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Leaf area index based nitrogen diagnosis in irrigated lowland rice

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Abstract

Leaf area index (LAI) is used for crop growth monitoring in agronomic research, and is promising to diagnose the nitrogen (N) status of crops. This study was conducted to develop appropriate LAI-based N diagnostic models in irrigated lowland rice. Four field experiments were carried out in Jiangsu Province of East China from 2009 to 2014. Different N application rates and plant densities were used to generate contrasting conditions of N availability or population densities in rice. LAI was determined by LI-3000, and estimated indirectly by LAI-2000 during vegetative growth period. Group and individual plant characters (e.g., tiller number (TN) and plant height (H)) were investigated simultaneously. Two N indicators of plant N accumulation (NA) and N nutrition index (NNI) were measured as well. A calibration equation ($LAI=1.7787LAI_{2000}-0.8816$, $R^2=0.870^{**}$) was developed for LAI-2000. The linear regression analysis showed a significant relationship between NA and actual LAI ($R^2=0.863^{**}$). For the NNI, the relative LAI ($R^2=0.808^{**}$) was a relatively unbiased variable in the regression than the LAI ($R^2=0.33^{**}$). The results were used to formulate two LAI-based N diagnostic models for irrigated lowland rice ($NA=29.778LAI-5.9397$; $NNI=0.7705RLAI+0.2764$). Finally, a simple LAI deterministic model was developed to estimate the actual LAI using the characters of TN and H ($LAI=-0.3375(TH\times H\times 0.01)^2+3.665(TH\times H\times 0.01)-1.8249$, $R^2=0.875^{**}$). With these models, the N status of rice can be diagnosed conveniently in the field.

Keywords: leaf area index, rice, LAI-2000, nitrogen diagnosis, plant characters

1. Introduction

Leaf surfaces are the primary border of energy and mass exchange. The important processes such as canopy interception, evapotranspiration, and gross photosynthesis are directly proportional to the leaf area index (LAI) (Fang and Liang 2008; Liu and Li 2016), defined as the one-sided green leaf area per unit ground area (Stroppiana *et al.* 2006). The LAI being a very important variable in agronomic research (Soltani and Galeshi 2002), has been integrated/implemented in crop growth modeling, dynamic simulations of carbon and water, and crop nitrogen (N) dilution and diagnosis (Wang *et al.* 2002; Heuvelink *et al.* 2007; Xue and Yang 2008; Ata-Ul-Karim *et al.* 2014).

The LAI can be measured *in situ* either directly or indirectly. Direct methods measure the area of representative leaf samples and they are the only way to determine the actual leaf area. However, they are laborious and destructive,

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which limits their practical implementation in field. Alternatively, indirect measurements can estimate LAI by evaluating some variables obtained easily. For example, optimal instruments are widely used to measure the radiation transmitted through the canopy, from which the LAI can be determined (Welles and Cohen 1996). Among the various commercial optical instruments currently available for indirect *in situ* LAI estimation, the LAI-2000 (LI-COR, Lincoln, NE, USA) is the most widely used. The LAI-2000 measures diffuse radiation in five distinct angular bands around the zenith to yield relatively accurate leaf area information with a single measurement only. This method is better than the one that relies on linear sensors (Welles and Cohen 1996). However, forest research has shown that the LAI determined with the LAI-2000 is considerably smaller than the actual LAI measured directly (Stenberg *et al.* 1994; White *et al.* 2000). By contrast, Dingkuhn *et al.* (1999) used the LAI-2000 to estimate the LAI of upland rice (*Oryza sativa* L.) and showed that the values within an LAI range of 0.2–2.0 were the same as those obtained by direct measurements. In the study of Sone *et al.* (2009), the two methods yielded equivalent results in upland rice for LAI values<4. However, the same research in paddy rice showed that LAI-2000 tends to underestimate LAI when LAI value>1, where the actual LAI can reach to 4 just at the end of tillering stage (Stroppiana *et al.* 2006). These studies indicated proper validation is needed when using the LAI-2000 to measure the LAI of a specific species or genotype both in forest and in crops.

