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RESEARCH ARTICLE

Review grain yield and nitrogen use efficiency in rice production regions in China

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Abstract

As one of the staple food crops, rice (*Oryza sativa* L.) is widely cultivated across China, which plays a critical role in guaranteeing national food security. Most previous studies on grain yield or/and nitrogen use efficiency (NUE) of rice in China often involved site-specific field experiments, or small regions with insufficient data, which limited the representation for the current rice production regions. In this study, a database covering a wide range of climate conditions, soil types and field managements across China, was developed to estimate rice grain yield and NUE in various rice production regions in China and to evaluate the relationships between N rates and grain yield, NUE. According to the database for rice, the values of grain yield, plant N accumulation, N harvest index (HI_N), indigenous N supply (INS), internal N efficiency (IE_N), reciprocal internal N efficiency (RIE_N), agronomic N use efficiency (AE_N), partial N factor productivity (PEP_N), physiological N efficiency (PE_N), and recover efficiency of applied N (RE_N) averaged 7.69 t ha^{-1}, 152 kg ha^{-1}, 0.64 kg kg^{-1}, 94.1 kg kg^{-1}, 53.9 kg kg^{-1}, 1.98 kg kg^{-1}, 12.6 kg kg^{-1}, 48.6 kg kg^{-1}, 33.8 kg kg^{-1}, and 39.3%, respectively. However, the corresponding values all varied tremendously with large variation. Rice planting regions and N rates had significant influence on grain yield, N uptake and NUE values. Considering all observations, N rates of 200 to 250 kg ha^{-1} commonly achieved higher rice grain yield compared to less than 200 kg N ha^{-1} and more than 250 kg N ha^{-1} at most rice planting regions. At N rates of 200 to 250 kg ha^{-1}, significant positive linear relationships were observed between rice grain yield and AE_N, PE_N, RE_N, IE_N, and PFP_N, and 46.49, 24.64, 7.94, 17.84, and 88.24% of the variation in AE_N, PE_N, RE_N, IE_N, and PFP_N could be explained by grain yield, respectively. In conclusion, in a reasonable range of N application, an increase in grain yield can be achieved accompanying by an acceptable NUE.

Keywords: rice, grain yield, nitrogen uptake, nitrogen use efficiency, China

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1. Introduction

Rice (*Oryza sativa* L.) yields have substantially increased in the past 64 years from only 48.6 million tons (Mt) in 1949 to 204 Mt in 2012 (National Bureau of Statistics 2013), which accounts for *ca*. 28.6% of global rice production (FAO 2012).

As population continuously increasing, projected to rise to 1.5 billion by 2030 (NPDSRG 2007; Zhao *et al.* 2010), an increase by 13.8% in rice production compared to in 2010 should be demanded to ensure food security (Cheng *et al.* 2007). However, the development of urbanization process and negative effects of climate limited the potential of available arable land for crops cultivated (Cheng *et al.* 2007; Peng *et al.* 2009), so rather than planting area expanding, increasing crop yield per unit area was required to meet population growth in the future.

Part of the progress in rice production in the past attributed to a large amount of chemical fertilizer input, specially nitrogen (N) (Zhu and Chen 2002), consuming 38.3 Mt N in China in 2011, accounting for more than 30% of the world consumptions (FAO 2012). Simultaneous increase in the amounts of N fertilizer applied and rice production in the past led to farmers usually input luxurious N fertilizer to maximize crop yield (Lemaire and Gastal 1997; Peng *et al.* 2006; Gao *et al.* 2012). However, excessive application of chemical N can also lead to higher N surplus in soil and/or more losses by different pathways, such as emissions of gaseous, denitrification, surface runoff, and leaching. Low N use efficiency (NUE) and negative environmental impacts consequently occurred (Zhu and Chen 2002; Zhang *et al.* 2012).

