.6 to 3.6 t ha^{-1}, averaging 1.9 t ha^{-1}. Compared to the national average yield in 2016 (4.26 t ha^{-1}; FAO 2018) and the yield in a plot-to-plot irrigation system in the semi-mountainous village in Vientiane Province (3.54 t ha^{-1}; Ikeura et al. 2016), the yield in Koudkher Village was extremely low. Fig. 3 shows the average grain yield for each toposequential position. The yield in the upper fields was significantly lower than in the lower fields (Ikeura et al. 2019).

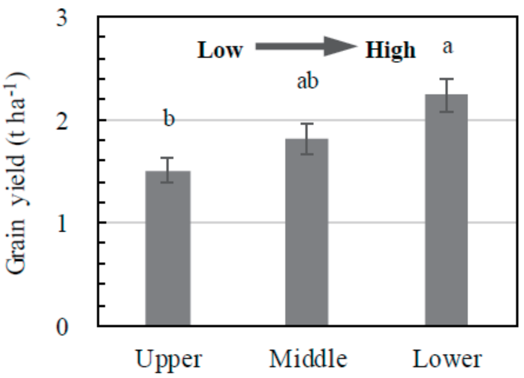


Fig. 3. Average rice grain yields in upper, middle and lower position fields
This figure was modified to reference Ikeura et al (2019).
Error bar showed standard error.

Surface water depth in the fields

Fig. 4 shows the average surface water depth for each toposequential position. Throughout the observation period, the surface water depth in the lower fields was larger than those in the upper and middle position fields. However, even in high and middle position fields, surface water was mostly maintained above ground level except before harvesting. In the upper and middle fields, harvesting was completed by mid-October, suggesting that drought stress in 2017 may have been slighter than usual (Ikeura et al. 2019).

Soil chemical properties

Fig. 5 shows the soil chemical properties in the upper, middle, and lower fields. The values of total C and total N were the highest in the lower fields but the lowest in the middle fields. The available P was the lowest in the lower fields; this was the opposite trend as the rice grain yield. Exchangeable K showed the highest content in the upper fields and the lowest in the middle fields.

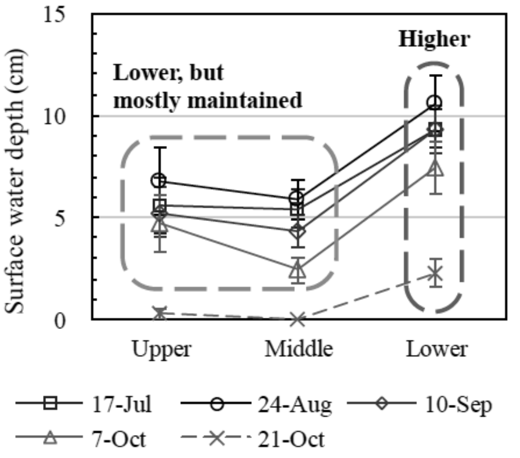
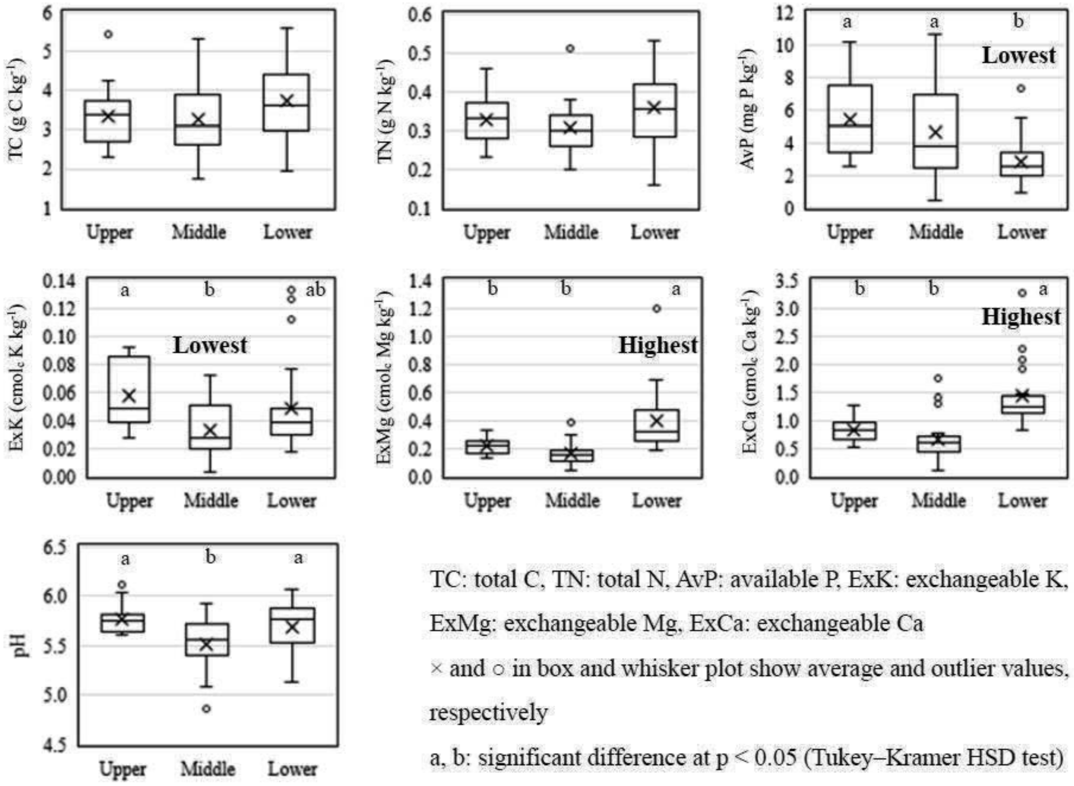


