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# The potential mechanism of long-term conservation tillage effects on maize yield in the black soil of Northeast China

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ABSTRACT

The severe soil deterioration and the accompanying decline in maize yield are the main factors jeopardizing the sustainability of agricultural production in the black soil region of Northeast China. Conservation tillage practices have been proposed as new practices to enhance soil fertility and to produce food from a dwindling land resource in this region, but wide adoption of these practices can occur only when the practices demonstrate a steady increase in agricultural production. To compare the effects of tillage on corn yield, the structural equation modeling (SEM) was used in analyzing the relationships between maize growth/yield and soil properties (physical and chemical characteristics) based on a long-term (12 years) tillage study that included no tillage (NT), ridge tillage (RT) and conventional tillage (CT) practices. Compared with CT, NT and RT had higher maize grain yield, soil carbon/nitrogen ratio and soil moisture, and lower soil temperature and seedling emergence rate. The advantages of NT and RT in maize yield were primarily ascribed to the favorable soil nutrients and soil water content, which could increase plant size at the later growing season and ultimately yield more maize grain. The lower soil temperature and subsequently lower emergence rates in NT and RT at early stages (sowing to emergence) of maize growth did not exert negative effects on maize yield. These adverse effects of low soil temperature and low emergence rates could be offset by postponing sowing date without compromising the maize yield. Our study indicated that both NT and RT practices could offer a potentially significant improvement over the current conventional tillage practice in the black soil region of Northeast China.

## 1. Introduction

To reconcile the need for increasing food production to feed a growing population without significantly increasing the area under agricultural production in China, appropriate tillage management strategies are needed. The Songnen Plain dominated by black soils in Northeast China is one of the main agricultural production bases in China; and well known as the ‘bread basket’ for the nation. Spring maize is one of the most common grain crops and often under continuous cropping in this area. The cultivated area of maize is 6.54 Mha, and annual yield is 42.5 Mt, which is around 20% of the total national maize area and 31.2% of the total national maize yield (Wang et al., 2014).

Maize grain yields vary greatly from year to year in this region, and main limiting factor is drought with strong drying winds in spring and long periods of consecutive dry days in summer (Liu et al., 2013). These effects are reinforced by current conventional tillage (CT) practices, which include post-harvest removal of crop residues and moldboard or rotary plowing. This type of practice has caused the reduction of soil organic carbon, degradation of soil structure and extensive wind-water erosion (Liu et al., 2010). To combat this scourge, conservation tillage practices, including no tillage (NT) and ridge tillage (RT), have been proposed to farmers as alternatives to CT. The effectiveness of conservation tillage for reducing soil erosion and enhancing soil quality and fertility is well documented in other parts of the world (Lal, 2004; Lal et al., 2007; Liang et al., 2007; Triplett and Dick, 2008), and it is expected that this advantage will be reflected in crop yield.

A number of field experiments (Rusinamhodzi et al., 2011; Soane et al., 2012; Liu et al., 2013) have studied the response of grain yield to contrasting tillage effects, but the results vary with

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climatic conditions and soil properties. For example, conservation tillage can improve crop yield in warm-dry climate or well drained soil (Govaerts et al., 2005; He et al., 2011; Verhulst et al., 2011; Cullum, 2012). However, in cool-humid climate or poorly drained soil, conservation tillage resulted in lower crop yield relative to CT (Anken et al., 2004; Chen et al., 2011; Arvidsson et al., 2014). These inconsistent yield responses impede the adoption and development of conservation tillage practices because crop yield is the most common and useful parameter influencing the acceptability by farmers of any production practice (Abeyasekera et al., 2002; Rusinamhodzi et al., 2011). Consequently, the large-scale adoption of these practices can be achieved only when crop yield benefits are certain.

Tillage-involved factors influencing crop growth are complex (Chen et al., 2011). The changes in soil quality, including soil moisture, soil temperature and soil nutrient availability all have been considered as the dominant reasons of crop yield differences among tillage practices in a variety of studies (Astier et al., 2006; Triplett and Dick, 2008; Soane et al., 2012). However, little is known about the relative contributions of these tillage-involved factors on crop yield in a study system. Long-term experiments (*i.e.*, >10 years) are the most valuable source of data to accurately diagnose the cause of crop yield variability (Borrelli et al., 2014). They provide unique information on the sustainability of crop production systems; and the interactions between management practices and a broad range of environmental conditions (Grover et al., 2009; Rusinamhodzi et al., 2011). Thus, the objectives of this study were to (1) evaluate maize yield variations in response to the transition from CT to NT and RT, and (2) explore the potential mechanism of different tillage effects on the maize yield based on a long-term trial (12 years) in black soil region of Northeast China. We hypothesized that: (1) compared with CT, NT and RT will maintain or enhance productivity, and will lead to more stable yield; (2) the contributions of tillage-involved factors to maize yield are different.