Many studies have been conducted to estimate NUE (Novoa and Loomis 1981; Dobermann 2005). According to Dobemann (2005), common NUE values for general crops ranged from 30 to 60 kg kg^{-1} for internal N efficiency (IE_N), 40 to 70 kg kg^{-1} for partial N factor productivity (PFP_N), 10 to 30 kg kg^{-1} for agronomic N use efficiency (AE_N), and 30 to 50% for recover efficiency of applied N (RE_N), respectively, whilst at well managed systems or at low levels of N applied, NUE would break the upper thresholds. Cassman *et al.* (1996) indicated AE_N of rice ranged from 15 to 18 kg kg^{-1} in farmers' fields in Philippines. Ohnishi *et al.* (1999) reported RE_N of rice ranged from 35.4 to 55.5%, with the mean of 43.9% in northeast Thailand. Zhu *et al.* (1992) reported that RE_N of crops in China ranged from 28 to 41%, with an average of 35%. NUE of rice in China is considered low, even the lowest among the major rice-growing regions (Peng *et al.* 2006). Wang *et al.* (2001) confirmed that RE_N of rice in farmers' N management practices was only 18%. Zhang *et al.* (2008) summarized 179 observations, finding that NUE of rice in China averaged 28.3% for RE_N, 10.4 kg kg^{-1} for AE_N, 54.2 kg kg^{-1} for PFP_N, and 36.7 kg kg^{-1} for PE_N, respectively. In recent years, a decline trend in NUE was observed to some degree (Li *et al.* 2013). Lin (1989) reported that AE_N of rice in China declined from 15–20 kg kg^{-1} within 1958–1962 to only 9.1 kg kg^{-1} within 1981–1983. Based on national statistics, Li *et al.* (2013) indicated that PFP_N in China declined greatly from more than 1 000 kg kg^{-1} in the 1950s to nearly 30 kg kg^{-1} in 2008.

However, most previous studies on estimating NUE for rice in China often involved site-specific field experiments, or small regions with insufficient data (Dai *et al.* 2009; Fan *et al.* 2009), or summarized long ago or just used data within a few years (Zhu *et al.* 1992; Zhang *et al.* 2008). This concern is whether these values can best represent the current use efficiency of N applied into paddy soil. Therefore, in this study, we collect mass data for rice covering a wide range of water conditions, soil types, parent material, and field managements in China. The objectives of this study were to: (1) estimate grain yield and NUE at various rice production regions in China; (2) evaluate the relationships between N rates and grain yield, NUE; (3) elaborate the potential possibility of increase in NUE with rice yield increasing.

2. Results

2.1. Yield response

Considering all 2 949 observations (Appendix A), rice grain yield averaged 7.69 t ha^{-1}, tremendously varying from 1.99 to 12.6 t ha^{-1} (Table 1). Northeast China (NE) had a significantly higher grain yield of 8.49 t ha^{-1} compared to the other regions, maybe due to a longer rice growth duration caused by the lower air temperature supposed to improve the yield potential. The grain yields in Southwest China (SW) and the middle and lower plain of the Yangtze River (MLYR) were slightly higher than those in south of the Yangtze River (SYR) and north central China (NC), but no significant difference was observed. While significantly lower grain yield in South China (SC) was detected than the other regions (Table 2). Li *et al.* (2009) also has found the region-variation in rice grain yield between Taoyuan and Nanjing in China.

Under control treatments without fertilizer-N applied, the mean rice grain yield obtained was 5.83 t ha^{-1} over China. SW recorded the average yield of 6.75 t ha^{-1} for zero-N applied, which was significantly higher than those in NE, NC, MLYR, SYR, and SC (Table 2). As N applied, rice grain yield increased significantly by 42% across China. However, the increasing extent of grain yield as applied N increasing gradually reduced, even when exceeded 250 kg N ha^{-1}, additional N fertilizer applied only obtained an increase in grain yield by 1.48%. This trend was further confirmed by the similar trend of stagnant or diminishing under most rice production regions, such as SYR, NC, NE, SW, and MLYR (Table 2). A parabolic model could significantly describe the response of rice grain yield to N rates applied (Fig. 1-A), and 41.6% of variation in N uptakes could be interpreted by applied N rates.