Effects of conservation tillage on soil porosity in maize-wheat cropping system

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ABSTRACT

A study was conducted on the effect of two single practices, including soil tillage and returning straw to soil, and their interaction on soil porosity of maize-wheat cropping system. Field experiments involved four tillage practices, including conventional tillage (C), zero-tillage (Z), harrow-tillage (H) and subsoil-tillage (S), with straw absent (A) or straw present (P). Total porosity, capillary porosity and non-capillary porosity of soil were investigated. The results showed that the soil total porosity of 0–10 soil layer was mostly affected; conventional tillage can increase the capillary porosity of soil, but the non-capillary porosity of S was the highest. Returning of straw can increase the porosity of soil. Through the analysis of affecting force, it can be concluded that interaction of soil tillage and straw is the most important factor to soil porosity, while the controlling factor to non-capillary porosity was soil tillage treatment.

Keywords: soil tillage; maize-wheat cropping system; soil porosity; affecting force

In northern China, growing of maize (*Zea mays* L.) and wheat (*Triticum aestivum*) as two crops a year is the dominating cropping system (Yu et al. 2006, Quanqi et al. 2008). Conventional soil management practices resulted in losses of soil, water and nutrients in the field, and degraded the soil with low organic matter content and a fragile physical structure, which in turn led to low crop yields and low water and fertilizer use efficiency (Wang et al. 2007). Therefore, scientists and policy makers put emphasis on conservation tillage systems (Lal 2002). Compared to conventional tillage, there are several benefits from conservation tillage such as economic benefits by labor, cost and time saved, erosion protection, soil and water conservation, and increases of soil organic matter (Uri et al. 1998, Wang and Gao 2004). Hence, the Chinese Ministry of Agriculture formulated a plan for promoting a widespread application of conservation tillage in northern China. Demonstration areas covered 130 thousand km^2 in 2003 and are expected to reach 0.10 million km^2 in 2015 (Wang et al. 2007).

Soil porosity characteristics are closely related to soil physical behavior, root penetration and water movement (Pagliai and Vignozzi 2002, Sasal et al. 2006). Porosity characteristics differ among tillage systems (Benjamin 1993) and nowadays, study on the soil porosity of different tillage treatment is one of the hotspots in tillage research. Previous researches showed that straw returning could increase the total porosity of soil (Lal et al. 1980) while minimal and no tillage would decrease the soil porosity for aeration, but increase the capillary porosity; as a result, it enhances the water capacity of soil along with bad aeration of soil (Wang et al. 1994, Glab and Kulig 2008). However, Børresen (1999) found that the effects of tillage and straw

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treatments on the total porosity and porosity size distribution were not significant. Nevertheless, Allen et al. (1997) indicated that minimal tillage could increase the quantity of big porosity. In previous studies the effects of conservation tillage were studied as a whole, the independent effect and interaction of tillage and straw returning could not be divided, which limited the further study to know the real mechanism of conservation tillage. Based on these questions, this article was carried out to study the independent effect and interaction of tillage and straw to soil porosity and its components in maize-wheat cropping system.

MATERIAL AND METHODS

Experiment design. The experiment was carried out in the Experiment Farm of Shandong Agricultural University from 2004 to 2006. The soil of the study area is classified as Cambisols with thick soil layer, containing 12.4 g/kg organic matter, 1.1 g/kg total N, 101.3 mg/kg alkali-hydrolyzable N (determined by the Olsen method), 5.2 mg/kg available P (determined by the Olsen method) in the topsoils. The cropping system was wheat (*Triticum aestivum* L.) – maize (*Zea mays* L.) as two crops a year, with wheat cultivars of Jimai20 and maize cultivars of Zhengdan958. The wheat was sown on October 8, 2004 with the sowing rate of 90 kg/ha and row spacing of 20 cm, and harvested on June 10, 2005. The maize was sown on June 15, 2005 after the harvest of wheat with the density of 6.66×10^6 plants/ha, and harvested on October 2, 2005. Then, the second wheat was sown on October 14, 2005 with the sowing rate of 105 kg/ha, and harvested on June 10, 2006. The second maize was sown on June 13, 2006 after the harvest of wheat with the same density as in 2005, and harvested on October 5, 2006. For wheat, 160 kg N/ha, 66 kg P/ha, 87.2 g K/ha were used as base fertilizers, and all the treatment was irrigated with 160 mm and 80 kg N/ha was applied at the jointing stage. For maize, 120 kg N/ha and 52.8 kg P/ha were used as base fertilizers, and 120 kg N/ha was applied to the treatment at the male tetrad stage.

