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Full Length Research Paper

Influence of no tillage controlled traffic system on soil physical properties in double cropping area of North China plain

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An experiment was conducted to determine the effects of tillage on soil properties in the field of maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.) annual double cropping region in North China Plain. Measurements were made following six years (2005 to 2010) of three tillage treatments; no till with controlled traffic (NTCT), no till random trafficking (NTRT) and conventional tillage (CT) on a silt loam according to the USDA texture classification system soil in Daxing district, which lies in the suburb of Beijing. Long term no till with controlled traffic significantly (P < 0.05) increased macro-aggregates, infiltration rate, soil moisture, together with reductions in soil bulk density, soil compaction in different layers compared with the no till random traffic and traditional mould board tillage treatment currently used in this region. Consequently, mean winter wheat and summer maize yields for the NTCT treatment were improved by 2.8 and 7.1% when compared with the soils under no till random traffic, while huge improvement was found when it was compared with conventional ploughing management (4.2 and 12.08% for wheat and maize, respectively). The long-term experiment demonstrated that no-tillage controlled traffic with residues retained, offers a potentially significant improvement over the current farming systems in annual double cropping areas of North China Plain.

Key words: No tillage, controlled traffic, soil physical properties, North China Plain.

INTRODUCTION

The North China Plain is the main agricultural production area which mainly includes the provinces of Hebei, Henan, Shandong, Beijing and Tianjin with about 18 million hectares of farmland (18.3% of the national total), and represents 20% of total food production in China (Sun et al., 2007). The main cropping system in the North China Plain is an annual two-crop system (summer maize and winter wheat) with an average total yearly yield of 15 $t.ha^{-1}$ (Li et al., 1997), in which maize was seeded in early June immediately after the winter wheat harvest and harvested in the middle September. Winter wheat was then seeded in early October and harvested in the following June. Over one million hectares of farmland are now estimated to be under conservation tillage in arid and semiarid regions of northern China (McGarry, 2005).

Long-term food security and environmental quality are closely linked to maintaining soil quality. Therefore, the assessment of the effect of tillage practices on soil physical, chemical and biological parameters provided fundamental information about sustainability. The loss of topsoil due to erosion and a reduction of soil organic matter under conventional tillage practice together with escalating fuel prices, have led to the increased implementation of conservation tillage practice (Bassett, 2010). With regards to ecological and economical aspect, the discussion about conventional tillage system and conservation tillage system seems to be increasingly important. Generally, the conventional tillage practice requires multiple pass of machines for land preparation like ploughing, harrowing, compacting/leveling and seeding while in conservation tillage practice, the seeding

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can be done directly in single pass with straw chopping mechanism attached in the front of planter. This conservation tillage system aimed to develop favorable soil conditions and save energy. However, in random traffic conservation tillage practice, 60% of the ground area is being trafficked by wheel using minimum tillage systems and 100% for zero tillage systems (Tullberg, 1990; Raper et al., 1994; Radford et al., 2000). Since multiple wheel traffic strongly influences the physical properties of soil, the conservation tillage with controlled traffic lane is taken as one of the treatment in this study. Soil physical properties represents a group of properties having the substantial impact on the different physical-chemical and biological processing in soil and hence they should be kept optimal (Lal, 1991). For this reason, it is essential to know the soil physical properties not only during the growing seasons but also after the harvest of agricultural crops in crop rotation as well as the choice of the soil tillage method.

Bulk density, porosity and water retention capacity are usually recognized as important indicators of soil quality. However, farming method can influence these by altering soil physical properties. Continuous long term (11 years) no tillage and residue cover practice in semiarid North China Plain led to significant positive effects on soil properties. The benefits included significantly greater soil organic matter content and improved nutrient status, increased macro-aggregate stability, higher proportions of macropores and mesopores as well as enhanced soil water storage (He et al., 2011). Tillage and wheel traffic can affect soil structure by fragmentation and compaction (Lamande et al., 2003; Pagliai et al., 2004), and create heterogeneity in tilled soil between compacted and uncompacted zones. McGarry (2001) identified this as the most serious environmental problem caused by conventional tillage. Frequent passing of tractor with implements or machines over compacting soil sometimes induces hardly reparable changes in the soil that influence growth and development of the plants. One of the most efficient ways to decrease the soil compaction is by reducing the number of working operations (Fili, 2008). The study in North China plain showed that controlled traffic conservation tillage, constricted compactions in certain lanes, avoiding unnecessary energy dissipation on compacting and undoing compacted soils wheeled by implement itself, and largely improved both tillage efficiency and traffic efficiency (Wang et al., 2009).

