Evaluation of the dynamics of the leaf area index (LAI) of rice in farmer’s fields in Vientiane Province, Lao PDR

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Abstract

Rice is the most important crop in Lao People’s Democratic Republic (Lao PDR). The improvement of its productivity is strongly recommended, but information about its growth characteristics in farmers’ fields is limited. This study evaluated the dynamics of the leaf area index (LAI) and analyzed the relationship between the rice productivity and soil in farmers’ fields in Vientiane province, Lao PDR. Because the LAI in the farmers’ fields increased almost linearly, a straight-line regression was used for the analysis. The rice yield in the farmers’ fields ranged from 63.8 g m⁻² to 411.8 g m⁻² and correlated with the LAI during the later growth stage. The variability in the LAI was explained by the LAI growth rate but rarely by the effective accumulated temperatures from the estimated transplanting date. The LAI growth rate was associated with the nitrogen and carbon content in the soil. These results suggest that the rice productivity in farmers’ fields is governed by the soil fertility through LAI growth, and that LAI monitoring is an effective tool to evaluate the production.

Key words: Farmers’ fields, Lao PDR, Leaf area index (LAI), Rice, Soil fertility.

1. Introduction

Rice is by far the most important crop in the Lao People’s Democratic Republic (Lao PDR), and here, approximately 70% of the total calorie supply in diets comes from rice (Maclean et al., 2002). The wet season lowland is the main rice-producing environment (Schiller, 2006). The production constraints in the lowland paddy fields in Lao PDR are poor soil fertility, drought, flooding and diseases, contributing to the low rice yield (Schiller et al., 2001). To increase the yield in farmers’ fields, improved rice varieties (Fukai et al., 1999), soil fertility management (Bell and Seng, 2003) and weed management (Inamura et al., 2003) are recommended. In particular, poor soil fertility is the fundamental problem in the rice production (Wade et al., 1999; Inthavong et al., 2011), and, therefore, understanding the relationship between the soil fertility and rice growth and production is thought to be very important. Although several studies have investigated the rice production and soil properties in farmers’ fields (Inamura et al., 2003; Asai et al., 2009; Saito et al., 2009), information about the growth of rice plants is limited.

The leaf area index (LAI) is an important trait that is related to canopy photosynthetic rate and dry matter production during growth periods (Vaesen et al., 2001). An evaluation of the dynamics of LAI may enable us to quantify the growth of rice plants and to explore the factors that limit the dry matter production in farmers’ fields.

The objective of this study was (1) to evaluate the dynamics of LAI and (2) to analyze the relationship between the rice productivity and soil in farmers’ fields in Vientiane province, Lao PDR.

2. Materials and Methods

2.1 Sites

This study was conducted in 2013 in farmers’ fields in Vientiane province, Lao PDR. 66 farmers’ paddy fields from 33 places were selected in this area for surveying throughout the growth period (Fig. 1). Altitude of the 33 places is from 168 m – 178 m. The longitude and latitude of the study sites were recorded by the Global Positioning System (GPSMAP 62SJ, GARMIN). The rice plants of the investigated farmers’ fields varied in cultivation methods (direct seeding/transplanting, fertilizer, planting density and cultivar). Preliminary interviews with farmers suggested that transplanting, non-fertilization, 25 hill m⁻² of planting density and traditional cultivars were the majority.

2.2 Measurements

The leaf area index (LAI) was measured using a plant canopy analyzer (LAI-2200, LI-COR) with a single sensor mode in a sequence of two above and four below canopy at each field. In order to reduce the influence of the adjacent fields and the operator, a 90° view-cap was applied to the optical sensor. The measurement was conducted 4 times before the heading period (from 22 to 25 July, from 10 to 12 Aug., from 30 Aug. to 1 Sep. and from 16 to 18 Sep.). The LAI for each measurement was referred to as LAI₁st, LAI₂nd, LAI₃rd and LAI₄th. Because the peak of the

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heading in the study site was on 22 Sep., LAI_{4th} contained almost all of the maximum LAI values.

Nine rice plant samples were harvested, and the plant density was measured in 56 of the 66 farmers’ fields to determine the grain yield (g m^{-2}) and total dry weight (TDW; g m^{-2}) at the maturing stage (from 22 to 25 Oct.). The other 10 fields were excluded from the sampling because the rice plants during these periods were too premature to harvest or had already been harvested. The grain yield and TDW were determined after oven-drying at 70\(^\circ\)C for more than 2 days.