The experiments were conducted in triplicate, using randomized block design of two factors. The plot area was 15 m × 8 m. Straw treatments were straw absent (A) or straw present (P) to the field; the tillage treatments were conventional tillage (C), zero-tillage (Z), harrow-tillage (H) and subsoil-tillage (S). The field working procedures of each treatment was as follows:

Zero tillage (Z): maize harvest → straw out of field or crushed to cover the surface of soil → sowing wheat → wheat harvest with straw crushed to cover the surface of soil → sowing maize.

Harrow-tillage (H): maize harvest → straw out of field or crushed to cover the surface of soil → harrowing with nick rake → sowing wheat → wheat harvest with straw crushed to cover the surface of soil → sowing maize.

Subsoil-tillage (S): maize harvest → straw out of field or crushed to cover the surface of soil → deep loosening with subsoiler → sowing wheat → wheat harvest with straw crushed to cover the surface of soil → sowing maize.

Conventional tillage (C): maize harvest → straw out of field or crushed to cover the surface of soil → stubble cleaning with nick rake → plowing → rotary tilling → sowing wheat → wheat harvest with straw crushed to cover the surface of soil → sowing maize.

The depth of H, S and C was 12–15 cm, 40–45 cm and 20–25 cm, respectively. Straw returning was carried out at the stages of wheat harvest and maize harvest. The straw of wheat was all crushed to cover the surface of soil; the straw of maize under Z treatment was crushed to cover the surface of soil, while that of other treatments was mixed with the top soil.

Soil porosity determination. Undisturbed soil cores at different soil depths of each treatment were taken by a steel cylindrical ring of 100 cm^3 volume with three replicates to determine total porosity, capillary porosity and non-capillary porosity of soil by the core method (Huang et al. 2005).

Data calculations and statistics. The independent effects of tillage and straw and their interaction were calculated adopting following formula:

$$\text{Effect of tillage (\%)} = \frac{\text{square sum of tillage}}{\text{total square sum}} \times 100$$

$$\text{Effect of straw (\%)} = \frac{\text{square sum of straw}}{\text{total square sum}} \times 100$$

$$\text{Interaction (\%)} = \frac{\text{square sum staw} \times \text{tillage}}{\text{total square sum}} \times 100$$

Statistical analyses of data were performed using the analysis of variance (ANOVA) in the General Linear Model procedure of SPSS (SPSS Inc, 1999). Differences between treatments were considered significant if $P < 0.05$.

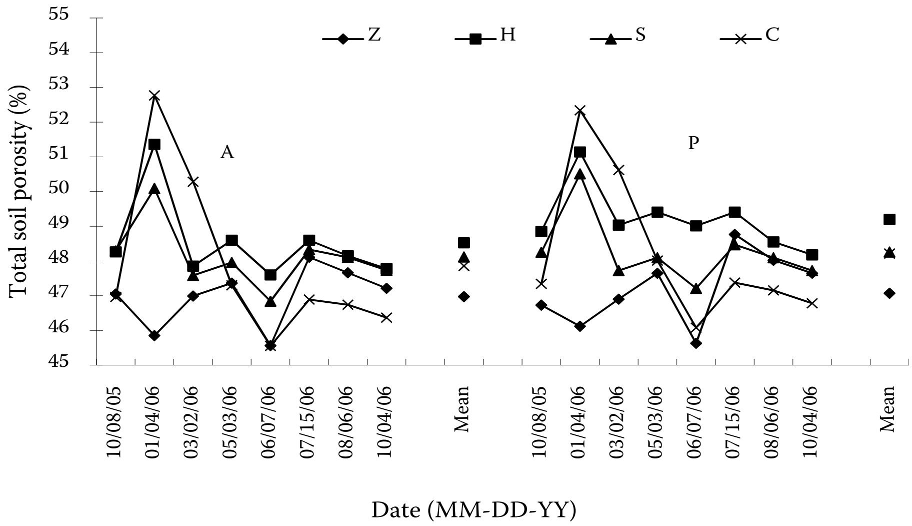

Figure 1. Annual changes of total soil porosity in 0–10 cm layer under different treatments. Z, H, S, and C stand for zero-tillage, harrow-tillage, subsoil-tillage and conventional tillage, respectively; and A and P stand for absent straw and present straw returning to the field

RESULTS AND DISCUSSION

Annual changes of soil total porosity under conservation tillage. The annual change of soil total porosity under conservation tillage in 0–10 cm soil layer was in a great fluctuation with two obvious inflexions. The first inflexion appeared at wheat overwintering period (06-1-4), the maximum porosities of H, S and C were found, and the porosities were C > H > S (Figure 1). However, the changes of porosities of AZ and PZ were reverse to the other treatments, with AZ by 2.1% and PZ by 1.3% lower than those before sowing. The second inflexion appeared at the harvest of wheat, when the porosities of all treatments were lowest. As for the average of treatment with and without straw returning, the soil porosity of harrow tillage was the highest, while that of zero tillage was lowest; the permeability of harrow tillage was therefore better than the other tillage treatments.

