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Quantification of yield gap and nutrient use efficiency of irrigated rice in China

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ABSTRACT

Analyzing attainable yield (YA), yield gap (YG), and nutrient use efficiency (NUE) will help develop and inform agricultural policies and strategies to increase grain yield. Data from a total of 2218 on-farm rice experiments were collected between 2000 and 2013 from the main rice production areas of China. Common treatments in each study included the optimum nutrient management (OPT), farmers' fertilizer practices (FP) and nutrient omission treatments which were used to assess YG, yield response to nutrient (YR), and NUE. This study used meta-analysis and ANOVA to evaluate differences across the four rice planting seasons (early, middle, late, and single-season rice). The average YA from the OPT was 8.5 $t\,ha^{-1}$, and the yield gap between OPT and FP was 0.6 $t\,ha^{-1}$. The YR to nitrogen (N), phosphorus (P), and potassium (K) averaged 2.4, 0.9, and 1.0 $t\,ha^{-1}$ across all sites, respectively. Results using the Pearson' correlation analysis showed significantly negative coefficients for YR to soil nutrient contents and soil organic matter. The large variations in YR were attributed to differences in climatic conditions and soil indigenous nutrient supplies. As compared to FP, the average recovery efficiency (RE) to N, P, and K with OPT increased by 10.1, 5.0 and 8.6 percent across all sites, respectively. In order to narrow the YG and increase NUE, effective soil, plant, nutrient management measures, advances in knowledge and technologies would be required to sustain higher crop production.

1. Introduction

Crop yield must increase substantially over the coming decades to keep pace with the increasing food demand of the world's population (Van Ittersum et al., 2013). Rice is an important staple food worldwide, and is the primary staple food in China. At present, the Chinese rice cultivation area is 30.3 million hectares with total rice yield reaching 203.6 million tons, and an average unit area yield of 6.7 $t\,ha^{-1}$ (China Agriculture Statistical Report, 2013). It is projected that world rice production needs to increase to 771.1 million tons by 2030 (Van Nguyen and Ferrero, 2006). Using aggregated data to quantify the yield gap (YG) on a regional, or agro-climatic zone, scale is helpful to quantify the scope for future yield improvement (Neumann et al., 2010; Van Wart et al., 2013).

Exploiting and narrowing the current yield gap (YG) between farmers practice and attainable yield by optimizing soil and nutrient management practices is one way to increase rice production. For sustainable intensification of rice cropping, it is important to identify areas with the greatest potential to narrow the YG, because there are large differences in climate, soil, and economic inputs among regions (Neumann et al., 2010; Van Ittersum et al., 2013). Many factors have contributed to the current YG, for example, the availability of production technologies, differences among rice varieties, a lack of balanced fertilizer application, and sub-optimal crop management by farmers. Many studies have shown that rice yield

Abbreviations: AE, agronomic efficiency; FP, farmers' practice; IKS, indigenous potassium supply; INS, indigenous nitrogen supply; IPS, indigenous phosphorus supply; NUE, nutrient use efficiency; OPT, optimum management; PFP, partial factor productivity; RE, recovery efficiency; YA, attainable yield; YG, yield gap; YR, yield response.

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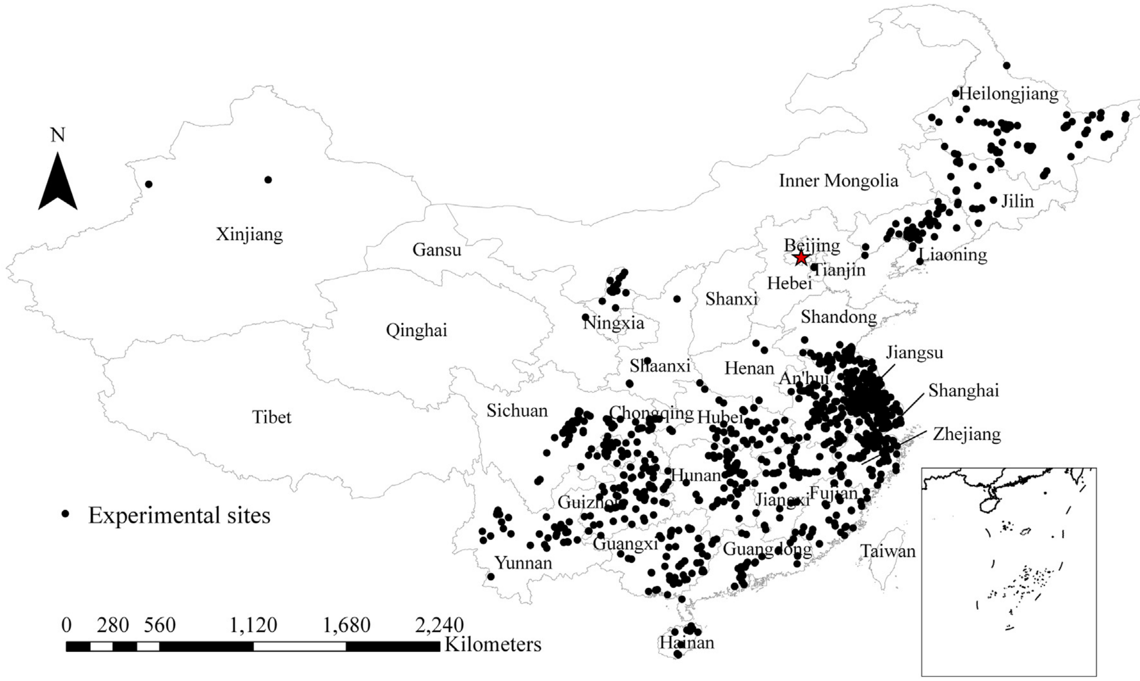