Most of the previous reports about the effect of tillage on soil structure have been focused on conventional tillage versus conservation tillage (no tillage/minimum tillage) on one crop a year region, and also for the short period of time. This study was done to investigate the effects on some soil physical properties in the two crops a year region with the comparison between two conservation tillage systems [no tillage with controlled traffic (NTCT), and no tillage with random traffic (NTRT)] with conventional farming system (CT) practice in the region.

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MATERIALS AND METHODS

Site description

The experiment was conducted at Daxing (39°7'N, 116°4'E) district, Beijing, during 2005 to 2010. Daxing lies in south of Beijing in a semi-humid region of North China Plain which is 45 m above sea level. Average annual temperature is 11.9°C with 186 frost-free days. Average annual rainfall is 526 mm in which more than 70% occurs during June to September. Double cropping system with winter wheat and summer maize is the main cropping system practice in this region. Soil is defined as silt loam according to the USDA texture classification system, which is low in organic matter (< 1%) and slightly alkaline (pH 7.7). Soil in this region is generally described as porous and homogenous to considerable depth with limited variance across fields (He, 2007).

Experimental design

The experimental design used three treatments with three replications in randomized blocks. Each treatment was 9 m wide and 90 m long. The treatments included NTCT, NTRT and conventional (moldboard plough) tillage (CT). The operation schedule for each treatment is presented in Table 1.

No tillage treatments were with full straw cover (100% soil cover). Standing stubble of 0.30 m height was retained with all wheat straw left as soil cover (about 3.8 t/ha) after wheat harvest and maize stubble were retained in the field during wheat planting period. The layout of crop rows and permanent traffic lanes (0.45 m for wheel track) were designed to accommodate the characteristics of the local tractors and planters.

Measurements

Soil sampling analysis

Soil sampling for soil physical properties measurements was carried out in June 2010 after wheat harvest. Undisturbed soil samples using the 50.4 mm diameter × 50 mm long manual stainless steel core sampler were collected from random location in all three treatments. Three disturbed soil samples were collected at 0 to 10, 10 to 20 and 20 to 30 cm soil depths in each plot, and mixed to form a single composite sample for each depth band for aggregate stability measurements. All the measurements were replicated three times.

Bulk density, soil gravimetric water content and total soil porosity

In each plot, nine random soil samples were taken in the depth of 0 to 10, 10 to 20 and 20 to 30 cm, and then weighed wet, dried at 105°C for 48 h and weighed again to determine bulk density and soil gravimetric water content. Total porosity (TP) was calculated from bulk density (BD) and the particle density was measured (that is, 2.65 mg/m^3) (Sasal et al., 2006).

Soil water-stable aggregation

Soil water-stable aggregate distribution was determined by placing the soil sample on a nest of sieves, immersing directly in water and agitating the sieves up and down 35 mm at 30 cycles min^{-1} for 15 min. Samples remaining on each sieve were dried and proportions of wet stable aggregates > 2, 2 to 1, 1 to 0.5, 0.5 to 0.25 and < 0.25 mm were calculated. The fraction of micro-aggregates were taken

Table 1. The operation schedules for NTCT, NTRT and CT treatments in Daxing during the experimental years from 2005 to 2010.

Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Maize												
Rotary ploughing + planting (CT)						x						
No-till planting (NTCT and NTRT)						x						
Spraying (NTCT and NTRT)							x					
Harvesting (CT)									x			
Harvesting + residue chopping (NTCT and NTRT)									x			
Wheat												
Ploughing/harrowing/ Leveling/ planting (CT)										x		
No-till wheat planting (NTCT and NTRT)										x		
Irrigation (NTCT, NTRT and CT)			x		x						x	
Harvesting wheat (NTCT, NTRT and CT)						x						

NTCT, No till control traffic; NTRT, no till random traffic; CT, conventional tillage.

as those < 0.25 mm (Oades and Waters, 1991). All the measurements were replicated three times.

