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RESEARCH ARTICLE

Nutrient uptake requirements with increasing grain yield for rice in China

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Abstract

Improved estimates of nutrient requirements for rice (*Oryza sativa* L.) in China are essential to optimize fertilization regulation for increasing grain yields and reducing the potential of environmental negative influences, especially under high-yielding intensive systems. A database involving rice grain yields, nutrient concentrations and accumulations collected from on-field station experiments in the literatures published from 2000 to 2013 in China was developed to understand the relationships between grain yields and plant nutrient uptakes, and to quantify nutrient requirements for different yield levels. Considering all data sets, rice grain yield ranged from 1.4 to 15.2 t ha^{-1} with the mean value of 7.84 t ha^{-1}, and *ca*. 10.4% of yield observations were higher than the yield barrier level of 10 t ha^{-1}. N requirement to produce one ton grain was 21.10 kg for the yield range <4.0 t ha^{-1} with a high variation of 45.8%. Except of the yield range <4.0 t ha^{-1}, the values of N requirement, firstly increased from 18.78 kg for yield range 4.0–5.5 t ha^{-1} to 20.62 kg for yield range 7.0–8.5 t ha^{-1}, then decreased slightly to 19.67 and 19.17 kg for the yield range 8.5–10 and >10 t ha^{-1}, respectively. Phosphorus (P) and potassium (K) requirements showed increasing trends, from 3.51 and 19.87 kg per t grain for <4.0 t ha^{-1} yield range to 4.10 and 21.70 kg for >10.0 t ha^{-1} range. In conclusion, nutrient requirement varied with increasement of grain yield, and N, P and K presented various response trends, increasing, declining or stagnating, which would be of great benefit for improving fertilizer strategies.

Keywords: rice, nutrient requirement, nitrogen, phosphorus, potassium

1. Introduction

As one of the staple food crops，Rice (*Oryza sativa* L.) is widely cultivated across China with a planting area of 30.1 million ha, accounting for about 32.5% of total corn area (National Bureau of Statistics of China 2013). Rice production, playing a critical role in guaranteeing national food security in China, has substantially increased in the past 65 years from only 48.6 Mt in 1949 to 204 Mt in 2012 (National Bureau of Statistics of China 2013). Much of

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the achievements in rice yield increase would be primarily attributed to the development of high-yielding varieties, improved field management practices and increased fertilizer consumption (Zhu and Chen 2002; Cassman *et al*. 2003; Yu *et al*. 2012). However, recently a stagnant or even declining trend in grain yield had been observed, such as a 9% lower rice production in 2006 compared to 1997 (Fan *et al*. 2009; Peng *et al*. 2009).

Appropriate fertilizer management practice is essential for increasing rice yield and reducing the risk of negative environmental impacts, particularly in intensively managed cropping systems. Recently, concerns over low recovery efficiency (RE) of fertilizer applied and sequence deleterious environmental effects result in increasing interest in optimizing nutrient management strategies (Fan *et al*. 2009; Sui *et al*. 2013; Xue *et al*. 2014). However, in agricultural practices for farmers, uncertainties in the crop requirements for N, P, and K may lead to fertilizers supplied in excess or in insufficient, accompanying with nutrient imbalance, low RE and increased environmental negative problems (Wang *et al*. 2001; Zhang and Wang 2005; Timsina *et al*. 2006; Guo *et al*. 2010; Zhao *et al*. 2011). For example, according to the report presented by Peng *et al*. (2006) in South China, the maximum grain yield of about 7.5 t ha^{-1} for irrigated rice was mostly achieved at N rates of 60 to 120 kg ha^{-1}, significantly lower than the value of 180 to 240 kg N ha^{-1} currently applied at farmers' fields. Therefore, determining the nutrient requirements response to rice production would be of great benefit for optimizing agricultural strategy, particularly under high-yielding systems.

