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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 LAI_{1st}, LAI_{2nd}, LAI_{3rd} and LAI_{4th}. Because the peak of the

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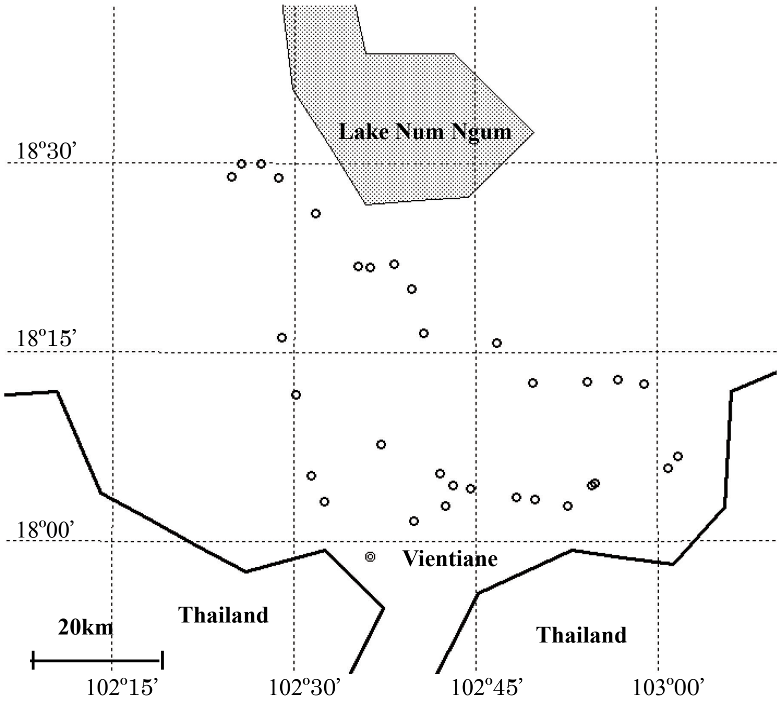

Fig. 1. Thirty-three survey places in Vientiane Province, Lao PDR. Altitude of the thirty-three places is from 168 m–178 m. The measurements were conducted in 2 paddy fields in each place.

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℃ for more than 2 days.

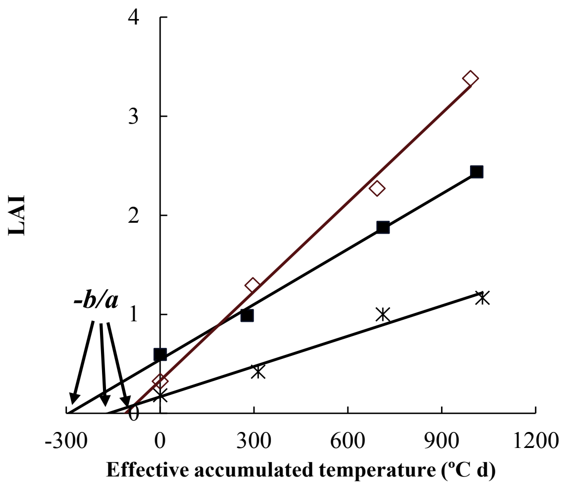

Fig. 2. Changes with the effective accumulated temperature (℃ d; base temperature of 10℃) of the LAI. The effective accumulated temperature was calculated from 22 July.

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:

$$LAI = a\,T + b \qquad (1)$$

where a and b are the regression coefficients, and T is the effective accumulated temperature (℃ d; base temperature of 10℃) 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℃. The average temperature of the middle growth period (22 August to 21 September) was about 1.5℃ greater than that of the early (22 July to 21 Aug.) and late

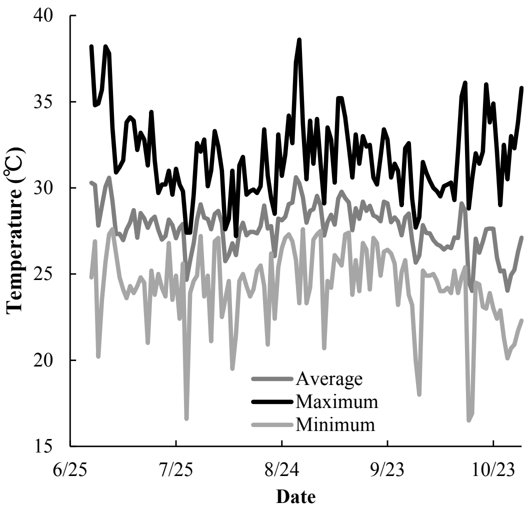

Fig. 3. The seasonal changes in the average, maximum and minimum air temperature as acquired using a field monitoring system in Vientiane in 2013 during the rice growth periods.