Soil compaction

The soil compaction data were collected in February during the dry period of wheat season. The soil compaction was measured by the SC900 Field Scout Soil compaction meter, Spectrum Technologies, Inc. The soil compaction of different tillage systems were measured at the depths from 0 to 30 cm in the interval of 2.5 cm. All the measurements were replicated three times.

Infiltration rate

Infiltration of water into the soil was determined in each treatment using a double ring infiltrometer (Bouwer, 1986) with a 30 cm inner diameter and 60 cm outer diameter cylinder inserted 10 cm into the soil at the experiment field. Water entering the soil was measured with a calibrated Marriot bottle. A constant water head of 20 mm was maintained in both rings. Infiltration measurements were made at three separate randomly selected points in each treatment.

Yield

Wheat and maize grain yields were determined at 12% moisture content by manually harvesting 3 m length of rows taken randomly in each plot with three replications in each year.

Statistical analysis

The SPSS analytical software package was used for all statistical analyses. Mean values were calculated for each of the measurements, and ANOVA was used to assess the effects of conservation tillage on the measured variables. When this indicated a significant F-value ($P < 0.05$), multiple comparisons of mean values were made on the basis of the least significant difference (L.S.D.).

RESULTS AND DISCUSSION

Bulk density, soil gravimetric water content and total soil porosity

Soil bulk density is a first approximation of potential changes in soil structure with improved management (Arshad et al., 1999). Mean soil bulk density in 0 to 10 cm from NTCT (crop zone), NTRT, CT and Wheel Track (WT) in NTCT field were 1.25, 1.26, 1.05 and 1.45 g/cm^3, respectively. This shows that the bulk density in NTCT was 16.67% and NTRT was 16%; significantly higher ($P < 0.05$) than the CT and WT which was 13.8 and 13.1% higher ($P < 0.05$) than NTCT and NTRT, respectively.

Mean soil bulk density in 10 to 30 cm depth was significant between NTCT and NTRT treatments ($P < 0.05$) with NTRT bulk density of 5.8% in 10 to 20 cm and 5.6% in 20 to 30 cm higher than NTCT treatment, demonstrating the increase in bulk density which occurred in the NTRT treatment; this was probably caused by wheel traffic. Mean bulk densities of CT and WT in 20 and 30 cm were significantly high ($P < 0.05$) when compared with NTCT and NTRT treatments (Figure 1). The greater bulk density in this layer of the conventional treatment indicated the development of a compacted “hard pan” beneath tillage depth caused by the traffic associated with tillage. The changes of soil bulk density were consistent with the findings of Mou et al. (1999), who showed that soil bulk density in 20 to 30 cm soil depth in northern China was 5.4% lower for no-tillage