Most experiments reported have been conducted to analyze the characteristics of rice grain yield and nutrient accumulations of N, P and K in total above-ground dry matter (DM) within or without rice varieties, cropping sequences and regions (Dobermann *et al*. 2003; Katsura *et al*. 2008; Dai *et al*. 2010; Zhang *et al*. 2013). In the Huai-River Basin, for a dryland rice-winter wheat cropping system, rice grain yield ranged from 3.2 to 4.1 t ha^{-1} while plant nutrient uptake varied from 60 to 100 kg N ha^{-1}, from 14 to 19 kg P ha^{-1}, and from 68 to 102 kg K ha^{-1}, respectively (Dai *et al*. 2010). In tropical and subtropical Asia, rice nutrient accumulation in plant of N, P and K averaged 91.2, 16.0, and 88.1 kg ha^{-1}, respectively, with the mean grain production of 5.2 t ha^{-1} (Witt *et al*. 1999). In Sahelian West Africa, based on a database comprising 261 observations from farmers' fields, the mean rice grain yield was 4.2 t ha^{-1} with the minimum and maximum of 0.3 and 9.2 t ha^{-1}, while N, P and K uptakes varied from 4.7 to 201.7 kg ha^{-1}, from 6.0 to 33.1 kg ha^{-1}, and 10.2 to 300.0 kg ha^{-1}, with the average values of 63.8, 12.7, and 80.7 kg ha^{-1}, respectively (Haefele *et al*. 2003). Therefore, understanding the relationship between nutrient requirements and rice production would be of great benefit for ensuring high yield and minimizing fertilizer losses.Previous studies on estimating nutrient requirements for rice in China often involved site-specific field experiments, or small regions with insufficient data (Fan *et al*. 2009; Dai *et al*. 2010), which limited the credibility of extrapolating to the whole rice-growing regions to estimate plant nutrient requirements under current intensive rice production systems in China. Therefore, in this study, we collected data of rice covering a wide range of climatic conditions, soil types, parent materials and field managements across China. The objectives of this study were to: (1) determine grain yield, nutrient concentration, nutrient uptake, harvest index (HI) and N-, P-, and K-HI across China; (2) evaluate the relationships between aboveground plant nutrient (N, P and K) uptakes and grain yield; (3) quantify the nutrient uptake requirement per ton rice grain for different rice grain yield levels.

2. Results and discussion

2.1. Grain yields and yield component

Across all observations collected from field experiments, average grain yield was 7.84 t ha^{-1} (at 13.5% moisture), ranging widely from 1.40 to 15.2 t ha^{-1}, while straw yield ranged from 2.58 to 22.88 t ha^{-1} with an average of 7.70 t ha^{-1} (Table 1). The averaged value of rice production in this study was 16.3% higher than the national averaged yield of 6.74 t ha^{-1} in China, and 77.8% higher compared to the world's mean of 4.44 t ha^{-1} in 2012 (FAO 2013). The main reason for these differences was that the paddy fields for fertilizer experiments were usually located in plain regions resulting in lower soil erosion and nutrient loss, and had better field management compared with farmers' practice. Based on a database comprising 829 measurements from 1981 to 1983, the grain yield ranged from 3.82 to 6.06 t ha^{-1} (Lin 1989), which was lower than our data mainly due to newly developed rice varieties with high-yield potential, improved agricultural regulations, and application of more fertilizer (Zhu and Chen 2002; Peng *et al*. 2009; Yu *et al*. 2012). 10 t ha^{-1} of rice grain production has been deemed as the productivity potential for modern cultivars under adjusted growing environment (Peng *et al*. 1999; Witt *et al*. 1999; Haefele *et al*. 2003; Wang *et al*. 2007). However, the achieved yield in this study, higher than the yield barrier, accounted for *ca*. 10.4% of our observations with the highest value of 15.2 t ha^{-1}, which was slightly lower compared to the highest record of 16.5 t ha^{-1} under the "super-hybrid" variety in China (Katsura *et al*. 2008).

Total above-ground dry matter (DM) ranged from 3.81 to 33.00 t ha^{-1} with an average of 15.44 t ha^{-1}, while HI ranged from 0.23 to 0.70 with the mean of 0.50 (Table 1). The mean HI value was similar to the value achieved in 2011 by Xie