Figure 2 showed that, the change trends of soil porosity of AC and PC treatments in 10–20 cm soil layer gave a single peak curve, which reached maximum before tillage and then decreased. The

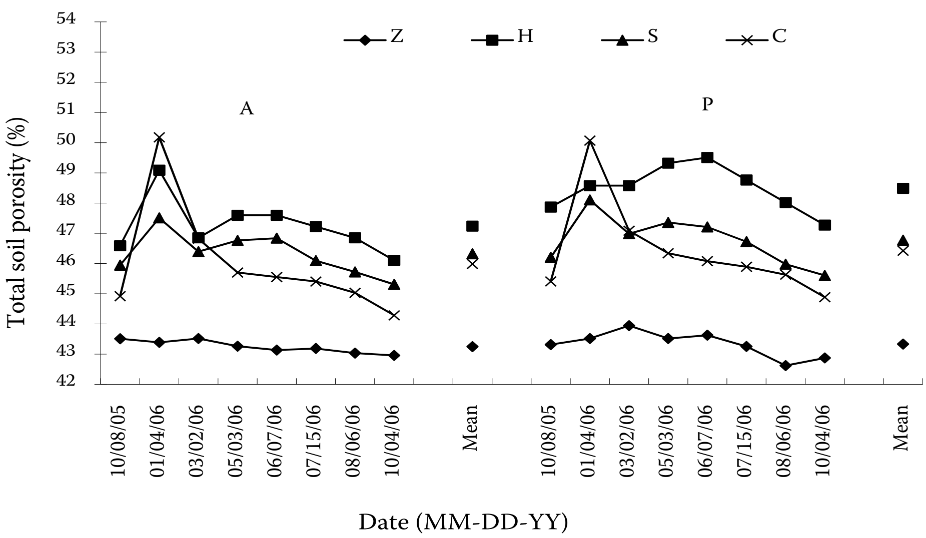

Figure 2. Annual changes of total soil porosity in 10–20 cm layer under different treatments. Z, H, S, and C stand for zero-tillage, harrow-tillage, subsoil-tillage and conventional tillage, respectively; and A and P stand for absent straw and present straw returning to the field

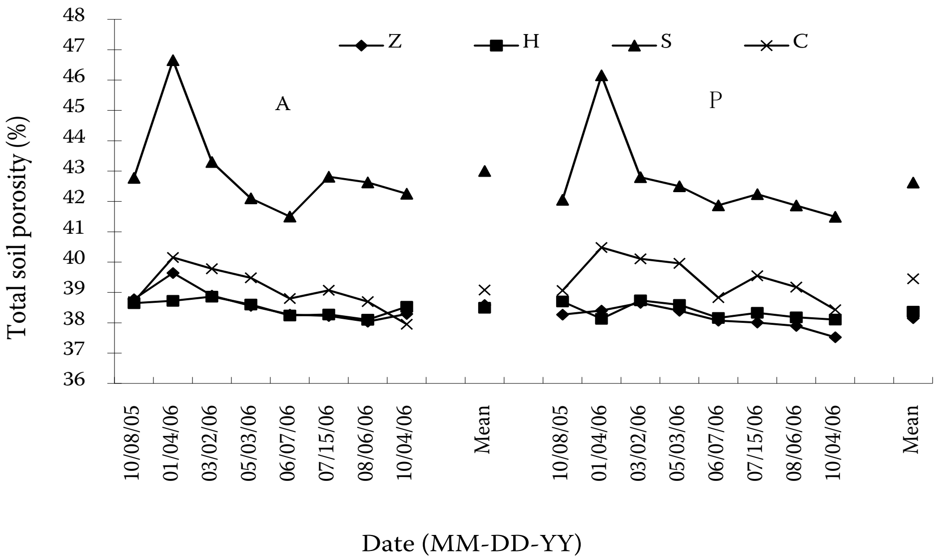

Figure 3. Annual changes of total soil porosity in 20–40 cm layer under different treatments. Z, H, S, and C stand for zero-tillage, harrow-tillage, subsoil-tillage and conventional tillage, respectively; and A and P stand for absent straw and present straw returning to the field

trends of H and S showed an 'M' type curve, the first peak appeared at overwintering period and the second peak of AH, PH and AS appeared at wheat harvest, while the second peak of PS appeared at anthesis stage of wheat. Judged from the yearly average, as the depth and intensity of each tillage treatment was different, the soil porosities ranked H > S > C > Z. Moreover, straw returning increased the total porosity in 10–20 cm soil layer of the treatments of H, S and C.