The soil samples from 33 of the 66 fields were collected from the surface soil (0 to 20 cm deep) at the same date as LAI measurement. All of the soil samples were air-dried and ground to pass through a 2-mm sieve before analysis. The total nitrogen (N) and carbon (C) contents in the soil were analyzed using a trace mass spectrometer (Tracer MAT, Fisons Instruments).

2.3 Weather data and analysis method

The air temperature (maximum temperature, minimum temperature and average temperature) was measured by humidity temperature and vapor pressure sensor (VP-3, Decagon devices). The data was recorded using a field monitoring system (Mizoguchi, 2012) in Vientiane.

The LAI data were analyzed by the following regression line:

\[
LAI = a T + b
\]

where \(a\) and \(b\) are the regression coefficients, and \(T\) is the effective accumulated temperature (\(^\circ\)C d; base temperature of 10\(^\circ\)C) from 22 July. The coefficient \(a\) is defined as the LAI growth rate, and the transplanting date was estimated based on the x-intercept (-\(b/a\)) (Fig. 2). In order to validate the estimated transplanting date, we defined the observed transplanting date as that estimated from interview and the observation based on normal rice growth during the first and second investigation from 22 to 25 July and 10 to 12 Aug., respectively.

3. Results

Figure 3 shows the seasonal changes in the average, maximum and minimum air temperature in Vientiane during the rice growth periods. Almost all of the daily average temperatures during the growth period were 25-30\(^\circ\)C. The average temperature of the middle growth period (22 August to 21 September) was about 1.5\(^\circ\)C greater than that of the early (22 July to 21 Aug.) and late
The TDW ranged from 248.4 g m$^{-2}$ to 1089.0 g m$^{-2}$ (660.0 g m$^{-2}$ on average), and the grain yield ranged from 63.8 g m$^{-2}$ to 411.8 g m$^{-2}$ (235.8 g m$^{-2}$ on average). The TDW and the LAI were correlated with the grain yield (TDW: $R^2 = 0.52$; LAI: $R^2 = 0.18$) (Fig. 4). The average harvest index (grain yield / TDW) was 0.36. The TDW was correlated with the LAI during the fourth investigation from 16 to 18 Sep. ($LAI_{4th}$) ($R^2 = 0.48$) (Fig. 5).

Figure 2 shows the changes with the effective accumulated temperature of the LAI as measured by LAI-2200 in typical three farmers’ fields. The LAI in the farmers’ fields increased almost linearly. The slope of the regression line is defined as the LAI growth rate. The LAI growth rate in the 66 fields varied widely from $0.56 \times 10^{-3}$ to $3.63 \times 10^{-3}$ m$^2$ m$^{-2}$ $\degree$C$^{-1}$ ($1.94 \times 10^{-3}$ m$^2$ m$^{-2}$ $\degree$C$^{-1}$ on average). The estimated transplanting date calculated by the x-intercept ($-b/a$) was consistent with the observed transplanting date. The estimated transplanting date was substantially underestimated in the 4 plots (Fig. 6).

The product of the LAI growth rate and the effective accumulated temperatures was strongly correlated with the $LAI_{4th}$ ($R^2 = 0.768$) (Fig. 7 (a)). $LAI_{4th}$ was correlated with the LAI growth rate ($R^2 = 0.776$) but rarely with the effective accumulated temperatures ($R^2 = 0.004$) (Fig. 7 (b), (c)). The N and C contents in the soil in the farmers’ fields ranged from 0.41 to 1.98 g kg$^{-1}$ (0.99 g kg$^{-1}$ on average) and from 2.4 to 24.0 g kg$^{-1}$ (10.1 g kg$^{-1}$ on average), respectively. The N and C contents in soil had a positive correlation ($R^2 = 0.926$). The LAI growth rate was associated with the N and C contents of the soil in most of the fields (Fig. 8).

4. Discussion

The average grain yield of 56 investigated fields was 235.8 g m$^{-2}$, and this yield level is low. The yield level was very similar to
that of Inamura et al. (2003), who also evaluated the rice yield in the farmers’ fields in the study area in Lao PDR in 1999 and 2000, suggesting that the improvement in the yield was not obvious for a decade.