## 2. Materials and methods

### 2.1. Experimental site

The tillage experiment was conducted at the Experimental Station (44°12′N, 125°33′E) of the Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, in Dehui county, Jilin province, China. The region has a typical temperate continental monsoon climate. The mean annual temperature is 4.4 °C. The mean annual precipitation is 520 mm and more than 70% of precipitation occurs from June to August. The average annual potential evapotranspiration is 1009 mm (1971–2000) and markedly exceeds annual precipitation. The soil is a typical black soil (Typic Hapludoll, USDA, 1993) with a clay loam texture consisting of 36.0% clay, 24.5% silt and 39.5% sand. Prior to the initiate of the tillage trials, the field had been used for continuous maize (*Zea mays* L.) with conventional tillage for more than 20 years (Liang et al., 2007).

### 2.2. Experimental design and management practices

The experiment was a split-plot design with four replicates initiated in the fall of 2001 (Liang et al., 2007). The dimension of each main plot was 10.4 m × 30 m, each main plot was split lengthwise into two 5.2 m × 30 m sub-plots. Three tillage treatments applied at the whole plot level in the experiment were no tillage (NT), ridge tillage (RT) and conventional tillage (CT), and rotations of maize and soybean (*Glycine max* Merr.) were applied at the sub-plot level with both crops present in each year in each whole plot.

Treatments in the CT consisted of fall mouldboard ploughing (20 cm) followed by the secondary seedbed preparation in the spring by disking (7.5–10 cm) and harrowing, and ridge-building. In RT, ridges were maintained year-to-year with a cultivator in June, and a modified lister and scrubber were used to form and press the ridge. Under the NT, no soil disturbance was practiced except for the planting using a no-till planter. Maize and soybean was planted with a no-till planter. Planting dates ranged from April 17 to May 17 (Table 1). Planting was done on the same day for all plots each year. The ridge configuration in RT and CT treatments were changed from 16 cm height and 75 cm width in 2002–2009 to 16 cm height and 65 cm width in 2010–2013 to match a different no-till planter width. The crops were harvested in October. After harvest, the maize stalks in NT and RT treatments was cut into about 30 cm pieces leaving 30–35 cm stubble stand, and pieces were then placed on the soil surface. Soybean residues was returned to the soil surface.

Varied with maize and soybean varieties, several scenarios of the seeding density and the amounts of base fertilizer were used over the course of the study (Table 2). Maize and soybean were seeded at depths of 3.0 cm and 2.5 cm, respectively. Base fertilizers were side-dressed into a furrow 6 cm deep and 10 cm from the seedbeds concurrent with the planting using the banding attachment on the no-till planter. An additional fertilizer N (135 kg ha$^{-1}$) was top dressed at the 6-leaf (V6) growth stage of maize. Weed control was done using broad-spectrum herbicide prior to and after sowing under NT. In RT and CT, a hoe was used to remove weed. Detailed information on cultural practiced is given by Fan et al. (2012).

### 2.3. Soil properties and crop parameters measurements

Each year, soil properties and crop parameters were measured. Soil samples were collected after fall harvest using a manual soil sampling core tube for 0–20 cm depth range. Soil bulk density (BD) was determined from surface to 20 cm depth at 5 cm intervals using a soil cutting ring (5 cm height × 5 cm diameter). Soil total carbon and nitrogen were determined using a FlashEA 1112 elemental analyser (ThermoFinnigan, Italy). Soil organic carbon (SOC) was assumed to equal to the total carbon because the soil was free of carbonate.

Except for rainy days, soil temperature (ST) was monitored daily from 3 days before sowing until one month after sowing. Data was collected using bent stem earth thermometers to a depth of 10 cm at 9 a.m. (T09:00) and 2 p.m. (T14:00). The average of T09:00 and T14:00 was regarded as the mean day-time soil temperature. Soil moisture (SM) was determined daily in three days before sowing and at the 12-leaf (V12) growth stage of maize using time-domain reflectometry (TDR) to a depth of 16.4 cm at 9 a.m.. Three replicates were recorded for each plot and the average of three was reported.

Maize emergence was measured in 3 m for 2 randomly selected rows. Emergence rate was calculated as the ratio of plants emerged 21 days after sowing. Maize height measurements was taken from five randomly selected plants per plot in the two middle rows with a measuring tape at the V6 and V12 growth stages. After maize

**Table 1**
Planting dates for all 12 years (2002–2013) at the long-term tillage trial in Dehui county, Jilin province, China.

| Year | Planting date | Year | Planting date |
|---|---|---|---|
| 2002 | April 22 | 2008 | May 7 |
| 2003 | April 21 | 2009 | May 10 |
| 2004 | April 17 | 2010 | May 17 |
| 2005 | April 28 | 2011 | May 11 |
| 2006 | May 1 | 2012 | May 8 |
| 2007 | May 1 | 2013 | May 17 |