# Impact of tillage on physical characteristics in a Mollisol of Northeast China

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**ABSTRACT**

Soil management is aimed at the maintenance of optimal soil physical quality for crop production. In order to explore the effects of tillage practices on soil physical properties, a study was conducted to compare the effects of no tillage (NT), moldboard plow (MP) and ridge tillage (RT) on soil bulk density (BD), soil penetration resistance (SPR), soil water content (SWC), soil macroporosity (MAC) and soil air-filled porosity (AFP) in Northeast China. Results showed that both NT and RT led to significant BD increment than MP at 0–20 cm ($P$ < 0.05). Compared with MP, NT and RT increased SPR at the depths of 2.5–17.5 cm ($P$ < 0.05). SWC of 0–10 cm layer was significantly higher in NT and RT than MP soils ($P$ < 0.05). NT showed a significantly lower MAC than MP and RT at 0–20 cm soil depths ($P$ < 0.05). All AFP values were above the limit of 0.10 $cm^3/cm^3$ under all tillage treatments. RT improved the soil physical quality as evidenced by decreased BD and SPR, and increased SWC, MAC and AFP relative to NT.

**Keywords**: soil bulk density; soil penetration resistance; soil water content; soil macroporosity; soil air-filled porosity

Soil physical properties can influence the availability and uptake of water, oxygen and nutrients for plant growth (Filho et al. 2013). Crop growth in the field is often slowed by a combination of soil physical stresses, including mechanical impedance, water availability, and oxygen deficiency (Bengough et al. 2006). Soil bulk density (BD) is often used in soil quality studies as an index of the soil's mechanical resistance to root growth (Reynolds et al. 2007). Soil penetration resistance (SPR) may control plant growth by reducing root elongation rate (Fasinmirin and Reichert 2011). Soil water content (SWC) is also a fundamental property affecting plant growth, transport and transformation of soil nutrients, and water and energy budgets in the soil-plant system (Kahlon et al. 2013). Soil macroporosity (MAC) is mainly responsible for the exchange of gases and water in the soil (Calegari et al. 2013). Another stress factor is soil air-filled porosity (AFP), an important criterion for soil aeration which is commonly used to estimate the availability of oxygen to plant roots (Wall and Heiskanen 2009). Hence, quantification of these soil physical characteristics is important for understanding the factors that influence crop growth.

Different tillage systems can affect soil physical properties by altering soil conditions and consequently have a direct bearing on crop growth and subsequent yield production (Jabro et al. 2011). Mollisols of Northeast China are noted for their high soil organic matter content and associated high crop productivity potential (Liu et al. 2006). Over-reclamation and improper management of these soils resulted in severe soil degradation and this has threatened the soil productivity potential in this region (Liu et al. 2010). Conservation tillage systems are useful to control soil degradation, but

Supported by the National Natural Science Foundations of China, Grants No. 41201217, 31170483 and 41101241; by the Key Knowledge Innovation Program of Chinese Academy of Sciences, Project No. KZCX2-EW-QN307, and by the Jilin Provincial Guided Planning Project of Science and Technology, Project No. 201205057.

may lead to excessive soil compaction, negatively impacting crop growth (Feng et al. 2010). However, effect of no tillage (NT), moldboard plow (MP) and ridge tillage (RT) on crop yields did not differ significantly on the basis of an 8-year average in our field site (Fan et al. 2012). Thus, research is needed to analyze the effects of tillage systems on soil physical properties related to crop growth. In addition, since RT is not as common as MP and NT, and little information was available on the influence of RT on soil physical properties, more data in the comparison of soil physical properties under NT, MP and RT are required for the adoption of conservation tillage practices in Northeast China. Therefore, the objective of this study was to compare the effects of tillage (NT, MP and RT) on BD, SPR, SWC, MAC and AFP. The present paper may provide valuable information to propose future soil management for optimal production in Northeast China.

## MATERIAL AND METHODS

**Experimental site and treatments**. The studied tillage trial was established in 2001 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 type of soil in this study is a clay loam (Typic Hapludoll). Soil pH of 0–20 cm layer is approximately 6.5, classified as neutral or slightly acidic. The climate is a semi-humid temperate continental monsoon. The mean annual temperature is 4.4°C, and the mean annual precipitation over the past 30 years is 520 mm. More than 70% of the annual precipitation occurs in June, July and August. Before the establishment of this tillage experiment, the land had been used to grow monoculture corn under conventional management for more than 10 years. Selected soil physical and chemical properties were given by Liang et al. (2011) (Table 1).

