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Crop yields under no-till farming in China: A meta-analysis

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ABSTRACT

No-till (NT) farming is popular globally, however, the effects on crop yields remain debatable. A meta-analysis was conducted on crop yield responses to NT in China based on 1006 comparisons from 164 studies. Results showed that a decrease of 2.1 ± 1.8% on crop yield was observed under NT with residue removed (NT0) compared with that under plow tillage with residue removed (PT0), but the decreases can be diminished to 1.9 ± 1.0% when residue retention was combined with both the two tillage practices. On the contrary, NT with residue retention (NTR) may significantly increase crop yields by 4.6 ± 1.3% compared with that under PT0 ($P < 0.05$). Along with improvements in crop yields, increases in soil organic carbon (SOC) by 10.2 ± 7.2%, available nitrogen (N) by 9.4 ± 5.4%, available potassium by 10.5 ± 8.8%, and water storage by ∼9.3 ± 2.4% was observed under NTR compared with PT0, indicating that improvements in soil quality could benefit crop productivity under NTR. Categorically, results on meta-analysis and regression indicated large variations in crop yields under NTR because of differences in crop species, temperature and precipitation, antecedent SOC level, N fertilizer input, duration of adoption, and with or without residue retention. For example, crop yields significantly increased with increase in duration ($P < 0.0001$) under NTR, by 21.3% after 10 years of continuous NTR compared with PT0. Adoption of NTR under appropriate site-specific conditions can advance China's food security, improve yield stability and alleviate soil-related constraints.

1. Introduction

Increasing demand for food supply, stagnating crop yields, and changing climate are among serious global concerns (Foley et al., 2011; Tilman et al., 2011; Ray et al., 2012; IPCC, 2014). The challenge of doubling of food demand by the middle of this century necessitates an objective consideration of the environmental consequences of agricultural practices including those of indiscriminate plowing and other farm operations, excessive use of chemical fertilizers, and inappropriate irrigation practices (Foley et al., 2011; Ray et al., 2012). Notable among these consequences are increase in greenhouse gases (GHGs) emissions, soil degradation, and environmental contamination (Bai et al., 2008; IPCC, 2013; Chen et al., 2014; Lal, 2015a). Therefore, a prudent and sustainable management strategy is needed to feed the growing and increasingly affluent world population without jeopardizing the natural resources. Faced with numerous global challenges, conservation agriculture (CA); with the key components of no-till (NT), cover cropping and residue retention (RR), crop rotation, and integrated nutrient management (INM); is considered a viable option to: i) advance food security, protect agricultural resources, and mitigate climate change (Lal, 2004; Delgado et al., 2013; Derpsch et al., 2014; Lipper et al., 2014; Lal, 2015a,b), ii) sequester soil organic carbon (SOC), especially in degraded soils, iii) conserve soil and water, iv) restore soil quality, v) save labor, and vi) reduce inputs of chemical fertilizers and energy–based inputs. (Lal, 2013; Derpsch et al., 2014; Zhang et al., 2014).

Combined with RR and/or crop rotation, NT has been adopted on 155 million hectares (Mha), or almost 11% of the global arable land area (Kassam et al., 2014). However, the impacts of NT on crop production are debatable, as is evidenced by highly variable results reported in the literatures. Relatively better yields with NT compared with conventional tillage (e.g., plow tillage, PT) can be attributed to the restoration of soil quality, conservation of soil and water, sequestration of SOC in the root zone, and improvements in microbial communities and activities (De Vita et al., 2007;

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Mikha et al., 2013; Kohl et al., 2014; Islam et al., 2015; Lal, 2015a; Vanhie et al., 2015). In contrast, reductions in crop yields under NT reported in some studies may be ascribed to low crop stands, stunted seedling growth, compaction of soil in the row zone, immobilization of nitrogen (N), persistence of weeds (e.g., perennial weeds), and increased incidence of pests and pathogens(Arvidsson et al., 2014; Lal, 2015a; Nawaz et al., 2016). In China, low yields obtained under NT compared with PT with residue removed (PT0) have been ascribed to low crop stands and poor seedling emergence (Zhang et al., 2014).

Indeed, any decline in agronomic yield per unit area and time sets-in-motion a 'vicious cycle' leading to low input of biomass-C that causes a further decline in soil quality and crop productivity (Lal, 2015a). Therefore, when considering site-specific conditions, appropriate strategies are needed which could alleviate yield-related constraints and harness the benefits of NT. Understanding how and why specific trends in crop yields occur under NT requires in-depth and long term research. Some reports based on global meta-analysis indicate a decline in yield under NT based on sustainable intensification (SI) of agriculture and the factors influencing crop response following by aridity index, residue management, NT duration, and rate of N application (Pittelkow et al., 2015a; Pittelkow et al., 2015b). However, when combined with RR and crop rotation or under long-term adoption of both NT and PT0, the yield gaps may be minimal (Pittelkow et al., 2015a). Moreover, targeted adaptation of NT to specific biophysical conditions is needed to increase maize (*Zea mays* L.) grain yield under rain-fed conditions (Rusinamhodzi et al., 2011). Derpsch et al. (2014) observed that a lack of standardization in the methodology can lead to misunderstandings and confusions in data interpretation. Although, decreases in crop yields have been mostly reported under NT0, RR could either increase crop yields or diminish the yield gap between PT and NTR (Huang et al., 2013; Pittelkow et al., 2015a). In addition, the response of crop yields to NT varies among different management practices, crop species, eco-regions, and climatic conditions (Ludwig et al., 2010; Van den Putte et al., 2010; Zheng et al., 2014; Pittelkow et al., 2015b).