Fig. 4. Average surface water depths in upper, middle and lower position fields
This figure was modified to reference Ikeura et al (2019).
Error bar showed standard error.



TC: total C, TN: total N, AvP: available P, ExK: exchangeable K, ExMg: exchangeable Mg, ExCa: exchangeable Ca

× and ○ in box and whisker plot show average and outlier values, respectively

a, b: significant difference at $p < 0.05$ (Tukey–Kramer HSD test)

Fig. 5. Soil chemical properties in upper, middle and lower position fields
This figure was modified to reference Ikeura et al. (2019).

Exchangeable Mg and exchangeable Ca were the highest in the lower fields, but were the lowest in the middle fields; these two soil factors were higher than exchangeable K. Soil pH was 5.4–5.9, and the middle fields had lower pH than upper and lower field positions.

Determinant analysis

Table 3 shows the MLR results using all available variables (Model 1) and selected variables (Model 2). Through the stepwise variable selection procedure, the average water depth, total C, total N, available P, exchangeable K, exchangeable Mg, and exchangeable Ca were the selected variables for Model 2; total C, available P, exchangeable K, and exchangeable Ca were selected next. Exchangeable Ca showed the strongest significance ($p < 0.001$); suggesting that exchangeable Ca was the main factor for predicting *GY* (Ikeura et al. 2019).

Using the four variables selected in Model 2, a GLMM with a locational factor was applied. The slope of the exchangeable Ca was dependent on the locational factor. The results of Models 3 and 4 are shown in Table 4. Model 3 showed $R^2 = 0.541$, which more significant than Model 2. In Model 4, available P was not selected for the final model. Although Model 4 had lower R^2 (0.529) than Model 3 (0.541), the lowest Akaike Information Criteria (AIC) value shown in Model 4 suggested that it was the most appropriate model to predict *GY*. These results indicated that the main factor affecting difference in rice grain yield was exchangeable Ca, followed by total C, exchangeable K (Ikeura et al. 2019).

Table 3. Constant and coefficient of each model (MLR; Eq. 1)

	Constant	Regression coefficient (*b*)							R^2	AIC	RMSE
	(a)	*V1*	*V2*	*V3*	*V4*	*V5*	*V6*	*V7*			
Model 1		WDavg	TC	TN	AvP	ExK	ExMg	ExCa			
	70.0*	0.545	26.3	-98.0	4.65	-871.0*	14.7	74.5*	0.345	668.1	54.5
Model 2		TC	AvP	ExK	ExCa						
	67.0	18.3*	4.47	-878.5*	81.0***				0.378	662.4	54.7

WDavg: average water depth, TC: total C, TN: total N, AvP: available P, ExK: exchangeable K, ExMg: exchangeable Mg, ExCa: exchangeable Ca

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$. This table was modified to reference Ikeura et al. (2019).