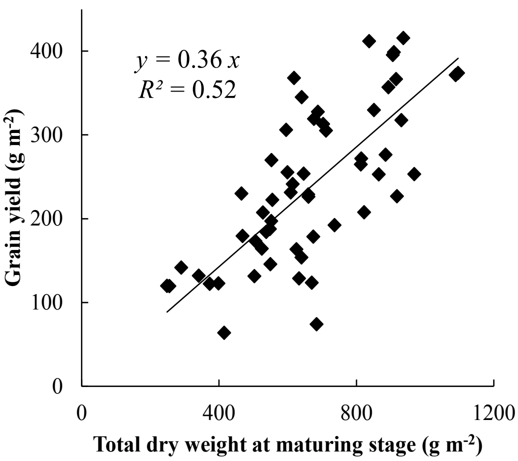

Fig. 4. Relationship between the grain yield (g m^{-2}) and the total dry weight during the maturing stage (g m^{-2}).

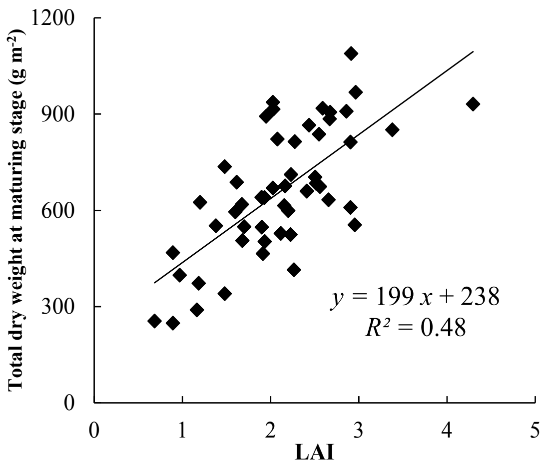

Fig. 5. Relationship between the total dry weight during the maturing stage (g m^{-2}) and the LAI at the fourth investigation (LAI_{4th}).

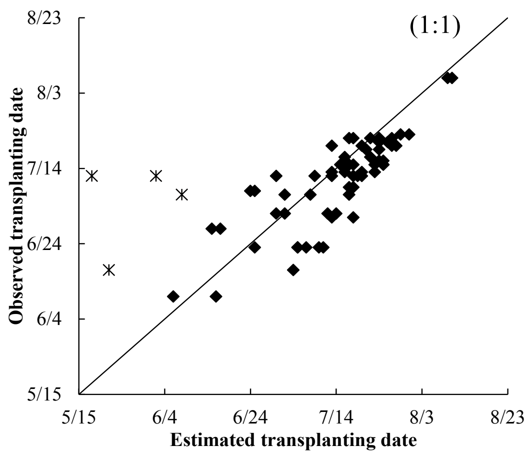

Fig. 6. Relationship between the transplanting date as estimated from equation (1) and the transplanting date from observation during the first survey. 4 plots(*) were excluded from the next analysis.

growth periods (22 Sep. to 21 Oct.).

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 0.56×10^{-3} to 3.63×10^{-3} $m^2 m^{-2}$ ℃$^{-1}$ (1.94×10^{-3} $m^2 m^{-2}$ ℃$^{-1}$ 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 (LAI_{4th}) (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} m^2 m^{-2} ℃$^{-1}$) 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 (Stropiana *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).

