Pedosphere **27**(2): 358–363, 2017
doi:10.1016/S1002-0160(17)60323-0
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

Elucidating Variations in Nitrogen Requirement According to Yield, Variety and Cropping System for Chinese Rice Production

ZHANG Yi[1,2], CHEN Xinping[1], MA Wenqi[3] and CUI Zhenling[1,*]

[1] *Centre for Resources, Environment and Food Security, China Agricultural University, Beijing 100193 (China)*
[2] *College of Bioscience and Biotechnology, Hunan Agricultural University, Changsha 410128 (China)*
[3] *College of Resources and Environmental Science, Hebei Agricultural University, Baoding 071001 (China)*

(Received April 23, 2016; revised January 18, 2017)

ABSTRACT

Better understanding of the factors that influence crop nitrogen (N) requirement plays an important role in improving regional N recommendations for rice (*Oryza sativa* L.) production. We collected data from 1 280 plot-level measurements in different reaches of the Yangtze River, China to determine which factors contributed to variability in N requirement in rice. Yield, variety, and cropping system were significantly related to N requirement. The N requirement remained consistent at about 18.6 kg N Mg^{-1} grain as grain yield increased from 7 to 9 Mg ha^{-1}, then decreased to 18.1, 16.9, and 15.9 kg N Mg^{-1} grain as yield increased to 9–10, 10–11, and > 11 Mg ha^{-1}, respectively. The decreased requirement for N with increasing yield was attributable to declining N concentrations in grain and straw and increased harvest index. Super rice variety had lower N requirement (17.7 kg N Mg^{-1} grain) than ordinary inbred and hybrid varieties (18.5 and 18.3 kg N Mg^{-1} grain, respectively), which was a result of lower grain and straw N concentrations of super rice. The N requirements were 19.2, 17.8, and 17.5 kg N Mg^{-1} grain for early, middle, and late rice cropping systems, respectively. In conclusion, the rice N requirement was affected by multiple factors, including yield, variety, and cropping system, all of which should be considered when planning for optimal N management.

Key Words: grain and straw N concentrations, grain yield, harvest index, N management, plant N uptake, reciprocal internal efficiency

Citation: Zhang Y, Chen X P, Ma W Q, Cui Z L. 2017. Elucidating variations in nitrogen requirement according to yield, variety and cropping system for Chinese rice production. *Pedosphere*. **27**(2): 358–363.

INTRODUCTION

Global yield of rice (*Oryza sativa* L.) more than doubled (from 1.9 to 4.4 Mg ha^{-1}) between 1961 and 2011 as a result of increased use of nitrogen (N) fertilizer, new high-yield varieties released after the 1960s, and massive investments in irrigation (Cassman, 1999; Peng *et al.*, 2000; FAO, 2012). In quest of achieving high yields and avoiding the risk of N deficiency, farmers in some intensive agricultural regions (especially in China) often apply N fertilizer in excess of rice growth requirements (Peng *et al.*, 2002). For example, farmers applied 240 kg N ha^{-1} to single rice crops in early 2000 in Zhejiang Province of China (Wang *et al.*, 2004) and *ca.* 300 kg N ha^{-1} in the Taihu Lake region, Jiangsu Province, China (Xia and Yan, 2011). The national average rate of N application in rice production is *ca.* 200 kg N ha^{-1}, two-fold higher than Japan for a similar yield (Peng *et al.*, 2010). The overuse of N fertilizer can be partially attributed to variations in N requirement among rice varieties, cropping systems, and environmental variables as well as farmers' knowledge gap about crop N requirements and the need for improving N management.

Previous studies have reported that rice N requirements vary depending on yield, variety, and cropping system (Wada *et al.*, 1986; Williams *et al.*, 1996; Witt *et al.*, 1999; Wang *et al.*, 2011). For example, Wada *et al.* (1986) found that rice required 15–17 kg N Mg^{-1} grain for an average yield of 5–6 Mg ha^{-1} and 19 kg N Mg^{-1} grain for higher yields. However, other studies reported that the N requirement was relatively stable in tropical rice, *ca.* 20 kg N Mg^{-1} grain, regardless of yield (Yoshida, 1981). Fageria *et al.* (2003) reported that the N requirement ranged from 13 to 22 kg N Mg^{-1} grain among rice varieties, and Wang *et al.* (2011) found that the N requirements decreased from early to middle and late rice in numerous field experiments in China.