Table 4. Constant and coefficient of each model (GLMM; Eq. 1)

	Constant (a_i)			Regression coefficient (*b*)						R^2	AIC	RMSE
				V1	*V2*	*V3*	Vn_{Li}					
	L_1	L_2	L_3				L_1	L_2	L_3			
Model 3				TC	AvP	ExK	ExCa					
	72.6	37.2	177.1	22.0**	3.66	-689.9*	64.9	118.4	-93.6	0.541	664.6	48.2
Model 4				TC	ExK		ExCa					
	86.9	44.8	196.9	23.0**	-609.6*		58.4	120.8	-104.6	0.529	664.3	48.9

TC: total C, AvP: available P, ExK: exchangeable K, ExCa: exchangeable Ca

*: $p < 0.05$, **: $p < 0.01$. This table was modified to reference Ikeura et al. (2019).

The surface water depth was not selected as a major factor affecting differences in rice yield in this study. Although the average water depths of the upper and the middle fields were lower than those of the lower fields, water was mostly maintained above ground level. In the year of our study, the low yields in the upper fields were not caused by drought stress (Ikeura et al. 2019).

Exchangeable Ca was selected as the first factor of yield difference. One (1) g of rice grain and rice straw contained 0.5 mg Ca and 3.5 mg Ca, respectively (Dobermann and Fairhurst 2002). The grain and straw weights were 300 g m^{-2} and 400 g m^{-2}, respectively (Figs. 9 and 10), and Ca requirement was 1.55 g Ca m^{-2}. The amounts of exchangeable Ca in topsoil (0–10 cm depth, bulk density: 1.5 g cm^{-3}) was 25.2, 19.2, and 44.4 g Ca m^{-2} in the upper, middle, and lower fields, respectively. This suggests that exchangeable Ca contained in the field soil in the target village was not negligible for rice growth, and the difference in exchangeable Ca contents may have affected rice yield (Ikeura et al. 2019).

Total C, selected as the second factor, was before total N as the determinant of this analysis because it had higher variation than total N. Total C showed strong collinearity with total N (R^2 = 0.94). Therefore, total N was a similar factor to total C for affecting differences in yield (Ikeura et al. 2019).

The average total N, available P, and exchangeable K contents in topsoil (0–10 cm depth) were calculated using the soil analysis results as 495 kg ha^{-1}, 6.24 kg ha^{-1}, and 26.9 kg ha^{-1}, respectively. When available N was defined as 3% of the total N (Murata et al. 1997a, 1997b), available N was 14.9 kg ha^{-1}. N and P were deficient in the rainfed fields of the target village and K barely met the required minimum (60 kg ha^{-1} of N, 13 kg ha^{-1} of P, 25 kg ha^{-1} of K; Linquist and Sengxua 2001). Considering the poor soil conditions, N, P, and K fertilization is essential for increasing rice yield in sandy rainfed paddy fields of the target village (Ikeura et al. 2019).

2. Pot experiment for efficient fertilization of sandy fields

Fig. 6 shows the rice plant height for each treatment. There were similar growth trends for standard fertilization (C), 6-split fertilization (SF), and basal fertilization (BF). The maximum plant heights in C, SF and BF were 87.3 cm, 87.4 cm and 87.4 cm at 78 DAT, respectively. No fertilization (NF) grew slower than C, SF, and BF until 18 DAT, then grew at a similar speed until heading (Phongchanmixay et al. 2019).

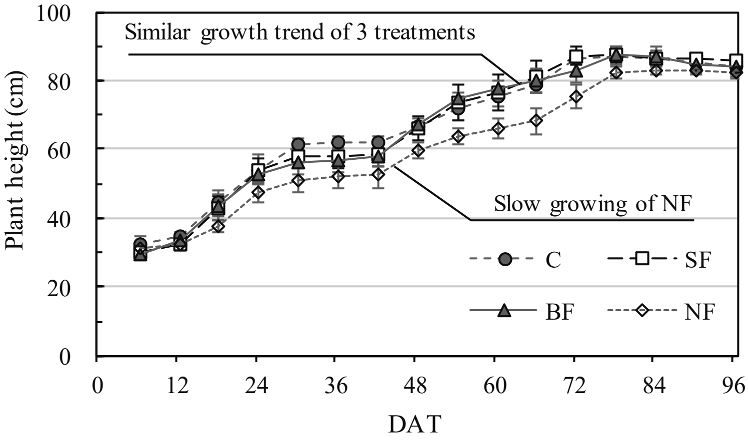


Fig. 6 Rice plant height

This figure was modified to reference Phongchamixay et al. (2019).
Error bar shows standard deviation.

Fig. 7 shows the number of tillers. In all treatments, tiller increase stopped at 42 DAT. At 84 DAT, the number of tillers in all treatments decreased rapidly; this timing coincided with changes to the irrigation intervals (3-day interval to 10-day interval). Therefore, drought stress may have affected this decreased tillering. At this point, C and BF had lost half of their tillers, while SF had retained 70% of tillers. The final topdressing fertilizer for SF contributed to maintaining the number of tillers (Phongchanmixay et al. 2019).