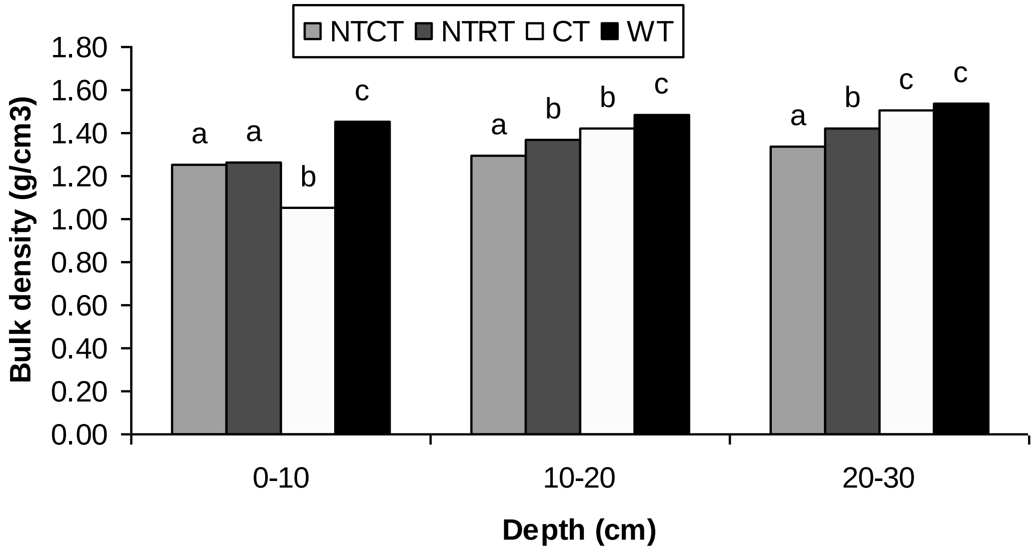

Figure 1. Mean soil bulk density (g/cm^3) of the three treatments (NTCT, NTRT, CT) and wheel track (WT) in 0 to 30 cm soil profile. Means within the same column followed by the same letter are not significantly different at P ≥ 0.05.

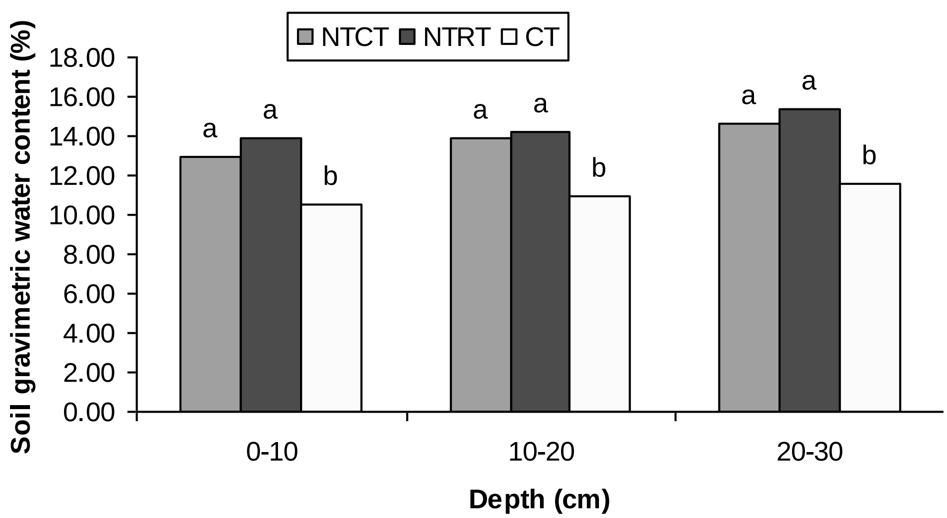

Figure 2. Mean soil gravimetric water content (%) of the three treatments in 0 to 30 cm soil profile. Means within the same column followed by the same letter are not significantly different at P ≥ 0.05.

than for conventional tillage after five years. The results also coincided with the findings of Sefa et al. (2011), where the highest soil bulk density values were found with the rotary tiller with roller at both 0 to 5 cm and 5 to 10 cm soil depths; this was due to the roller used which caused more soil compaction than in the rotary tiller and conventional farming systems.

The effects of tillage systems on soil gravimetric water content were found statistically significant ($P < 0.05$) in the depth of 0 to 10, 10 to 20 and 20 to 30 cm (Figure 2). No tillage systems (NTCT and NTRT) conserved more soil moisture compared to the conventional tillage (CT). Hajabbasi (2003) also reported that soil gravimetric water content capacity is increased by reducing soil tillage intensity. The moldboard plow used in CT caused more moisture loss because it inverted the soil in the tillage depth. The highest temperature was found in CT in all level of depths followed by NTRT and NTCT.

The total soil porosity in 0 to 10 cm soil layer was found to be 60.38% in CT while only 52.7, 52.33 and 45.38% were found in NTCT, NTRT and WT. However, as the depth increases (10 to 30 cm), CT and WT total soil porosity was significantly less ($P < 0.05$) in comparison with NTCT and NTRT which is illustrated in Figure 3.