Table 1. Soil capillary porosity in different conservation tillage practice (%)

Treatment	Soil layer (cm)		
	0–10	10–20	20–40
Zero-tillage with straw absent	38.85[c]	36.19[b]	29.17[d]
Zero-tillage with straw present	38.93[c]	34.72[c]	33.40[b]
Harrow-tillage with straw absent	41.52[b]	35.08[c]	31.23[c]
Harrow-tillage with straw present	42.89[a]	37.99[a]	33.17[b]
Subsoil-tillage with straw absent	31.89[d]	36.82[b]	33.24[b]
Subsoil-tillage with straw present	40.45[bc]	30.12[d]	20.70[e]
Conventional tillage with straw absent	32.00[d]	34.56[c]	34.36[a]
Conventional tillage with straw present	33.06[d]	32.79[d]	18.43[e]
Effects (%)			
Block	0.13	0.80	0.28
Tillage	22.49*	29.24*	22.96*
Straw	42.26*	13.95*	19.34
Straw × tillage	33.72*	52.29*	56.94*
Error	1.40	3.72	0.48

Small letter and * after the data were showed different at 5% level. The analysis of variance of data was conducted between the annual average soil capillary porosity

Table 2. Soil non-capillary porosity in different conservation tillage practice (%)

Treatment	Depth of soil (cm)		
	0–10	10–20	20–40
Zero-tillage with straw absent	8.36[c]	6.51[e]	8.87[c]
Zero-tillage with straw present	8.72[c]	8.20[d]	3.87[e]
Harrow-tillage with straw absent	6.26[d]	11.03[b]	6.84[d]
Harrow-tillage with straw present	6.29[d]	9.28[cd]	4.77[e]
Subsoil-tillage with straw absent	7.28[d]	8.49[cd]	9.01[c]
Subsoil-tillage with straw present	15.83[a]	15.49[a]	20.79[a]
Conventional tillage with straw absent	6.37[d]	9.73[c]	3.59[e]
Conventional tillage with straw present	13.72[b]	12.10[b]	20.00[b]
Effects (%)			
Block	4.54	3.46	7.85
Tillage	41.86*	47.73*	33.22*
Straw	18.35*	8.63*	16.56
Straw × tillage	25.49*	24.50*	38.08
Error	9.76	15.68	4.30

Small letter and *after the data were showed different at 5% level. The analysis of variance of data was conducted between the annual average soil capillary porosity

The soil layer of 20–40 cm was less disturbed than the above layers, only S and C could affect the soil of this depth (Figure 3). The soil porosity of S reached a peak at overwintering period and then decreased. The soil porosity of C increased at overwintering period, which could be affected with straw returning. The soil porosities of H and Z fluctuated. In four tillage treatments, the effects of straw returning were not significant. Overall, the soil porosity of 20–40 cm soil layer was S > C > H > Z.

Wang et al. (1994) reported that conservation tillage can obviously affect soil porosity in 0–10 cm soil layer, increase the porosity of soil in the stage from wheat sowing to overwintering period, but loosen the soil by autumn tillage. Similar finding was reported by Zhang et al. (2003) where the soil porosity of conventional tillage was higher than the other treatments after tillage in autumn. The soil deeper than 10 cm was untouched in zero tillage, so the soil porosity had a decreasing trend (Grzegorz et al. 2001). The results of this study showed that the effect of straw on soil porosity was related to the depth of processed soil; in the touched soil, the porosity was increased by straw returning. Straw returning thus increased the soil porosity of zero tillage in 0–10 cm soil layer, while the other tillage modes increased the soil porosity in 0–20 cm soil layer, without an obvious effect to other soil layers, which corresponded to previous studies (Gomez 2001, Liu et al. 2005).

Effects of conservation tillage on soil capillary porosity. Table 1 shows the situation of soil capillary porosity at the harvest of maize in 2006. In 0–10 cm soil layer without straw returning, the soil capillary porosities were AH > AZ > AC > AS; that of AH was by 6.87%, 29.75% and 30.2% higher than AZ, AC and AS, respectively. With straw returning, the soil capillary porosities of PH, PS and PZ were 29.7%, 22.4% and 17.8% higher than that of PC, respectively. The results of multiple comparisons of tillage treatments showed that soil capillary porosities of H, S and Z were by 29.7%, 19.6% and 11.2% higher than that of C, respectively. Soil capillary porosity of treatments with straw returning was on average by 7.7% higher than those without straw returning.

