Available at www.sciencedirect.com

INFORMATION PROCESSING IN AGRICULTURE XXX (2017) XXX–XXX

journal homepage: www.elsevier.com/locate/inpa

Leaf chlorophyll and nitrogen dynamics and their relationship to lowland rice yield for site-specific paddy management

Asa Gholizadeh [a], *Mohammadmehdi Saberioon* [b,*], *Luboš Borůvka* [a], *Aimrun Wayayok* [c], *Mohd Amin Mohd Soom* [d]

[a] *Department of Soil Science and Soil Protection, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Prague, Czech Republic*
[b] *Laboratory of Signal and Image Processing, Institute of Complex Systems, South Bohemia Research Centre of Aquaculture and Biodiversity of Hydrocenoses, Faculty of Fisheries and Protection of Waters, University of South Bohemia in České Budějovice, Nové Hrady, Czech Republic*
[c] *Department of Biological and Agricultural Engineering, Faculty of Engineering, University Putra Malaysia, Selangor, Malaysia*
[d] *Faculty of Sustainable Agriculture, University Malaysia Sabah, Sandakan, Malaysia*

A R T I C L E I N F O

Article history:
Received 18 November 2016
Received in revised form
11 August 2017
Accepted 17 August 2017
Available online xxxx

Keywords:
Spatial variability
Non-invasive measurement
Precision farming
Decision support

A B S T R A C T

The optimum rate and application timing of Nitrogen (N) fertilizer are crucial in achieving a high yield in rice cultivation; however, conventional laboratory testing of plant nutrients is time-consuming and expensive. To develop a site-specific spatial variable rate application method to overcome the limitations of traditional techniques, especially in fields under a double-cropping system, this study focused on the relationship between Soil Plant Analysis Development (SPAD) chlorophyll meter readings and N content in leaves during different growth stages to introduce the most suitable stage for assessment of crop N and prediction of rice yield. The SPAD readings and leaf N content were measured on the uppermost fully expanded leaf at panicle formation and booting stages. Grain yield was also measured at the end of the season. The analysis of variance, variogram, and kriging were calculated to determine the variability of attributes and their relationship, and finally, variability maps were created. Significant linear relationships were observed between attributes, with the same trends in different sampling dates; however, accuracy of semivariance estimation reduces with the growth stage. Results of the study also implied that there was a better relationship between rice leaf N content ($R^2 = 0.93$), as well as yield ($R^2 = 0.81$), with SPAD readings at the panicle formation stage. Therefore, the SPAD-based evaluation of N status and prediction of rice yield is more reliable on this stage rather than at the booting stage. This study proved that the application of SPAD chlorophyll meter paves the way for real-time paddy N management and grain yield estimation. It can be reliably exploited in precision agriculture of paddy fields under double-cropping cultivation to understand and control spatial variations.

* Corresponding author.
E-mail address: msaberioon@frov.jcu.cz (M. Saberioon).

Peer review under responsibility of China Agricultural University.
http://dx.doi.org/10.1016/j.inpa.2017.08.002
2214-3173

1. Introduction

Intensive agricultural production systems have increased the use of Nitrogen (N) fertilizers in an attempt to produce and sustain high crop yields [1,2]. Symptoms of insufficient N supply, which is one of the most critical nutrients in crop production, include lower chlorophyll content, less biomass production, and a decreased grain yield and quality [3,4]. On the other hand, excessive N application is the key reason for N Use Efficiency (NUE) decrease, diminished water, atmospheric quality as well as adverse biodiversity effects [5,6]. Therefore, diagnosing plant N status has become one acute purpose to balance N application and achieve higher yield [7,8].

Several methods are available for assessing the N status of crops. The most common method is the conventional method of tissue analysis, which determines the Kjeldahl N. It is a direct and accurate method; however, it is time-consuming and operators are required [2]. Various other techniques have also been reported for site-specific assessment of N status of crops and for amplifying the yield based on leaf and canopy optical properties [5,9,10]. Although these techniques are faster than laboratory procedures, they require expensive high-tech instruments. As leaf N content is strongly correlated with chlorophyll content [11–13], the use of Soil Plant Analysis Development (SPAD) meter has been introduced as a popular, fast, and cheap technique to estimate N levels from the measurement of leaf transmittance [2,14,15]. The technique helps the real-time N control, which leads to variable rate application and site-specific crop management. For instance, Ali et al. [16] revealed that the N fertilizer requirements based on SPAD readings were 15 and 40 kg ha^{-1} lower compared to conventional N management during wet and dry seasons, respectively.