The tillage treatments, consisting of NT, MP and RT, were arranged in a randomized complete block design with four replicates. The tillage treatment was applied to the main plots which were 10.4 m × 20 m; each main plot was split lengthwise into two 5.2 m × 20 m sub-plots. Different crop rotations were applied at the sub-plot level: corn-soybean (C-S) with both crops present each year under NT, MP and RT; and continuous corn (C-C) under NT and MP. Tillage treatments employed in the experiment were used in this study, including the C-S under NT, MP and RT. NT had no soil disturbance except for planting using a KINZE-3000 NT planter (Kinze Manufacturing Inc., Williamsburg, USA). MP included one fall moldboard plowing (approximately 20 cm in depth) after harvest, one spring disking (7.5 cm to 10 cm in depth), and ridge-building before planting, crop under MP had two tillage practices after planting. RT included ridge-building in June and corn root chopping in fall (approximately 1/3 row width) and no other soil disturbance after harvest and permanent ridge planting in the next year, crop was cultivated three times after planting. For corn, 100 kg N/ha, 45.5 kg P/ha and 78 kg K/ha were applied each year as starter fertilizer and additional 50 kg N/ha was applied as top dressing at the V-6 stage. For soybean, all fertilizers were applied as starter fertilizer, including 40 kg N/ha, 60 kg P/ha and 80 kg K/ha.

**Soil sampling and analysis**. In fall 2013 (after harvest and before fall moldboard plowing), two replications of four undisturbed soil samples from each NT, MP and RT plot were collected with 5 cm diameter cylinders at the four (0–5, 5–10, 10–20 and 20–30 cm) depths. To determine the MAC, the undisturbed soil samples were saturated and exposed to a potential of –10 kPa on a tension table (Bhattacharyya et al. 2006). The above undisturbed

Table 1. Selected soil physical and chemical properties at different depths in the study site before running this experiment (Liang et al. 2011)

| Depth (cm) | pH | Clay (%) (< 2 μm) | Silt (%) (2–20 μm) | Sand (%) (20–200 μm) | Bulk density (g/cm$^3$) | Soil organic carbon (g/kg) | Total soil nitrogen (g/kg) |
|---|---|---|---|---|---|---|---|
| 0–5 | 6.48 | 36.03 | 24.00 | 39.97 | 1.24 | 16.48 | 1.42 |
| 5–10 | 6.45 | 35.83 | 23.78 | 40.39 | 1.38 | 16.29 | 1.39 |
| 10–20 | 6.51 | 35.68 | 24.35 | 39.98 | 1.36 | 16.08 | 1.37 |
| 20–30 | 7.03 | 36.56 | 25.00 | 38.72 | 1.38 | 14.22 | 1.16 |

soil samples were finally oven dried at 105°C for 24 h to obtain BD and gravimetric SWC (Chan 1981). SPR was measured *in situ* down to a 30 cm depth at intervals of 2.5 cm using a SC-900 handheld digital penetrometer (Spectrum Technologies Inc., Plainfield, USA). AFP was estimated from the following equation:

$$AFP = \frac{PD}{BD} - 1 \quad (1)$$

Where: PD – particle density assumed to be 2.58 g/cm$^3$ (Mcbride and Joose 1996).

Since the depth of soil sampling (0–30 cm) is corresponding with the depth of plough layer of the Mollisol in Northeast China (Liang et al. 2011), presented results in the current study are valid just for studied soil depth and no data are available for deeper horizons.

**Statistical analysis**. The SPSS 13.0 software (SPSS Inc., Chicago, USA) was used for all of the statistical analyses. Treatment main effects on BD, SPR, SWC, MAC and AFP were tested using one-way analysis of variance (ANOVA). Treatment means were compared using the least significant difference (*LSD*) and a significance level of $P < 0.05$.