In 10–20 cm soil layer, soil capillary porosity of AZ, AH and AS was by 4.7%, 1.5% and 6.5% higher than that of AC, respectively. With straw returning, soil capillary porosity of PH was by 9.4%, 26.1% and 15.9% higher than that of PZ, PS and PC, respectively. The results of multiple comparisons of tillage treatments showed that the soil capillary porosity of S and Z was by 8.5% and 5.3% higher than that of C, respectively.

In 20–40 cm soil layer, soil capillary porosity of AZ was by 6.6%, 12.2% and 15.1% lower than those of AH, AS and AC, respectively. Soil capillary porosity of treatments with straw returning was on average by 17.4% lower than that without straw returning, which was mostly due to multiple coming of machine come into field.

Affecting force analysis showed that the affecting force of straw to soil capillary porosity was 42.26% in 0–20 cm, which was the main controlling factor. In 20–40 cm soil layer the main controlling factor was, however, interaction of tillage and straw.

Soil capillary porosity of harrowing was higher than at conventional tillage and zero tillage, mainly because harrowing increased the permeability and mostly maintained the original porosities in deeper soil layer only by mixing the soil with straw in 0–10 cm. But conventional tillage overturns the soil layer, which breaks the structure of soil and as a result, decreases the permeability of soil (Kribaa et al. 2001). As for zero tillage, the capillary porosity was decreased because of the higher soil bulk density (Zhang et al. 2006). Li et al. (2008) reported that straw returning could increase the capillary porosity of soil, which was benefit for water maintained in soil. And conversion from conventional tillage to conservation tillage usually increases available water capacity and infiltration rate (McGarry et al. 2000).

Effects of conservation tillage on soil non-capillary porosity. In 0–10 cm soil layer, soil non-capillary porosity of AZ was by 33.5%, 14.8% and 31.2% higher than AH, AS and AC, respectively (Table 2). With straw returning, soil non-capillary porosity of PS was by 76.4%, 151.2% and 12.2% higher than that of PZ, PH and PC, respectively. Multiple comparisons of tillage treatments showed that soil non-capillary porosity of S was by 35.3%, 14.8% and 15.0% higher than that of Z, H and C, respectively. And soil non-capillary porosity of treatments with straw returning was on average by 57.6% higher than that without straw returning. The affecting force of straw, tillage and straw × tillage was related to soil non-capillary porosity at 0.05 levels.

In 10–20 cm soil layer, soil non-capillary porosity of AH was by 69.4%, 29.9% and 13.4% higher than that of AZ, AS and AC, respectively. With straw returning, soil non-capillary porosity of PS was on average by 57.1% higher than that of the other treatments. Soil non-capillary porosity of Z was lower than other tillage treatments. Straw returning increased soil non-capillary porosity of Z, S and C by 26.0%, 82.4% and 24.4%, respectively. But soil non-capillary porosity of H was decreased by 15.9% with straw returning.

In 20–40 cm soil layer, soil non-capillary porosity of Z and H was lower because it was less disturbed by tillage. With straw returning, soil non-capillary porosity of Z and H was decreased by 129% and 43%, respectively. Straw returning increased soil non-capillary porosity of Z and H 1.3 and 4.6 times, respectively.

It appears that tillage significantly affected soil non-capillary porosity of 0–40 cm, the affecting force of which was 40.9% of the total. But straw returning only had obvious effect on 0–10 cm soil layer. The straw × tillage was related to soil non-capillary porosity in 0–20 cm soil layer, which occupies 25.0% of the total, higher than the independent effect of straw. And the results were also related to the process depth. The effect of conservation tillage was to reduce the volume fraction of large pores and to increase the volume fraction of small pores relative to conventional tillage (Bhattacharyya et al. 2008). Soil organic matter was increased because of straw recycling, which can increase soil porosity (Lal et al. 1980, Blanco-Canqui and Lal 2007). The superiority of conservation tillage is due to more effective water storage and better rearrangement of pore size classes.

To conclude, soil total porosity of 0–10 soil layer was mostly affected, conventional tillage can increase capillary porosity of soil, but non-capillary porosity of S was the highest. Straw returning can increase soil porosity. Affecting force analysis showed that interaction of soil tillage and straw were both important factors to soil porosity, while the controlling factor to non-capillary porosity was only soil tillage treatment.

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