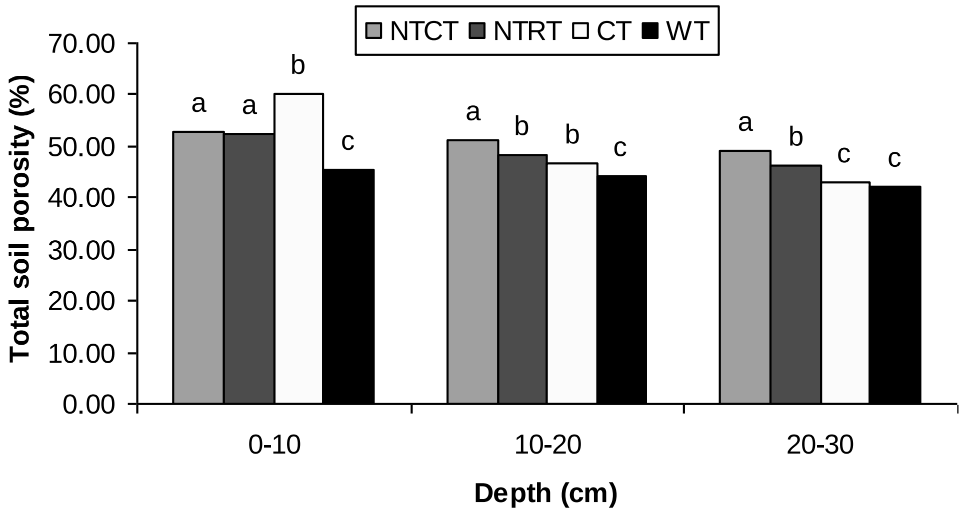

Figure 3. Mean total soil porosity (%) of the 3 treatments (NTCT, NTRT, CT) and wheel track (WT) in 0 to 30 cm soil profile. Means within the same column followed by the same letter are not significantly different at P ≥ 0.05.

Table 2. Soil wet stable aggregate size classes (mm) at 0 to 0.10, 0.10 to 0.20 and 0.20 to 0.30 cm depths (%).

Soil depth (m)	Treatment	Aggregate				Macro	Micro
		> 2	2 to 1	1 to 0.25	< 0.25	> 0.25	< 0.25
0 to 0.10	NTCT	12[a]	15[a]	29[a]	44[a]	56	44
	NTRT	9[b]	20[b]	24[b]	47[a]	53	47
	CT	5[c]	15[a]	14[c]	66[b]	34	66
0.10 to 0.20	NTCT	14[a]	30[a]	16[a]	40[a]	60	40
	NTRT	10[b]	23[b]	21[b]	46[b]	54	46
	CT	9[b]	18[c]	15[a]	58[c]	42	58
0.20 to 0.30	NTCT	19[a]	28[a]	14[a]	39[a]	61	39
	NTRT	12[b]	24[b]	16[a]	48[b]	52	48
	CT	7[c]	13[c]	21[b]	59[c]	41	59

Values within a column in the same depth followed by the same letters are not significant (P > 0.05).

These results are consistent with those of He et al. (2011) and demonstrated the negative long-term effects of conventional tillage on macro- and meso-pore volumes.

Soil water-stable aggregation

Soil aggregates are influenced by organic matter and organisms present in the soil, soil texture, crop rotation and tillage practices. Soil aggregation is an important variable, influencing soil structure and soil erosion (Eldridge and Leys, 2003). Table 2 illustrates the treatment effects on aggregate wet stability in two size classes and for three treatments at 0 to 10, 10 to 20 and 20 to 30 cm depths. Significant (P < 0.05) treatment differences could be seen in the size distribution of water-stable soil aggregates. In long term no-till soil both in NTCT and NTRT, the percentage of water-stable aggregates of the largest size class (> 2 mm) was approximately twice that in ploughed soil (CT) in all 0 to 10, 10 to 20 and 20 to 30 cm depths, which was consistent with the findings of Li et al. (2007) in long term no-till soil, where the percentage of water-stable aggregates of the largest size class (> 2 mm) was approximately twice that in ploughed soil in both 0 to 0.10 and 0.10 to 0.20 m. The highest percentage of largest size class (> 2 mm) was found in NTCT with 23.7, 30.5 and 36.8% in 0 to 10, 10 to 20 and 20 to 30 cm, respectively; significantly higher (P < 0.05) than NTRT. Similarly, the percentage of water-stable aggregates of