Fig. 8 shows the volume of drainage water. The drainage water volume for NF was higher than the other groups. Drainage from C, SF, and BF mostly stopped after 54 DAT, while NF drained continuously over the 3-day irrigation interval period. Because NF showed the lowest plant height and number of tillers among the four treatments, it can be concluded that evapotranspiration was lower than for the other groups, causing higher drainage volumes (Phongchanmixay et al. 2019).

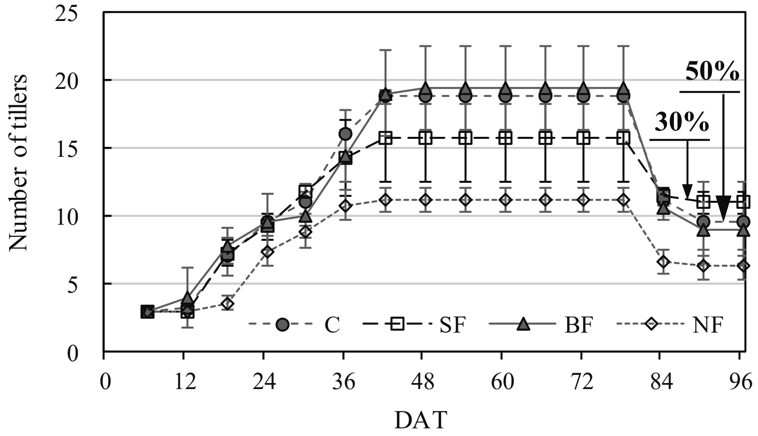


Fig. 7. Number of tillers
This figure was modified to reference Phongchanmixay et al. (2019).
Error bar shows standard deviation.

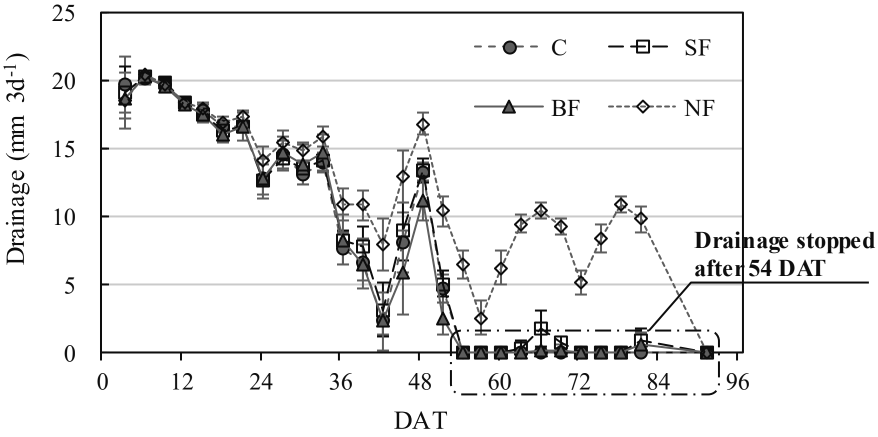


Fig. 8. Drainage water volume
This figure was modified to reference Phongchanmixay et al. (2019).
Error bar shows standard deviation.

Fig. 9 shows the rice grain yield for each fertilizer treatment. SF had the highest yield of all treatments, although there were no significant differences between yields with the C and BF treatments. Our results also indicated that the SF treatment had the potential to increase yield by 70%, 50%, and 30% above NF, BF, and C, respectively. Fig. 10 shows the weight of rice straw. The weight of straw in NF was significantly lower than the other three treatments. There were no significant differences in the weight of straw among C, SF, and BF treatments. These results suggest that SF used nutrients most efficiently to increase grain yields (Phongchanmixay et al. 2019).

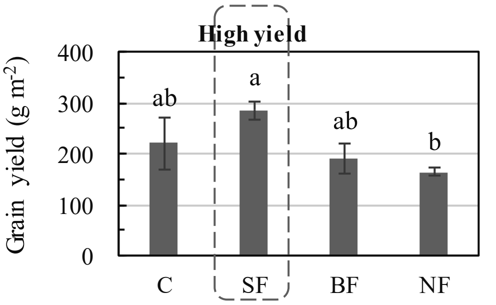


Fig. 9. Rice grain yield
This figure was modified to reference Phongchanmixay et al. (2019).
Error bar shows standard error.
a, b: significant difference ($p < 0.05$).