## RESULTS AND DISCUSSION

**Soil bulk density**. Tillage practices affected BD significantly (Table 2). Compared with MP, NT and RT led to a significant BD increment at 0–20 cm depth ($P < 0.05$) (Table 2). BD at 20–30 cm under all tillage treatments was similar (Table 2). This should be attributed to the difference in tillage intensity between conservation and conventional tillage systems. Though NT resulted in similar BD values with RT, the latter was on average 4.57% lower than the former of 0–20 cm (Table 2). It was mainly attributed to the impact of different degrees of soil disturbance in NT and RT (Müller et al. 2009). Treatments BD varied from 1.01 to 1.38 g/cm$^3$ at 0–30 cm depth (Table 2). Although these values at each depth (except 0–5 cm) were above the optimal range for field-crop production (0.9–1.2 g/cm$^3$), they were lower than the range where root elongation became severely restricted (1.4–1.6 g/cm$^3$) (Reynolds et al. 2007) (Table 2).

**Soil penetration resistance**. Both NT and RT had significantly greater SPR than MP at the depths of 2.5–17.5 cm ($P < 0.05$) (Figure 1). It could be due to the cumulative soil consolidation over time under NT and RT and to the fall and spring tillage compaction in the case of MP (Alvarez and Steinback 2009). In addition, RT refers to management practices with reduced penetration depth and without topsoil inversion, leading to an increment in SPR (Shi et al. 2012). Though NT and RT systems gave similar SPR values in the 2.5–17.5 cm layer, the latter was on average 6.21% lower than the former (Figure 1). This result means that although the RT system dictates a controlled traffic pattern, the ridges are not subject to wheel traffic and therefore maintain better soil structure (Fasinmirin and Reichert 2011). No significant differences in SPR were observed among tillage practices in 20–30 cm ($P > 0.05$) (Figure 1). The SPR values under NT, MP and RT in the topsoil (2.5–17.5 cm) were below the critical value of 2000 kPa for relatively unimpeded root growth (Reynolds et al. 2007). However, all the tillage systems resulted in SPR values more than 2000 kPa below 20 cm depth (Figure 1). It was owing to less soil disturbance in NT and RT (Müller et al. 2009), and the emergence of a plough pan in the ploughed soils of MP (Chen and Weil 2011).

**Soil water content**. SWC in MP treatment of 0–10 cm was on average 17.63% and 23.33% lower

Table 2. Soil bulk density (BD), soil water content (SWC), soil macroporosity (MAC) and soil air-filled porosity (AFP) under no tillage (NT), moldboard plow (MP) and ridge tillage (RT) systems

| Soil property | Soil depth (cm) | Treatment | | |
|---|---|---|---|---|
| | | NT | MP | RT |
| BD (g/cm$^3$) | 0–5 | 1.15$^a$ | 1.01$^b$ | 1.10$^a$ |
| | 5–10 | 1.36$^a$ | 1.21$^b$ | 1.30$^a$ |
| | 10–20 | 1.38$^a$ | 1.23$^b$ | 1.32$^a$ |
| | 20–30 | 1.36$^a$ | 1.35$^a$ | 1.34$^a$ |
| SWC (weight, %) | 0–5 | 30.20$^a$ | 26.78$^b$ | 31.65$^a$ |
| | 5–10 | 24.78$^a$ | 20.23$^b$ | 25.99$^a$ |
| | 10–20 | 16.12$^b$ | 18.90$^a$ | 16.87$^b$ |
| | 20–30 | 12.36$^a$ | 12.50$^a$ | 12.47$^a$ |
| MAC (%) | 0–5 | 11.78$^b$ | 12.81$^a$ | 12.45$^a$ |
| | 5–10 | 10.53$^b$ | 11.56$^a$ | 11.16$^a$ |
| | 10–20 | 8.80$^b$ | 9.56$^a$ | 9.32$^a$ |
| | 20–30 | 7.73$^a$ | 7.86$^a$ | 7.67$^a$ |
| AFP (cm$^3$/cm$^3$) | 0–5 | 1.24$^c$ | 1.55$^a$ | 1.35$^b$ |
| | 5–10 | 0.90$^c$ | 1.13$^a$ | 0.98$^b$ |
| | 10–20 | 0.87$^c$ | 1.10$^a$ | 0.95$^b$ |
| | 20–30 | 0.90$^a$ | 0.91$^a$ | 0.93$^a$ |

Values followed by the same letter within a row indicate no significant difference at 0.05 level