The strategy is to replace PT0 by NT with residue retention (NTR). Thus, the effects of NTR on crop yields at regional or global scales need to be objectively assessed, especially in relation to the factors that govern the agronomic effects of NTR on crop yields. A regional assessment of crop yield responses upon conversion to NTR remains a high priority. Furthermore, there are still constraints which have limited a widespread adoption of NTR, and the underlying reasons for these must be identified. Therefore, the present study aims to evaluate the effects of NTR on crop yields and determine the probable reasons for the differences in yields compared with that under PT0. Meta-analysis, a useful tool to integrate and compare multiple individual studies on the response of treatments to controls and to evaluate a general trend and pattern based on a compiled dataset at regional or global scales, is widely used in agronomic studies (Philibert et al., 2012). The methodology can be used to assess yield responses to farming practices such as RR, water management, fertilization, cover cropping, organic agriculture, and climate change (Miguez and Bollero, 2005; Seufert et al., 2012; Huang et al., 2013; Quemada et al., 2013; Challinor et al., 2014; Liu et al., 2014). These studies are useful to understand changes in crop yield under different practices and to identify future strategies for sustainable and efficient increases in agricultural production under changing and uncertain climates.

It is important to build upon prior studies related to NTR and climate change mitigation and crop productivity (Lal, 2015a) and establish the cause-effect relationship. Data from some earlier studies showed distinct benefits of NTR to increasing SOC and reducing GHGs emission at regional or national scale in China (Zhang et al., 2014; Zhang et al., 2015; Zhao et al., 2015; Zhao et al., 2016). Therefore, it is pertinent to assess and summarize the effects of NTR on crop yields in diverse eco-regions of China. The present study was conducted to compile a national dataset, determine crop yield changes upon conversion of PT0 to NTR, assess variations under different site-specific conditions, and analyze the related soil properties in response to the conversion and which contribute to the differences in agronomic yields.

2. Materials and methods

2.1. Data collection

The data used in the present meta-analysis were collected from peer-reviewed papers which reported crop yields under NT compared with PT in China from the Web of Science (1900–2014, http://apps.webofknowledge.com/), Google Scholar (the year before 2015, Google Inc., Mountain View, CA, USA) and the China Knowledge Resource Integrated Database (the year before 2015, http://www.cnki.net/). The chosen comparisons among practices included NTR (no-till with residue retention) versus PT0 (plow tillage with residue removed), NTR versus PTR (plow tillage with residue retained), and NT0 (no-till with residue removed) versus PT0 with the former as treatment and the later as control. If two or more tillage treatments were reported in a study, treatment with the maximum soil disturbance was chosen as PT0 or PTR. Further, NTR or NT0 was not required to be used continuously in a double or multiple cropping systems, implying that only those crop yield comparisons with the NTR or NT0 were included which were implemented before sowing of the corresponding crops.

Finally, 520, 316, and 170 comparisons under NTR versus PT0, NT0 versus PT0, and NTR versus PTR, respectively, from 164 studies on crop yields were compiled into the dataset. The detailed information of compiled peer-reviewed papers, along with other related information, is listed in Appendix A. It includes the location (region, longitude, and latitude), mean annual precipitation (MAP), mean annual temperature (MAT), duration of the experiment, number of crops per year, crop species, soil type, soil clay content, soil pH, N fertilization rate, number of replications etc. To identify reasons of changes in crop yield under NTR, 9 variables related to soil properties and plant nutrients were also compiled into the dataset (Table A1). Furthermore, if the data were available as graphs or in Figs, precise yield values were obtained by using the GetData Graph Digitizer (http://getdata-graph-digitizer.com/).

Standard deviations (*SD*) of selected variables, including crop yields, are needed as an important input variable to the meta-analysis. Thus, *SD* values were computed from *SE* by using Eq. (1):

$$SD = SE \times \sqrt{\text{n}} \tag{1}$$

where, n is the number of replications. In cases where *SD* or *SE* was not available, *SD* was reassigned as 10% of the mean for each variable (Luo et al., 2006; Gattinger et al., 2012).

2.2. Data analysis

A random-effects meta-analysis was used to assess the impact on crop yields and other selected variables under NTR compared with PT0. The natural log (ln*R*) of the response ratio was calculated as the effect size of this meta-analysis (Hedges et al., 1999), reflecting the effects responding to NTR computed by using Eq. (2):

$$\ln R = \ln\left(\chi_{\bar{t}}/\chi_{\bar{c}}\right) = \ln\left(\chi_{\bar{t}}\right) - \ln\left(\chi_{\bar{c}}\right) \tag{2}$$