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No-tillage effect on rice yield in China: A meta-analysis

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ABSTRACT

Rice production in China has been constrained by changes in socioeconomic and physical environments such as decreased labor availability and degraded soil. No-tillage (NT) may be an alternative system for rice production in China because it has potential benefits including labor saving and soil conservation. Here, we conducted a meta-analysis to evaluate the effect of NT on rice yield in China and to investigate how the effect varies with the environmental and management factors. Results showed that decrease in panicle number per unit land area was observed in NT rice across a wide range of environmental and management conditions in China, but grain yield was not reduced because it was compensated for by more spikelet number per panicle and higher spikelet-filling percentage. Grain yield responses to NT were affected by region (climate), soil, cropping system and proportion of N applied during the vegetative period (PNVP). Typically, grain yield showed a positive response to NT in south-west region (where the climate during rice-growing season is characterized by frequent fog and clouds, high humidity and insufficient sunlight). NT resulted in a decreased grain yield in soils with pH lower than 6.0 and low fertility. Grain yield was decreased in rice–rice cropping systems but increased in rice–upland cropping systems by NT. NT had negative effect on grain yield under PNVP of 70% and 80% but had no significant effect under PNVP of 90%. However, responses of grain yield to NT did not vary with establishment method (transplanting vs. seedling throwing vs. direct seeding), cultivar type (hybrid vs. inbred), duration of NT adoption (<3 years vs. 3–6 years vs. >6 years) and residue management practice (removal vs. retention). We conclude that adoption of NT for rice production in China should be site-specific and depend on agronomic practices including cropping system and N management.

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1. Introduction

Rice is the staple food crop for about 65% of the population in China (Zhang et al., 2005). Productivity of rice-based cropping systems is critical for national food security (Fan et al., 2009). However, yield stagnation of rice has been observed in the past decade in China. Total rice production in 2006 was 9% lower than in 1997, when the country had its biggest rice harvest in history (Peng et al., 2009a). Meanwhile, rapid population growth and economic development are posing a growing pressure for increased food production (Zhang, 2007a). According to the projected population increase, China needs to produce about 20% more rice by 2030 in order to meet its domestic needs if rice consumption per capita is to be maintained at the current level (Cai and Chen, 2000). This is not an easy task because of changes in socioeconomic and physical environments related to rice production (Peng et al., 2009a). For example, both the quantity and quality of labor for rice production have declined markedly due to labor migration (Fang et al., 2004); soil degradation, a reduction in soil quality as a result of human activities, has been very serious and widespread (Fan et al., 2012). There is no doubt that rice cultivation technologies must be developed that will be labor saving, environmentally friendly and will maintain rice yield potential (Huang et al., 2011a).

Conventional tillage (CT), namely ploughing followed by harrowing, is the most widely used method for rice production in China (Huang et al., 2011b). This method does not only require a large amount of labor but also may accelerate decomposition of soil organic matter, reduce soil fertility, and deteriorate soil chemical and physical properties (Bhushan et al., 2007; Chen et al., 2007). No-tillage (NT), characterized by minimal soil disturbance (Paremelee et al., 1990), may be an alternative system for rice production in China because it has potential benefits including labor saving and soil conservation (Huang et al., 2011a; Uri, 1997). In recent years, many studies have been conducted to determine the NT effect on rice yield in China. However, there is clearly inconsistency and uncertainty in the results so far, which vary from significant increase to significant decline. The effect of NT on crop yield could

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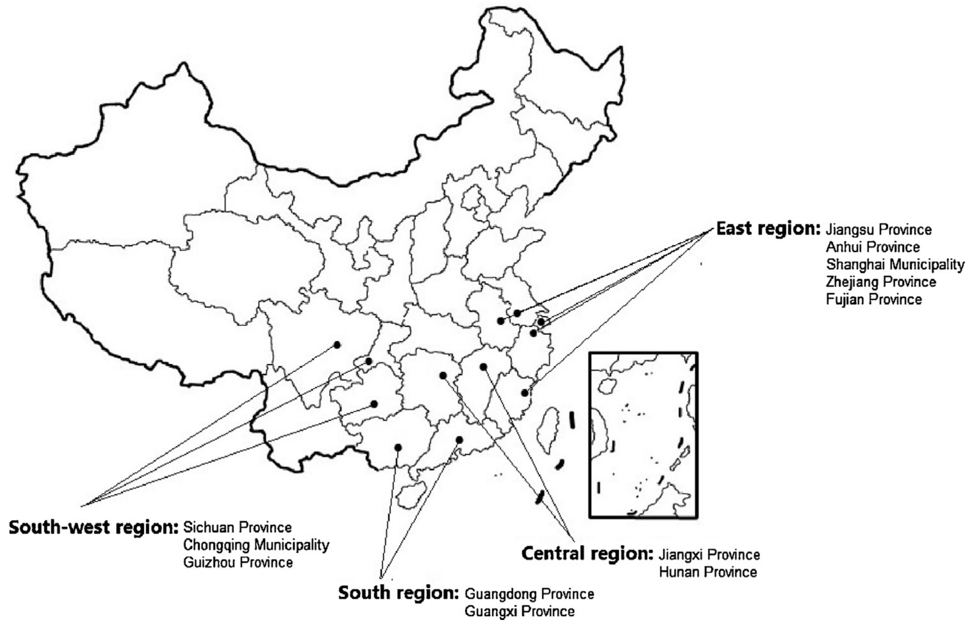