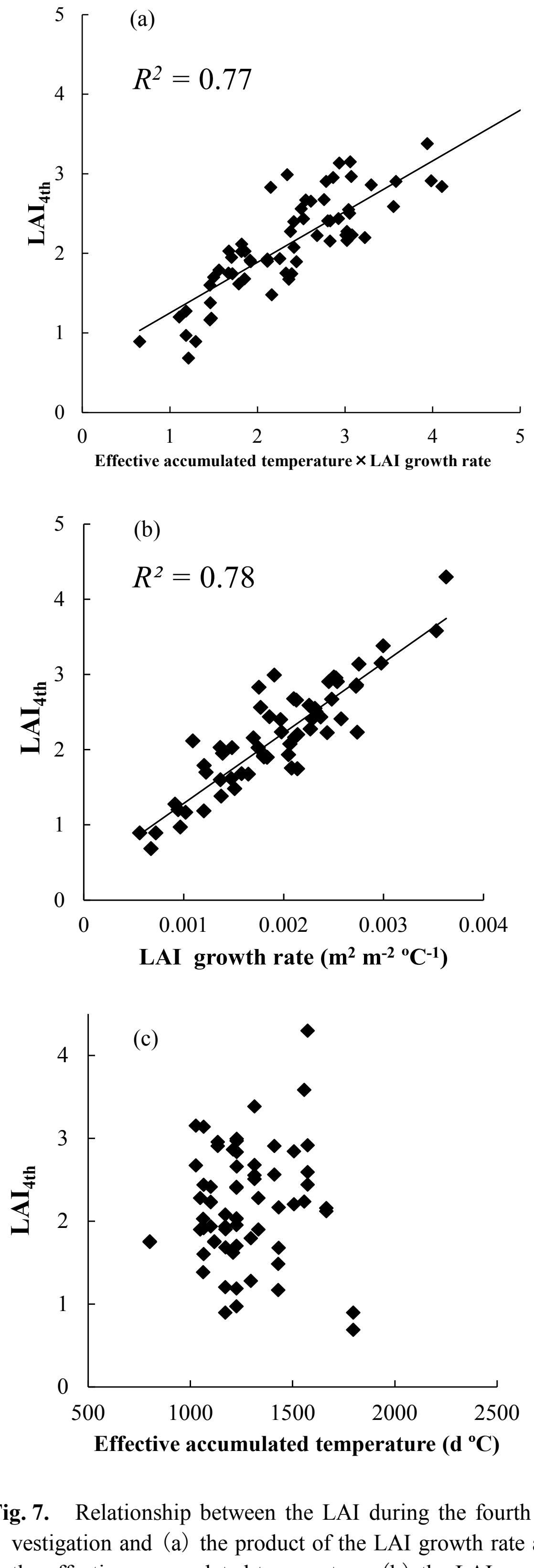

Fig. 7. Relationship between the LAI during the fourth investigation and (a) the product of the LAI growth rate and the effective accumulated temperature, (b) the LAI growth rate (m^2 m^{-2} ℃$^{-1}$), and (c) the effective accumulated temperature from the estimated transplanting date (℃ d).

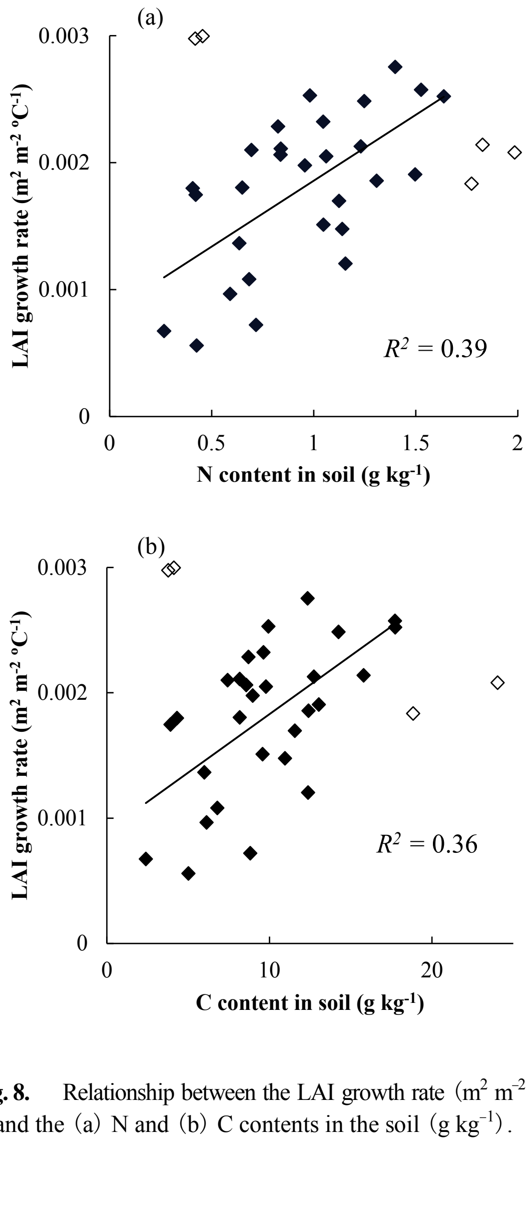

Fig. 8. Relationship between the LAI growth rate (m^2 m^{-2} ℃$^{-1}$) and the (a) N and (b) C contents in the soil (g kg^{-1}).

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 ($-b/a$) 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_{4th} 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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