Fig. 1. The distribution of the experimental sites.

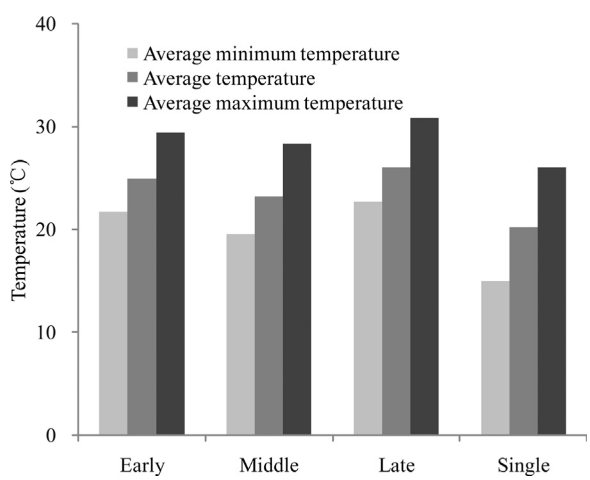

Fig. 2. The temperature during the growth period for the four rice plant types in China.

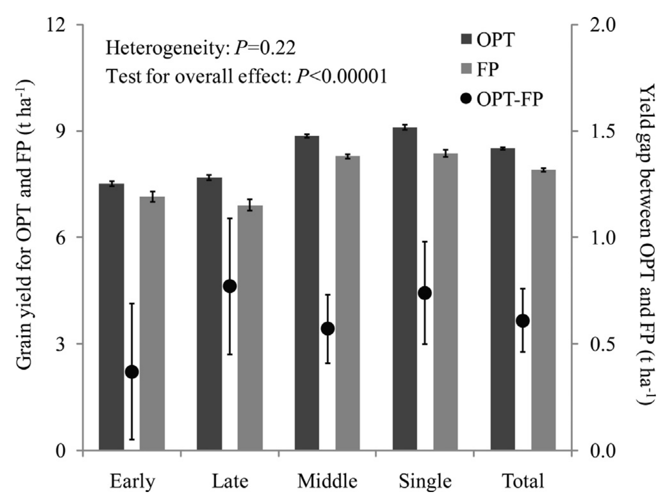

Fig. 3. The grain yield for optimum management (OPT) and farmers' practices (FP) and their yield gap (OPT–FP) for four rice plant types. Error bar for OPT and FP is SE, and 95% confidence intervals (CIs) for yield gap (OPT–FP).

could be significantly increased if new technologies and management activities were adopted by farmers (Khurana et al., 2007; Mueller et al., 2012; Alam et al., 2013).

There are several methods to estimate YG. Potential yield can be calculated using a model, actual yield and attainable yield (YA) can be determined from field based and on-station experiments, and farmers' current yields can be used to calculate YGs at a local, national, and even global scale (Lobell et al., 2009; Van Ittersum and Cassman, 2013; Van Ittersum et al., 2013; Van Wart et al., 2013). The YG is strongly related to fertilizer inputs and crop management, and dependent on indigenous soil fertility and nutrient content. Yield response (YR) to nutrients can reflect the soil indigenous nutrient supply, and can be used to guide precise fertilization and production management, because indigenous nutrient supply determines the YR (Pampolino et al., 2012; Chuan et al., 2013; Xu et al., 2014a,b). Thus, the indigenous nutrient supply is an indicator of soil fertility (Chuan et al., 2013; Xu et al., 2014a).

Nutrient use efficiency (NUE) has received much attention from both governments and the public, largely because the long-term excessive application of nutrients has negatively impacted on the environment (Robertson et al., 2008), and led to low NUE (Pampolino et al., 2007; Li et al., 2011; Zhang et al., 2013). Some agronomic indices commonly used to describe NUE include agronomic efficiency (AE, kg crop yield increase per kg nutrient applied), apparent recovery efficiency (RE, kg nutrient taken up per kg nutri-