Among rice ecosystems, irrigated lowland rice accounts for approximately 55% of the world's rice planted area and 76% of global rice production (Fageria 2003; Fageria *et al.* 2003). In addition, the LAI of irrigated lowland rice can reach 7 at the booting or heading stages, therefore it is essential to study the performance of LAI-2000 in irrigated lowland rice.

Nitrogen (N) is a major limiting factor after water deficit for crop production, and therefore has a marked effect on the LAI. Various diagnostic methods, including those based on soil nitrate measurements (Isfan *et al.* 1995), the N nutrition index (NNI) (Debaeke *et al.* 2006; Ziadi *et al.* 2008), and the leaf N concentration (LNC) (Errecart *et al.* 2012), have been developed to optimize N management in crops. However, each method has its limitation, and the improvement of N diagnostic models is still urgently needed. Since most of the N in crops is contained in the green leaves during crop growth period, LAI is a very sensitive indicator of changes in crop N demand within a growing season (Wood *et al.* 2003).

Since the LAI is mainly used to monitor changes of canopy structure, its application in N diagnosis requires firstly to relate with proper N indicators, such as leaf N and chlorophyll contents (Yin *et al.* 2003; Heuvelink *et al.* 2007). However, these two N indicators together account for <50% of whole-plant N uptake (Makino and Mae 1997), given that most of the plant N accumulation (NA) occurs in the shoots. Indeed, previous studies have shown a significantly positive correlation between plant NA and LAI under an adequate supply of N fertilizer (Plenet and Lemaire 1999). These observations suggest the use of NA as a promising N indicator in LAI-based N diagnosis. In recent years, the NNI, determined by dividing the actual plant N concentration by the critical N concentration, has been widely used in crop N diagnosis (Debaeke *et al.* 2006; Prost and Jeuffroy 2007; Yuan *et al.* 2016b). Since the NNI is linearly related to the chlorophyll content (Houlès *et al.* 2007), and NNI has a similar linear relationship to NA (Lemaire *et al.* 2008), thus, a key question is whether the NNI is an ideal N indicator for LAI. Although lots of researches have been conducted to optimize the N diagnosis in crops production, the controversy still exists. In comparison to soil nitrate measurement, LNC and NNI approaches, LAI approach was few reported in the literature. However, the LAI is of considerable importance as a basis for varying N supplementation rates, as it takes into account the current condition of growing crops. We hypothesized LAI approach is an appropriate tool for diagnosing the crop N status, and three LAI estimation methods were compared to facilitate the implementation of this tool.

The main objectives were, to analyze the correlation between LAI-2000 and LI-3000 based LAI in irrigated lowland rice, to develop N diagnostic models based on LAI and potential N indicators (NA and NNI), and to establish a simple model for estimating the LAI in the field that could be used for diagnosing rice N status.

2. Materials and methods

2.1. Field experiments

Four field experiments were conducted from 2009 to 2014 in Jiangsu Province of East China. Different N application rates (0–375 kg ha^{-1}) were used to generate contrasting conditions of N availability in four *japonica* rice, Wuxiangjing 14 (WXJ-14), Wuyunjing 19 (WYJ-19), Yongyou 8 (YY-8), and Wuyunjing 24 (WYJ-24), and two *indica* rice, Liangyoupei 9 (LYP-9) and Y liangyou 1 (YLY-1). Detailed information is shown in Table 1. A randomized complete design with three replications was used in experiments 2, 3 and 4, in which the hill spacing was 0.25 m×0.15 m. A split-plot design was used in experiment 1 to achieve different N rates (150 and 300 kg N ha^{-1}) and plant densities (0.5 m×0.15 m, 0.3 m×0.15 m, and 0.1 m×0.15 m). Two seedlings per hill were transplanted manually in the 5 m×6 m plots in all experiments. The distribution of total N at different growth stages was 50% before transplanting, 20% at tillering stage, and 30% at booting stage. Phosphorus and potassium