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# Estimation of nitrogen fertilizer requirement for rice crop using critical nitrogen dilution curve

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ABSTRACT

Estimating in-season N requirement (NR) is essential for managing N fertilizer application in crop production. Critical N ($N_c$) dilution curve is an effective and simple-to-use technique for assessment of in-season crop N status, yet its adaptation to make field decisions about dressing N fertilization remains to be determined. This study was endeavored to establish the relations between NR, N nutrition index (NNI) and relative yield (RY) at different crop growth stages in Japonica and Indica rice (*Oryza sativa* L.) eco-types and to estimate time-course NR for recommending supplemental N fertilization on $N_c$ dilution curve basis. Four field experiments of multi-N rates were carried out in east China using three Japonica and two Indica rice hybrids. Growth analysis was carried out at different growth stages from active tillering (AT) to heading (HD). The estimated NR under varied N rates has well differentiated the sub-optimal, optimal and supra optimal growth conditions at different stages in both rice eco-types. The NR-NNI and RY-NR relations for both rice eco-types at different growth stages were highly significant with $R^2$ values greater than 0.88 and 0.95 for NR-NNI, and 0.83 and 0.91 for RY-NR relations, respectively, the highest $R^2$ values for both eco-types were 0.98 and 0.99 for NR-NNI and 0.94 and 0.93 for RY-NR relations at panicle initiation (PI) and booting (BT) stages. Validation of the regression models with two independent datasets exhibited a solid model performance at PI and BT stages, with $R^2$ values greater than 0.96 for NR-NNI while 0.94 for RY-NR relations. Moreover, the root mean square error (RMSE) values lower than 20% for NR prediction from NNI, while 8% for RY prediction from NR also confirmed the robustness of the relationships at PI and BT stages. The kappa (k) coefficients at PI and BT stages for observed and predicted NR and RY were close to 1. Generally, the robust relations at PI and BT stages well elucidated the variation in NR and RY both under deficient and optimum N growing conditions, and gave reliable estimation of NR for quantifying supplemental N fertilization for rice grown in east China. The results of this study will offer a suitable approach for managing N application precisely during the growth period of rice crop.



## 1. Introduction

Nitrogen (N) fertilizer is the most extensively used agricultural input by rice (*Oryza sativa* L.) growers to enhance rice crop production in China (Chen et al., 2011). China alone contributes to 32% consumption of the world's total N fertilizer application, while 18% of this (1/5th of China's national use) is utilized in rice production (Heffer, 2009). Due to lower costs of N fertilizer in China as compared to that in other countries, it is often considered economically viable option for farmers. The average rate of N application (193 kg ha$^{-1}$) for rice cultivation in China is 90% higher than that of the world average, while in east China, it is double (387 kg ha$^{-1}$) of China's national average for rice cultivation (Heffer, 2009). In addition to its over-dosage, application at improper crop growth stages has led to low N use efficiency in China. The N recovery efficiency (NRE, the ratio of plant N to N supply) (30–35%) and agronomic N efficiency (the ratio of yield to N supply) (5–10 kg kg$^{-1}$ N) in China are much lower than those of other rice growing countries (50–60% and 15–18 kg kg$^{-1}$ N, respectively) (Peng et al., 2009). Furthermore, its over-application may actually reduce potential yield of rice by enhancing the risk of lodging, delaying maturity, as well as by increasing susceptibility to insects and diseases (Peng et al., 2010). Moreover, improper time and rate of N fertilizer applica-

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tion, as well as poor N management strategies result in substantial losses of applied and available N in the soil due to inherently low N uptake capacity and absence of extensive root system in rice (Sinclair and Rufty, 2012). Thus, correct in-season assessment of optimal N requirement (NR), the N fertilizer requirement for a crop at any stage of development for reaching the $N_c$ level, i;e. the crop N status corresponding to maximum growth at different crop growth stages is pivotal for precise management of N fertilization rates and timing.

The in-season N management requires development of rapid, effective and simple-to-use, economically feasible and technically rigorous N diagnostic tools. Precision N management can improve crop productivity and overcome adverse effects of N on cropping system (Gastal and Lemaire, 2002). Precision agriculture techniques can annually save up to 11 million tons N globally without any drop in crop yield (Mueller et al., 2012), which rises the need to develop generic, flexible and effective tools for guiding farmers for implementation of in-season N management practices. N fertilizer recommendation and enhancement of N use efficiency greatly depend on accurate appraisal of N status in plant and soil systems (Costa et al., 2001). Crop N status at different growth stages indicates the capacity of soil to supply N, capability of plant to uptake N, as well as interactions between plant and soil N (Wang et al., 2006). N concentration has a close relationship with plant dry matter (DM) and leaf area index (LAI) (Gastal and Lemaire, 2002). Time specific estimates of N concentration, as well as estimation of DM and LAI, can help to monitor plant N status and field diagnosis for N management. Thus, dynamics of DM, LAI and tissue N concentration, together with their time specific relationships should be helpful for developing effective N management and recommendation strategy. Similarly, N concentrations in shoots, leaves and stems of field crops have also been used as diagnostic indicators for assessment of N status for maintaining optimum crop growth rate.