Improved understanding of the variability in N requirements among different environmental and management conditions is a crucial step to improving regi-

*Corresponding author. E-mail: cuizl@cau.edu.cn.

onal N management practices (Zhang *et al.*, 2012). However, few studies have assessed the factors that contribute to differing nutrient requirements across rice-producing regions. Information about the sources of regional variability in rice N requirements among Yangtze River reaches, an irrigated region that accounts for *ca.* 59% of national rice production in China from 2005 to 2011 (National Bureau of Statistics of China, 2012), would help in optimizing current regional management practices. The objective of this study were to: 1) investigate the relationship between rice N uptake and grain yield and 2) quantify rice N requirement for different rice grain yields, varieties, and cropping systems.

MATERIALS AND METHODS

Database description

Data of 1 280 measurements of rice grain yield and plant N uptake (both determined at physiological maturity) were collected by various researchers from 2005 to 2010 in South China and the Yangtze River region, China. We excluded measurements with harvest index (HI) < 0.4 because a low HI of modern rice varieties is generally a result of biotic and abiotic stresses, *e.g.*, disease, insect pests, competition from weeds, *etc.* (Witt *et al.*, 1999). All sites were planted with local, high-yielding commercial rice cultivars and managed under favorable irrigation conditions. Planting date and density followed recommendations of local agricultural research institutions. Nitrogen, phosphorus (P), and potassium (K) fertilizer application rates followed agronomists' recommendations based on target yield and soil nutrient testing. The average nutrient application rates were 171 kg N ha^{-1}, 31 kg P ha^{-1}, and 78 kg K ha^{-1}. Fertilizer N (60%–70%) was applied 1 d before transplanting, 7 d after transplanting, and at panicle initiation (15%–20% at each application). The P and K were applied 1 d before transplanting.

The soil types at those sites were mostly hydromorphic and percolated paddy soil. Soil organic matter, alkali-hydrolyzable N, Olsen-P, and NH_4OAc-K in the top 20 cm soil profile were around 250 g kg^{-1}, 125, 13.5, and 91 mg kg^{-1} respectively. All on-farm trials used a double- or single-season rice cropping system. Modern commercial *indica* varieties were grown in all trials ($n = 542$) using sound agronomic methods based on local, high-yielding management practices. We divided the data set into three groups based on genotype: ordinary inbred (39 varieties, $n = 123$), ordinary hybrid (377 varieties, $n = 1\,031$), and super rice (126 varieties, $n = 126$). The cropping systems in all on-farm trials included early rice ($n = 536$), middle rice ($n = 274$), and late rice ($n = 470$).

Plant sampling and laboratory processing

At physiological maturity, 10 representative hills of plants were sampled from a 5-m^2 harvest area in each plot and divided into straw (leaf, culm, and chaff) and grain. The samples were oven-dried at 70 °C until constant weight to determine the dry weight (DW) of aboveground biomass and the HI. Nitrogen concentration in straw and grain were determined by the Kjeldahl method (Horowitz, 1970) and reported on a DW basis. Grain yields were reported at 13.5% standard moisture level.

Data analysis

The interquartile range (IQR, 25th to 75th percentiles), which represented 50% of all measurements centered around the median, was used to describe the most frequent values for each variable in our data set. The reciprocal internal efficiency (RIE) of N is the amount of N in aboveground dry matter (DM) per Mg of grain produced. The HI is expressed as the the fraction of grain yield in DM in the total aboveground plant DM (kg grain kg^{-1} DM). The N harvest index (NHI) is defined as the fraction of the amount of N of grain in total amount of N of the aboveground DM (Witt *et al.*, 1999).

The relationship between aboveground N uptake and grain yield was fitted to linear, quadratic, and power models using SigmaPlot 10 for Windows (Systat Software Inc, San Jose, USA). Among the three models, the power model produced the best fit.

RESULTS AND DISCUSSION

General overview of the data set

Grain yield at all sites ranged from 4.5 to 11.9 Mg ha^{-1} (Table I), approximately 98% and 33% higher than the global (4.3 Mg ha^{-1}) and Chinese (6.4 Mg ha^{-1} during 2005–2011) averages, respectively (FAO, 2012). The higher rice grain yield observed in our data set may have been attributable to the use of new hybrid varieties and good field-management practices. The HI ranged from 0.40 to 0.65. The average grain N concentration was 12.91 g kg^{-1}, and the average straw N concentration was 8.17 g kg^{-1}. Total N uptake in the aboveground DM averaged 155 kg ha^{-1}, and the average NHI was 0.62 (Table I).

Overall, the relationship between aboveground N uptake and rice grain yield can be described by a positive power function, and 61% of the variation in above-