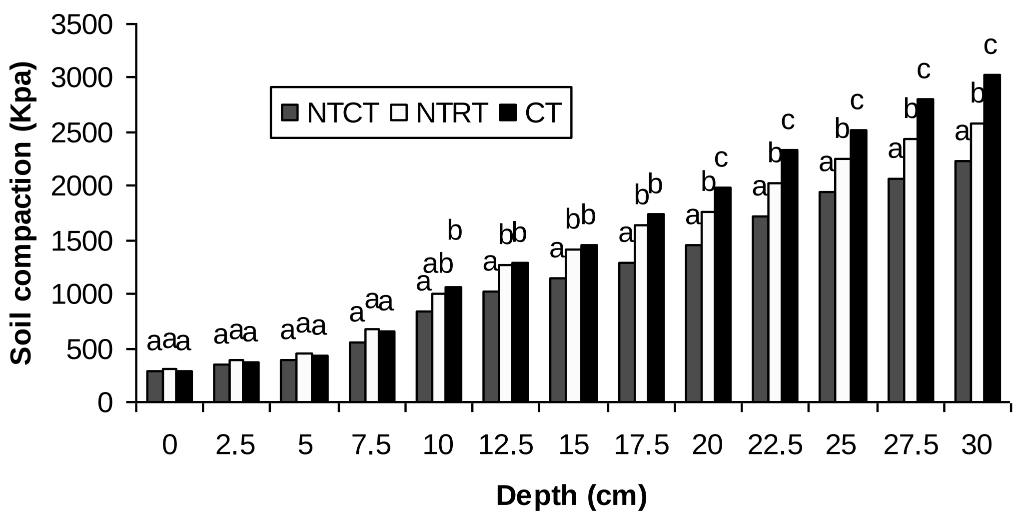

Figure 4. Mean soil compaction (Kpa) of the three treatments (NTCT, NTRT, CT) in 0 to 30 cm soil profile. Means within the same column followed by the same letter are not significantly different at P ≥ 0.05.

the smallest size class (< 0.25) was greater in CT. Macro-aggregates constituted 56, 60 and 39% in NTCT treatment of 0 to 10, 10 to 20 and 20 to 30 cm depths, respectively, whereas NTRT treatment constituted 53, 54 and 52% compared with 34, 42 and 41% for CT treatment. These results agreed with those of McHugh et al. (2004) who demonstrated the damaging effects of heavy tractor and machinery wheels on soil physical properties such as soil aggregates distribution, and its impact on water availability to plant roots.

Soil compaction

Figure 4 illustrates the soil compaction in response to different tillage systems after six years of planting wheat and maize crops. The soil compaction was increased by increasing soil depth in all of the treatments. The effects of tillage systems on the soil compaction were not significant between treatments till the depth of 5 cm. However, as the depth increases, the soil compaction level of NTRT was found to be significantly higher than NTCT ($P < 0.05$) from the depths of 12.5 cm, whereas it was non significant with CT till the depth of 17.5 cm. CT was found to be higher ($P < 0.05$) than NTCT in all the depths from 10 cm. In the depth of 20 to 30, all the treatments were highly significant between each other. The results indicate that controlled traffic conservation tillage could minimize the compaction of wheel traffic, make field operation timely and precisely, improve soil structure as well as increase soil moisture on crop zone, which is beneficial to crop establishment and growth (Wang et al., 2005). The results also agree with the findings of Tullberg (1990), that trafficking by wheeled farm machines were common in agricultural operations even in zero tillage systems.

Infiltration rate

Soil water infiltration rate under NTCT, NTRT and CT decreased with time (Figure 5). In the beginning stage of the infiltration test, differences between the infiltration rates of NTCT, NTRT and CT plots were negligible, probably due to the similarity of soil physical properties in the upper layer. However, when water infiltrated into deeper soil layers, NTCT and NTRT plots showed significantly ($P < 0.05$) higher infiltration rates than CT plots. Consequently, total infiltration under NTCT and NTRT treatment was greater, and final (steady state) infiltration rate for NTCT (22.0 mm min^{-1}) and NTRT plots (19.0 mm min^{-1}) was approximately five times that of the CT plots (4.0 mm min^{-1}). The greater final infiltration rate in the plots under NT was probably own to the residue retention of the surface, less disturbance to the continuity of water conducting pores (Acharya and Sood, 1992) and increased large (> 2 mm) aggregate stability (Jin He et al., 2009). In CT soils, the degradation at 20 to 30 cm depth after six years of conventional ploughing significantly reduced macro-aggregates and increased deep soil compaction, thereby decreasing water infiltration. These results confirm those of Wang et al. (2001) who reported that final infiltration rate under no-tillage with residue cover (3 years) was 1.5 to 1.6 times that of conventional moldboard plough in northern China.