The grain yield in this study correlated with the total dry matter during the maturing stage (TDW) (Fig. 4), which correlated with the LAI at the fourth investigation (LAI₄th) (Fig. 5). These results indicate that the limitation of the LAI development restricts the dry matter production and, thus, the yield in the study area. The average LAI growth rate in this study (1.94 × 10⁻³ m² m⁻² °C⁻¹) corresponds approximately to that which was obtained in the 56 years unfertilized fields in Japan (Hirooka et al., 2016). This study used a plant canopy analyzer, LAI-2200, to measure the LAI. Although the analyzer has the accidental error against the destructive measurements, the error would be acceptable (Stropišana et al., 2006; Sone et al., 2008). Moreover, the nondestructive measurement by this analyzer is suitable for research, such as this study, that targets a number of unspecified farmers’ fields. The analyzer also reduces the laboriousness of the destructive measurements for LAI and makes frequent measurements easier. Accordingly, the most advantageous aspect of this analyzer may be the quantification of the LAI dynamics based on frequent measurements (Hirooka et al., 2013; 2016).

![Fig. 7](image-url) Relationship between the LAI during the fourth investigation and (a) the product of the LAI growth rate and the effective accumulated temperature, (b) the LAI growth rate (m² m⁻² °C⁻¹), and (c) the effective accumulated temperature from the estimated transplanting date (°C d).

![Fig. 8](image-url) Relationship between the LAI growth rate (m² m⁻² °C⁻¹) and the (a) N and (b) C contents in the soil (g kg⁻¹).
Based on the aspect of the LAI changes in the different farmers’ fields (Fig. 2), a linear regression was employed to quantify the LAI dynamics. The estimated transplanting date calculated by the x-intercepts (-bd) was consistent with the observed transplanting date except for in 4 fields. These exceptions seem to be caused by the late measurement of the LAI: measurement when the LAI approaches saturation underestimates the developmental rate and overestimates the transplanting date. Therefore, it is suggested that the estimation of the transplanting date is possible by measuring the LAI when the LAI development is vigorous: the best timing is until approximately 2 months after transplanting. This simple method of estimating the transplanting date can be useful because the acquisition of accurate information from farmers is often difficult. The transplanting date is occasionally closely related to the dry matter production of rice (Homma et al., 2007; Jalota et al., 2009), although the relation was not significant in this study ($R^2 = 0.04$).

The LAI is determined by the LAI growth rate and the growth periods (Yoshida et al., 2007). Although the $LAI_{ab}$ was strongly correlated with the product of these two parameters in this study, Fig. 7 indicates that the LAI growth rate was the main determination factor of the LAI at the later growth stage of rice in farmers’ fields in Lao PDR. The result might derive from larger coefficient of variance of the LAI growth rate ($cv = 0.33$) than that in effective accumulated temperature ($cv = 0.16$).

N and C contents of the soil in this study were similar to those in Cambodia and Thailand investigated by Kawaguchi and Kyuma (1977), suggesting that soil fertility in this area is thought to be low. LAI growth rate was associated with the N and C contents of the soil. A few fields did not follow this relationship, where drought or fertilizer application may affect the LAI growth. Except for these fields, these results suggest that the rice productivity of farmers’ fields is mainly governed by the soil fertility through LAI growth. LAI development was depended on soil fertility and fertilizer (Yoshida et al., 2010). Thus, in order to enhance the LAI growth and to increase the rice production, fertilizer application may be necessary. Otherwise, an improvement of the soil fertility may be important. The close relationship between the C content and the LAI growth rate suggests that rice straw management after harvest is a key factor for sustainable production in farmers’ fields as was previously shown in Northeast Thailand (Homma et al., 2003). The results of this study also suggest that LAI monitoring can estimate the soil fertility in the study area and support the fundamental theory of evaluating the soil fertility using a simulation model with LAI monitoring and remote sensing (Homma et al., 2017; Maki et al., 2017).

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References

Asai H, Samson BK, Stephan HM, Songyikhangsuthor K, Inoue Y, Shiraiwa T, Horie T, 2009: Biochar amendmenttechniques for upland rice production in Northern Laos: soil physical properties, leaf SPAD and grain yield. Field Crops Research 111, 81–84.

Bell RW, Seng V, 2003: Rainfed lowland rice-growing soils of Cambodia, Laos, and North-east Thailand. CARDI International Conference on Research on Water in Agricultural Production in Asia for the 21st Century, 25–28 November, Phnom Penh, Cambodia, pp.161–173.

Fukai S, Inthapanyap P, Blamey FPC, Khonthosuvon S, 1999: Genotypic variation in rice grown in low fertile soils and drought-prone, rainfed lowland environments. Field Crops Research 64, 121–130.

Hirooka Y, Homma K, Shiraiwa T, Kuwada M, 2016: Parameterization of leaf growth in rice (Oryza sativa L.) utilizing a plant canopy analyzer. Field Crops Research 186, 117–123.