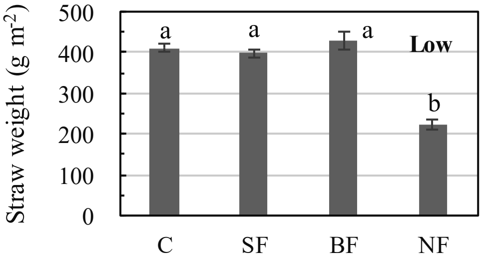


Fig. 10. Rice straw weight
This figure was modified to reference Phongchanmixay et al. (2019).
Error bar shows standard error.
a, b: significant difference ($p < 0.05$).

Table 5 shows the N, P and K amounts in the applied fertilizer, irrigation water and drainage. The N in drainage water of BF was significantly higher than in C, SF, and NF. Total N inputs by fertilizer and irrigation were 300 mg N and 14.4 mg N, respectively. The percentage of leached N from fertilizer and irrigation inputs in C, SF, and BF were 13.2%, 12.1%, and 22.7%, respectively. The drained N in NF plot came from irrigation water and the soil. Drained P was less than 2% of the fertilizer input. Drained P in NF was significantly higher than those in C, SF, and NF. The total K inputs were 83.0 mg K from fertilizer and 20.8 mg K from irrigation during the rice-growing period. The K leaching loss was 24-31% of the total K input. The drained K in SF plot was lower than that in BF plot; split K application seems to increase K uptake by rice and to decrease K leaching (Phongchanmixay et al. 2019).

Table 5. N, P and K amount of fertilizer application, irrigation and drainage

		Fertilizer ($mg\ pot^{-1}$)	Irrigation ($mg\ pot^{-1}$)	Drainage ($mg\ pot^{-1}$)	Leaching ratio*
N	C	300	14.4	41.5 ± 2.9 ^{b}	0.132
	SF	300	14.4	37.9 ± 3.2 ^{b}	0.121
	BF	300	14.4	71.3 ± 12.9 ^{a}	0.227
	NF	0	14.4	40.9 ± 5.1 ^{b}	2.838
P	C	43.7	0	0.418 ± 0.028 ^{b}	0.0096
	SF	43.7	0	0.469 ± 0.097 ^{b}	0.0107
	BF	43.7	0	0.542 ± 0.105 ^{b}	0.0124
	NF	0	0	0.765 ± 0.097 ^{a}	-
K	C	83.0	20.8	30.0 ± 1.3 ^{ab}	0.289
	SF	83.0	20.8	25.0 ± 2.3 ^{c}	0.241
	BF	83.0	20.8	32.4 ± 2.3 ^{a}	0.312
	NF	0	20.8	27.0 ± 2.2 ^{bc}	1.297

Fertilizer and irrigation are NPK input. Drainage is NPK output.
* Leaching ratio: drainage / (fertilizer + irrigation).
a, b, c: different characters show a significant difference ($p<0.05$) among treatments.
Phongchanmixay et al. (2019).

Conclusion

A field survey was conducted in the village in Savannakhet Province to assess rice yield and water and soil conditions in sloped rainfed rice fields with sandy soil, as well as to identify determinants of variation in rice yield. Additionally, to reduce nutrient loss from leaching and improve rice yields in sandy paddy fields, efficient six split fertilization (SF) was tested to compare rice plant growth and leaching loss. We obtained the following results:

1) The rice grain yield was higher in the lower fields than in the upper and middle fields (Ikeura et al. 2019).
2) Although the average depth of surface water was lower in the upper and middle fields than in the lower fields, standing water was sustained during the rice-growing period; surface water depth was not selected as the determinant variable for the observed year (Ikeura et al. 2019).
3) Contents of total C, total N, available P, and exchangeable K in rainfed lowland field soil in the target village were extremely low; fertilization is essential for improving rice yield. As the results of multiple linear regression analysis and generalized linear mixed model, Exchangeable Ca was selected as the highest influential factor to rice grain yield, followed by total C. (Ikeura et al. 2019).
4) The results of the pot experiment indicate that, although the difference was not significant, rice grain yield of SF (six split fertilization) was higher than C (standard fertilization: control), BF (basal fertilization), and NF (no-fertilization). The leaching ratios of N and K in SF pots were lower than in C and BF pots. SF was also advantageous for supplying N for panicle

initiation and maturity. This result shows that split fertilization is a useful method for increasing rice grain yield (Phongchanmixay et al. 2019).

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