Yield

During the first three years of growing seasons, mean

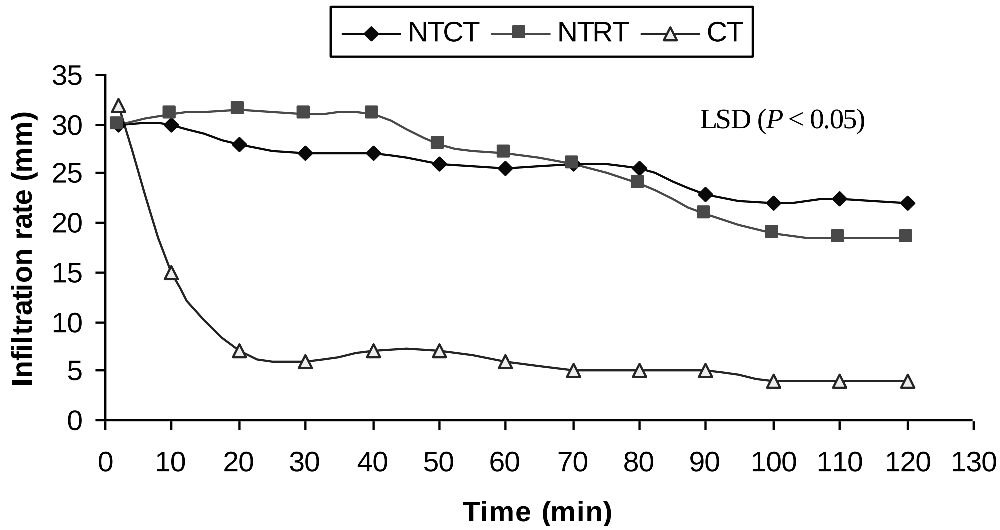

Figure 5. Changes in soil infiltration rate within 120 min under NTCT, NTRT and CT treatments.

Table 3. Mean yield for winter wheat for NTCT, NTRT and CT treatments during experiment period (2005 to 2010).

Year	Treatment	Grain per spike	Thousand grain weight (g)	Yield (t/ha)
Year 1	NTCT	37[a]	44.66[a]	4.54[a]
	NTRT	35[a]	45.92[b]	4.87[b]
	CT	35[a]	44.28[a]	4.51[a]
Year 2	NTCT	33[a]	42.56[ab]	4.72[a]
	NTRT	31[a]	45.08[a]	4.96[a]
	CT	31[a]	41.44[b]	4.91[a]
Year 3	NTCT	35[a]	42.42[ab]	4.90[a]
	NTRT	34[a]	42.85[a]	4.93[a]
	CT	32[a]	40.70[b]	4.81[b]
Year 4	NTCT	35[a]	43.10[a]	4.69[a]
	NTRT	33[a]	43.89[a]	4.71[a]
	CT	32[a]	40.75[b]	4.58[b]
Year 5	NTCT	37[a]	43.22[a]	4.78[a]
	NTRT	33[a]	42.30[a]	4.65[b]
	CT	32[a]	40.87[b]	4.58[b]

Means within the same column in the same year followed by the same letters are not significant ($P > 0.05$).

winter wheat yield and yield components were less affected between the treatments. In the first year, NTRT treatment showed higher values (6.7 and 7.3% in comparison with NTCT and CT, respectively) on yield with significant difference ($P < 0.05$), whereas in the second year, all the treatments were not significantly different. In the third and fourth year, the mean yield value of NTCT and NTRT were non significant ($P > 0.05$) but were significant with CT treatment. However, in the final year (fifth year) of the experimental period, winter wheat yield of NTCT treatment was 2.8 and 4.2% higher than NTRT and CT treatments, respectively, with significant difference at $P < 0.05$. Mean five years grains per spike remained non significant between all the

Table 4. Mean yield for maize for NTCT, NTRT and CT treatments during experiment period.