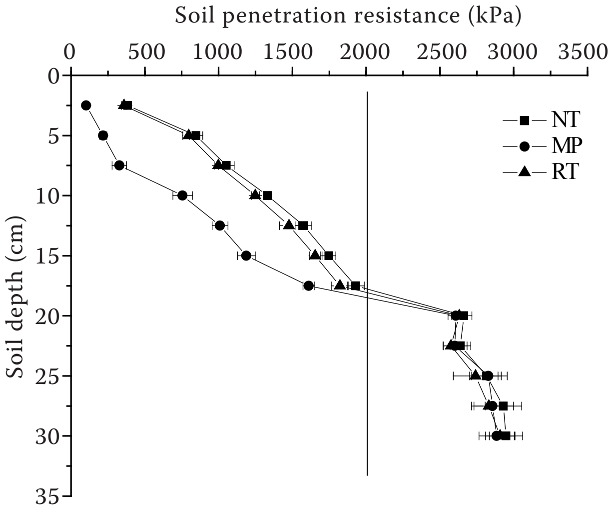


Figure 1. Soil penetration resistance under no tillage (NT), moldboard plow (MP) and ridge tillage (RT) systems

than NT and RT, respectively ($P$ < 0.05) (Table 2). This was mainly due to the retention of crop residues on the surface and less disturbance of NT and RT plots. However, in the 10–20 cm layer, the trend was reversed (Table 2). The possible explanation was a higher volume fraction of large pores, providing greater gravitational drainage under conventional tillage when compared to conservation tillage (Kahlon et al. 2013). In addition, though similar SWC values at 0–10 cm were obtained from the NT and RT systems, the latter was on average 4.84% higher than the former (Table 2). The reason for this situation was that capillary continuity under RT was the least disturbed due to no-tillage and controlled traffic and this accelerated the water sucking of crop roots from the surrounding soils (Li et al. 2007). SWC in the 20–30 cm soil layer among the tillage systems was not significantly different ($P$ > 0.05) (Table 2).

**Soil macroporosity**. Tillage treatments differed in regard to MAC in 0–20 cm depth, and MAC in NT soil was significantly lower than MP and RT ($P$ < 0.05) (Table 2). These results are related to disturbance of soil by primary or secondary tillage, which pulverized the soil, broke clods and loosen the soil, and thus an increase in the MAC of the tilled zone (Kay and VandenBygaart 2002). Water flows primarily through these pores during infiltration and drainage and consequently these pores exert a major control on soil aeration (Calegari et al. 2013). In addition, much of root growth is initiated in these pores (Calegari et al. 2013). In the current study, it meant that RT promoted the exchange of gases and water in soil compared to NT. Tillage practices had no significant effect on MAC at 20–30 cm ($P$ > 0.05) (Table 2).

**Soil air-filled porosity**. Tillage systems resulted in significantly different values of AFP in 0–20 cm layers ($P$ < 0.05) (Table 2). In contrast to MP, NT had a significantly lower AFP at the depth of 0–20 cm ($P$ < 0.05) (Table 2). This was in accordance with results obtained by Fasinmirin and Reichert (2011). AFP was significantly higher in RT than NT soils at 0–20 cm ($P$ < 0.05) (Table 2). This result indicated that RT had a greater soil aeration than NT soil. It is generally accepted that if air-filled porosity in soil is 0.10 $cm^3/cm^3$ or less, plant growth will be significantly limited (Wall and Heiskanen 2009). According to the above criterion, AFP is not a limiting factor related to crop growth in this study. No significant effect of tillage practices on AFP was observed in 20–30 cm layer ($P$ > 0.05) (Table 2).

From the above analysis, it can be seen that the reason why tillage treatments displayed no significant difference in crop yield of our field site were as follows: firstly, although NT and RT led to a significant BD and SPR increment compared to MP, the real resistance exerted by the soil against root penetration is generally less than the average resistance measured by the penetrometer because roots seek the path of least resistance during growth rather than penetrate straight through the soil (Olibone et al. 2010). Secondly, though MAC in both NT and RT plots were lower than MP, SWC was higher for NT and RT than MP. Another reason was that all AFP values in NT, RT and MP did not fell within the 'limited' designation.

In conclusion, tillage practices had different effects on BD, SPR, SWC, MAC and AFP. Compared with NT, RT performed to improve soil physical quality due to a lower BD and SPR, and a higher SWC, MAC and AFP in Northeast China.

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Received on March 27, 2014
Accepted on May 22, 2014

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