The concept of critical N ($N_c$), the minimum N concentration required for maximum crop growth has extensively been used for both diagnostic purposes, as well as for modelling plant-N-relations. The $N_c$ derived from DM, LAI and crop growth stages gives insight into development of $N_c$ dilution curve (Gastal and Lemaire, 2002). The $N_c$ dilution curves have been developed on whole plant DM basis for different eco-types of rice (Sheehy et al., 1998; Ata-Ul-Karim et al., 2013) as well as on LAI and specific organ (leaf and stem) DM basis for rice (Ata-Ul-Karim et al., 2014a,b; Yao et al., 2014). This concept can be potentially used for assessing N status, guiding dressing N recommendation and predicting grain yield in crop production (Debaeke et al., 2012; Ata-Ul-Karim et al., 2013, 2016). Numerous attempts have been made to develop a N fertilizer decision support tool using this approach to delay or split N fertilizer application. The relationships derived from $N_c$ based N nutrition index (NNI), the ratio between the actual crop N concentration and critical N concentration, with relative yield (RY), the ratio of the grain yield obtained for a given N rate with the highest grain yield among all N application rates have been previously implicated to assess RY of wheat, corn (Ziadi et al., 2008, 2010) and sunflower (Debaeke et al., 2012), yet no attempt has been made to estimate crop NR for a corrective N fertilization during crop growth period. Moreover, the previous studies used the averaged values of NNI acquired at different crop growth stages to develop these relations. NR and N use efficiency varies across the growth stages, and crop growth stage is a key plant characteristic for estimating the NR and for improving N use efficiency by estimating in-season crop N status. In present study, we hypothesized that, the NR-NNI and RY-NR relations of two rice eco-types at different growth stages can be implemented for reliable estimation on in-season NR, setting yield targets and improving N use efficiency.

This study was aimed to establish the NR-NNI and RY-NR relations at different growth stages of Japonica and Indica rice, and to estimate time-course NR on the basis of $N_c$ dilution curve for quantifying in-season corrective N fertilization and setting the yield targets. The results of this study will offer a useful methodology for managing N application precisely during the growth period of rice crop.

## 2. Materials and methods

### 2.1. Study site and experimental design

This study was conducted at two sites, Yizheng (32°16′ N, 119° 10′ E) and Rugao (32°23′ N, 120° 33′ E) situated in east China. This zone is categorized by a subtropical-temperate climate with hot summer and cold winter, and is suitable for planting different eco-types of rice. The region receives 2177 h of sunshine and 1030 mm of rainfall annually. The detailed soil characteristics of the top 20 cm depth and cropping practices of both sites are shown in Table 1.

To establish the relationships between NR, NNI and RY on the basis of $N_c$ dilution curve during vegetative growth, four field experiments were conducted in rice across the sites, as detailed in Table 2. In all experiments, five or six varied N fertilizer rates ranging from 0 to 375 kg N $ha^{-1}$ were imposed as N treatments. The source of N fertilizer was urea in all experiments across the sites. The detailed information about N treatments in four field experiments including N rates, N distribution (%) and N application timings are summarized in Table 2. Over the four experiments, three Japonica rice cultivars, Wuxiangjing-14 (WXJ-14), Lingxiangyou-18 (LXY-18) and Wuyunjing-24 (WYJ-24), as well as two Indica rice cultivars Shanyou-63 (SY-63) and Y-Liangyou-1 (YLY-1) were used. The cultivars/eco-types differences were used to test the reliability of newly developed models in different types of rice for making N management decisions.

All experiments were conducted with randomized complete block design having three replicates. The size of every plot was 4.5 m × 8 m with 15 rows in 2010 and 2011 while it was 5 m × 6 m with 20 rows in 2013 and 2014. The inter-row spacing of 30 cm was used at both sites. The planting density was approximately $22.2 \times 10^4$ plants $ha^{-1}$ in all experiments. In each experiment, every plot received 135 kg $P_2O_5$ $ha^{-1}$ and 190 kg $K_2O$ $ha^{-1}$ before transplantation. All experiments were carried out with optimal crop management according to each site, in order to obtain the potential yield (N fertilizer was the only limiting factor).

### 2.2. Plant sampling and measurements

Plant samples (five plants from each plot) were collected from 0.23 $m^2$ area at active tillering (AT), mid tillering (MT), stem elongation (SE), panicle initiation (PI), booting (BT), heading (HD), and maturity for growth analysis. The plant samples were divided into leaf (green leaf blade), stem (culm plus sheath) and panicle. All the samples were oven-dried for 30 min at 105 °C to quickly cease plant metabolic activities and then at 70 °C to constant weight to attain the plant DM (t $ha^{-1}$). The plant N concentration (%) was determined by using the standard Kjeldahl method. The N accumulation (kg N $ha^{-1}$) was calculated by multiplying plant DM by plant N concentration. In all experiments, grain yield in each plot was calculated by harvesting plants from three randomly identified areas of 1 $m^2$. Spikelets were removed from panicle and the final grain yield was adjusted to 14% moisture. The RY was calculated as the ratio of grain yield obtained for a given N rate to the highest grain yield among all N application rates.