Year	Treatment	Kernel row number per year	Kernel number per row	Hundred kernel weight (g)	Yield (t/ha)
	NTCT	13.3[a]	35.9[a]	29.23[a]	5.92[a]
Year 1	NTRT	12.7[a]	35.3[ab]	27.64[b]	5.47[b]
	CT	12.7[a]	34.9[b]	27.63[b]	5.52[b]
	NTCT	13.7[a]	38.4[a]	31.09[a]	6.63[a]
Year 2	NTRT	13.3[a]	37.2[ab]	29.60[b]	5.95[b]
	CT	12.3[a]	37.0[b]	29.36[b]	5.90[b]
	NTCT	13.3[a]	38.7[a]	31.46[a]	6.82[a]
Year 3	NTRT	13.3[a]	37.5[b]	30.36[b]	6.33[b]
	CT	12.3[a]	37.1[b]	30.20[b]	6.31[b]
	NTCT	13.7[a]	39.1[a]	31.35[a]	6.84[a]
Year 4	NTRT	13.3[ab]	38.0[b]	30.43[b]	6.04[b]
	CT	12.3[b]	37.4[b]	30.23[c]	6.11[b]
	NTCT	13.3[a]	39.4[a]	31.46[a]	8.00[a]
Year 5	NTRT	13.0[a]	38.3[ab]	30.55[b]	7.43[b]
	CT	12.7[a]	37.3[b]	30.22[c]	7.03[c]

Means within the same column in the same year followed by the same letters are not significant ($P > 0.05$).

treatments in all the experimental period as well as thousand kernel weight for NTCT and NTRT which were not significant between treatments but were highly significant with CT treatment during the experimental period.

For maize production, higher values of both yield components and yield were observed in NTCT treatment. In the average of five years, yield components in NTCT treatment were higher than that in NTRT and CT treatments with significant difference in mean hundred kernel weight (4.98% with NTRT and 3.94 % with CT). Consequently, higher yield was pronounced in NTCT treatment. In the first year, the increase in yield was 7.7 and 6.8% compared with NTRT and CT, respectively. In the final year of the experimental period, yield in NTCT was 12.08% significantly ($P < 0.05$) higher than that in CT, and 7.1% higher than NTRT treatments which was also significantly higher (5.34%) than CT treatment.

Chen et al. (2008) demonstrated that even with 20% of land used for permanent traffic lanes, overall mean wheat yield in controlled traffic treatments was 10% higher than that in CT treatment, and the differences were significant ($P < 0.05$) in four of eight years between 1999 and 2006 which agreed with the results found in this study. The soil physical properties factors obtained in this study signified the reasons for acquiring higher yield in NTCT when compared with NTRT and CT treatments.

Conclusion

The data from this study showed several significant changes in the physical properties of soil after six years of no till controlled traffic management when compared with the no till random traffic and conventional tillage of wheat and maize production in North China Plain, which are as follows:

1. Significant increase in macro-aggregates, infiltration rate, soil moisture, together with reductions in soil bulk density, soil compaction in different layers under no till controlled traffic, compared with the no till random traffic and conventional mould board tillage treatment currently used in this region.
2. Winter wheat and summer maize yields for the NTCT treatment were improved by 2.8 and 7.1% compared to

the soils under no till random traffic and huge improvement was found when compared with the conventional ploughing management (4.2% for wheat and 12.08% for maize).

3. The long-term experiment demonstrated that no-tillage controlled traffic with residues retained, offers a potentially significant improvement over the current farming systems in annual double cropping areas of North China Plain. These improvements in the physical condition of soils under controlled traffic are generally in agreement with those reported for similar treatments in Loess Plateau of China and Australia.

4. From the perspective of sustainable development, more long-term research on the relationships between conservation tillage, soil structure, crop productivity and environmental integrity is needed in annual double cropping areas in North China Plain.

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