Rice cultivation in Southeast Asia follows a double-cropping system. Under this system, accessibility of essential plant nutrients, including N, for plant is more critical than for a mono-cropping system, as during the off-season (dry season) the regeneration of N in soil takes place by the soil organic matter decomposition, so farming operations can be conducted properly [17]. Thus, for a sustainable off-season and adequate plant nutrient availability during the next season, it is essential to reduce distribution losses to an acceptable level to ensure a reliable amount of nutrients throughout the field. However, the ability to manage double-cropping systems is desirable, in order to reduce high cost inputs, and hence significantly improve the profitability of the crop production process. To the best of our knowledge, until now few research works have focused on the rice double-cropping system. Moreover, such relationships under different growth stages of double-cropping rice were not well documented. Therefore, the current study was conducted to create and describe spatial and temporal variability maps of SPAD, N content, and yield in a typical Malaysian paddy field under double-cropping cultivation. The research also aimed to determine the effect of real-time N management through assessment of the SPAD value, and to correlate them with total N in leaves and grain yield. This helps to introduce the best growth stage for the evaluation of N amount in crops and make N fertilizer top-dress recommendation.

2. Materials and methods

2.1. Study area

The current study was carried out at the Tanjung Karang rice irrigation scheme located on a flat coastal plain in the Integrated Agricultural Development Area (IADA) (Fig. 1). It is in the district of Kuala Selangor and Sabak Bernam (3°35′ N, 101°05′ E). The scheme included eight sections that have been separated into 24 blocks, specifically blocks A to X. Block C was chosen for this experiment, which contained 118 plots with a total area of about 142 ha.

The Tanjung Karang area is mainly composed of mineral and organic soils. The soils of the area are classified into 15 soil series. These are Kranji, Banjar, Sedu, Jawa, Sempadan, Karang, Telok, Selangor, Bernam, Bakau, Serong, brown clay, Briah, organic clay, and unclassified series. Kranji, Banjar, and Karang are developed on the marine alluvium along the coast and riverine alluvium along the Bernam River. Meanwhile, brown clay, Briah, and organic clay are transition soils between mineral and peat soils in the swamp. They are composed of brown clays derived from brackish water deposits, organic clays, and muck, which originate from peat soils. Within block C, there are only two major soil series, namely Telok series *(Typic Sulfaquept)* and Jawa series *(fine, mixed isohyperthermic Sulfic Tropaquept)*. Summary statistics of the block C soil parameters can be seen in Table 1.

2.2. Management practices

In the study area, rotovation is carried out twice per season; while ploughing and land leveling are rarely done or only once after several years. After the second rotovation, the field was irrigated to about 3–5 cm for pre-saturation. During pre-saturation, pre-germinated seeds (MR 219 cultivar, seeds soaked for 48 h) for transplanting or direct seeding system were prepared. Pre-germinated seeds were scattered manually or by blowing them over the field with a seed rate of 150 kg ha^{-1}. 15 Days After Planting (DAP) seedlings were transplanted to plots.

Fertilizer management in the study area is usually based on the general recommendation rate suggested by the Department Of Agriculture (DOA). The recommendation rate is 170:80:150 kg ha^{-1} for N:P_2O_5:K_2O. At the three leaves stage, the mixture of N:P_2O_5:K_2O (17.5:15.5:10 at the rate of 250 kg ha^{-1}, equal to 43.75, 38.75, and 25 kg ha^{-1}, respectively) is applied. During tillering, 135 kg ha^{-1} Urea (46% N, equal to 62.1 kg ha^{-1}) and 100 kg ha^{-1} Muriate Of Potash (MOP) (60% K_2O, equal to 60 kg ha^{-1}) are used. During panicle formation, a compound fertilizer of N, P_2O_5, K_2O, and Mg (12:12:17:2 at the rate of 250 kg ha^{-1}, equal to 46, 30, 42.5, and 5 kg ha^{-1}, respectively) and 35 kg ha^{-1} Urea are utilized. At the booting stage, N, P_2O_5, K_2O, and Mg compound fertilizer (12:12:17:2 at the rate of 150 kg ha^{-1}, equal to 18, 18, 25.5, and 3 kg ha^{-1},

Please cite this article in press as: Gholizadeh A et al. Leaf chlorophyll and nitrogen dynamics and their relationship to lowland rice yield for site-specific paddy management. Info Proc Agri (2017), http://dx.doi.org/10.1016/j.inpa.2017.08.002