Hirooka Y, Irie T, Homma K, Shiraiwa T, Toriumi A, 2013: Analysis of genotypic variation of leaf canopy dynamics in rice by using plant canopy analyzer. Journal of Crop Research 58, 51–56. (in Japanese)

Homma K, Horie T, Shiraiwa T, Sripodok S, Supapoj N, 2003: Delay of heading date as an index of water stress in rainfed rice in mini-watersheds in Northeast Thailand. Field Crops Research 88, 11–19.

Homma K, Horie T, Shiraiwa T, Supapoj N, 2007: Evaluation of transplanting date and nitrogen fertilizer rate adapted by farmers to toposequential variation of environmental resources in a mini-watershed (Nong) in northeast Thailand. Plant Production Science 10, 488–496.

Homma K, Maki M, Hirooka Y, 2017: Development of a rice simulation model for remote-sensing (SIMRIW-RS). Journal of Agricultural Meteorology 73(1), 9–15.

Inamura T, Miyagawa S, Singvilay O, Kono Y, 2003: Competition between weeds and wet season transplanted paddy rice for nitrogen use, growth and yield in the central and northern regions of Laos. Weed Biology and Management 3, 213–221.

Inthavong T, Fukai S, Tsubo M, 2011: Spatial variations in water availability, soil fertility and grain yield in rainfed lowland rice: a case study in Savannakhet Province, Lao PDR. Plant Production Science 14, 184–195.

Jalota SK, Singh KB, Chahal GBS, Gupta RK, Chakraborty S, Sood A, Ray SS, Panighrayi S, 2009: Integrated effect of transplanting date, cultivar and irrigation on yield, watersaving and water productivity of rice (Oryza sativa L.) in Indian Punjab: field and simulation study. Agric. Agricultural Water Management 96, 1096–1104.

Kawaguchi K, Kyuma K, 1977: Paddy Soils in Tropical Asia. Their Material Nature and Fertility. The University Press of Hawaii, Honolulu, pp.1-258.

Maclean JL, Dawe DC, Hardy B, Hettel GL, 2002: Rice alamanac. Los Banos (Philippines): International Rice Research Institute, Bouake (Cote d’Ivoire): West Africa Rice Development Association, Cali (Colombia): International Center for Tropical Agriculture, Rome (Italy): Food and Agriculture Organization, pp.1-253.

Homma K, Maki M, Hirooka Y, Oki K, 2017: Estimation of rice yield by assimilating remote sensing data into crop growth model (SIMRIW-RS). Journal of Agricultural Meteorology 73(1), 2–8.

Mizoguchi M, 2012: Field monitoring system. Water, Land and Environment 80, 50. (in Japanese)

Saito K, Linquist B, Atlin GN, Phanthaboon K, Shiraiwa T, Horie
Y. Hirooka et al.: Evaluation of dynamics of LAI of rice in farmer’s fields in Vientiane, Lao PDR

T, 2006: Response of traditional and improved upland rice cultivars to N and P fertilizer in northern Laos. *Field Crops Research* **96**, 216–223.

Schiller JM, 2006: *Rice in Laos*. International rice research institute, Metro Manila, pp.1-457.

Schiller JM, Lingquist B, Douangsila K, Inthapanya P, Douang Boupha B, Inthavong S, Sengxua P, 2001: *Constraints to rice production systems in Laos*. In: *Increased Lowland Rice Production in the Mekong Region* (ed. by Fukai S. and Basnayake J.). ACIAR, Tokyo, pp.3–19.

Sone C, Saito K, Futakuchi K, 2009: Comparison of three methods for estimating leaf area index of upland rice cultivars. *Crop science* **49**, 1438–1443.

Stroppiana D, M, Boschetti R, Confalonieri S, Bocchi PA Brivio, PA, 2006. Evaluation of LAI-2000 for leaf area index monitoring in paddy rice. *Field Crops Research* **99**, 167–170.

Vaesen K, Gilliams S, Nackaerts K, Coppin P, 2001: Ground-measured spectral signatures as indicators of ground cover and leaf area index: the case of paddy rice. *Field Crops Research* **69**, 13–25.

Wade LJ, Fukai S, Samson BK, Ali A, Mazid MA, 1999: Rainfed-lowland rice: physical environment and cultivar requirements. *Field Crops Research* **64**, 3–12.

Yoshida H, Horie T, Katsura K, Shirawa T, 2007: A model explaining genotypic and environmental variation in leaf area development of rice based on biomass growth and leaf N accumulation. *Field Crops Research* **102**, 228–238.

Yoshida H, Horie T, 2010; A model for simulating plant N accumulation, growth and yield of diverse rice genotypes grown under different soil and climatic conditions. *Field Crop Research* **117**, 122–130.