Fig. 1. Locations of the studies included in this meta-analysis.

be as a result of its effect on soil properties (Tesfahunegn, 2015). Previous studies that have compared soil properties of NT and CT have produced conflicting results because environmental (e.g., region, and soil) and management factors (e.g., cropping system, establishment method, residue management, and duration of NT adoption) are different (Derpsch, 2003). We hypothesize that the inconsistency in the current results in the responses of rice yield to NT in China is also caused by the environmental and management factors.

Meta-analysis provides formal statistical techniques for summarizing the results of independent experiments to quantitatively estimate the direction and magnitude of a treatment effect (Huang et al., 2013a). In our current study, we conducted a meta-analysis of published studies (1) to evaluate the effect of NT on rice yield in China and (2) to investigate how the effect varies with the environmental and management factors.

2. Materials and methods

An exhaustive literature search was conducted in China National Knowledge Infrastructure (cnki.net) and Google Scholar (scholar.google.com) databases on March 8, 2014 to collect data on rice yield responses to NT in China. The search was restricted to studies that were conducted under field conditions; no pot and greenhouse experiments were included. NT referred to the planting crops into untilled soil. An article was considered eligible if it contained available grain yield data. This process identified 51 published articles (Table 1). The studies in these articles were performed in 12 provinces or municipalities (Jiangsu, Anhui, Shanghai, Zhejiang, Fujian, Jiangxi, Hunan, Guangdong, Guangxi, Sichuan, Chongqing and Guizhou), which are distributed in east, central, south and south-west regions of China (Fig. 1). The soils in the studies vary with pH from acid to slightly alkaline as well as with soil fertility from low to medium–high organic matter, N, P and K levels. According to the classification standard of soil nutrient indicators in China (CNSSO, 1992), the soil parameters were classified into two groups with threshold values of 6.0 for pH, 20 g kg^{-1} for organic matter, 1.0 g kg^{-1} for total N, 90 mg kg^{-1} for available N, 10 mg kg^{-1} available P, and 100 mg kg^{-1} available K. In addition, the studies involve different cropping systems (rice–rice and rice–upland), establishment methods (transplanting, seedling throwing and direct seeding), cultivar types (hybrid and inbred), duration of NT adoption (dividing into three groups: <3, 3–6, and >6 years), residue management practices (removal and retention), and proportions of N applied during the vegetative period (PNVP) (70%, 80% and 90%).

Yield attribute data of NT and CT treatments were extracted from the selected articles as response variables, including grain yield, panicle number per unit land area, spikelet number per panicle, spikelet-filling percentage and grain weight. In some studies, there were several types of tillage treatments, in which cases we chose the tillage treatment that disturbed soil the most as CT. The natural log of the response ratio (*ln R*) was used as a measure of effect size (Hedges et al., 1999): $\ln R = \ln (X_{NT}/X_{CT})$, where X_{NT} and X_{CT} are the measured values of the response variable under NT and CT, respectively. Meta-analysis was performed using a nonparametric weighting function. Effect sizes were weighted by replication. To avoid bias toward studies reporting results for multiple years, the weight of each effect size was divided by the number of years for which data were included from the corresponding study: $w_i = n/y$, where w_i is the weight for the *i*th effect size, *n* is the number of field replicates, and *y* is the number of years for which comparisons were included in the data set from the study corresponding to the *i*th comparison. Mean effect sizes were estimated as follows: $\ln \bar{R} = \sum(\ln R_i \times w_i)/\sum(w_i)$, where $\ln R_i$ is the effect size from the *i*th comparison, w_i as the above definition. MetaWin 2.1 software was used to calculate mean effect sizes and to generate bias-corrected 95% confidence intervals (CIs) for each mean effect size by a bootstrapping procedure (4999 iterations). To ease interpretation, the effect size was expressed as the percentage change, which was estimated by $(R - 1) \times 100\%$. A negative percentage change indicates a decrease in the response variable under NT relative to under CT, while a positive value indicates an increase. Mean percentage change was considered to be significantly different from zero if the 95% CI did not overlap with zero (Hedges et al., 1999).

3. Results and discussion

Overall, NT did not significantly affect grain yield (Fig. 2). However, it had significant effect on yield components except grain weight. Panicle number per unit land area was decreased by NT by

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