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Research Article

Effect of Wheel Traffic on Crop Performance in North China Plain

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Abstract: Controlled traffic system was an effective solution to soil compaction, thus to promote sustainable development. The objective was to evaluate the effect of small and medium machinery wheel traffic on soil conservation and crop performance in annual two-crop region in North China Plain. Three treatments were included, zero tillage with Controlled Traffic (NTCN), zero tillage with random Traffic (NT) and traditional tillage treatment with random traffic (CK). Based on the two-year controlled traffic experiment in North China Plain, it was illustrated that controlled traffic system NTCN reduced soil bulk density in 0-30 cm soil layer in crop zone by applying permanent wheel track. Due to the avoiding of compaction, crop performance was enhanced. Both winter wheat and summer maize yield components value were increased in NTCN, compared with NT and CK. Even 30% of the field was occupied by the permanent traffic lanes, controlled traffic still increased total annual yield and WUE by compensating yield loss in winter wheat from the yield benefit in summer maize. It was indicated that controlled traffic system improved soil structure, promoted crop performance and induced higher annual crop yield in the annual two crops region in North China Plain. Although these results are preliminary, it was indicated that controlled traffic system was a valuable farming system in small and medium machinery condition in North China Plain.

Keywords: Controlled traffic, crop performance, north china plain, soil compaction

INTRODUCTION

As the main agricultural production base, the North China Plain, which includes the provinces of Hebei, Henan, Shandong, Beijing and Tianjin, has 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 annual two-crop, summer maize and winter wheat. Conservation tillage showed significantly higher performance in both soil conservation and crop yield in the region (Jin *et al*., 2009. Over 1 million ha of farmland are now under conservation tillage in arid and semiarid regions of northern China (Li *et al*., 2011).

As less mechanical loosen methods were utilized in conservation tillage system, soil compaction due to wheel track was stressed out. Sixty percent of the ground area was trafficked by wheel using minimum tillage systems and 100% for zero tillage systems (Kingwell and Fuchsbichler, 2011). Soil compaction induced by wheel traffic had adverse effects on soil properties and crop growth (Hamza and Anderson, 2005) and eventually reduced crop yield in both dryland and irrigated farming systems (Sadras *et al*., 2005; Wang *et al*., 2009).

Due to the high level of agriculture mechanization level with medium and small scale machinery, serious soil compaction had been observed in previous studies on conservation tillage in annual two-crop region in North China Plain (He *et al*., 2011), which resulted in soil degradation and yield reduction, thus, endangered sustainable development of agriculture in this area.

Controlled traffic farming has been shown to reduce soil bulk density, increase water infiltration and crop yield, by separating traffic lanes and crop zones permanently (Tullberg, 2010; Gasso *et al*., 2013). Its effectiveness in arid environments has also been demonstrated by Chen *et al*. (2008a) and Bai *et al*. (2008) which showed that controlled traffic with conservation tillage is a useful solution for reducing soil degradation, conserving water and improving yield in the Loess Plateau of China.

However, there were only a few preliminary researches on the controlled traffic system with conservation tillage system in this area (Jin *et al*., 2009). The effect of controlled traffic system on crop performance was not clear in the irrigated area of North China Plain. Based on the field experiments, this study was aimed to determine the effect of controlled traffic system with medium and small machinery on crop performance and present suggestions for further

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controlled traffic system research, thus to enhance the sustainable development of this area.

MATERIALS AND METHODS

Site: Experiments was conducted at Daxing (39°7'N, 116°4'E) district, Beijing, from 2004 to 2007. Daxing lies in south Beijing in a semi-humid region 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-September. Double cropping system with winter wheat and summer maize is the main cropping system practiced in this region. Summer maize is seeded in early June and harvested in the middle of September. Winter wheat is then seeded in early October and harvested in the following June.

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.

Experimental design: At the beginning of the experiment in 2004, the entire field was ploughed to a depth of 40 cm to mix soil thoroughly and provided uniform soil condition in each experimental plot. The plot was 9 m wide and 90 m long. The experimental design was a random block with 4 replications. Three treatments were used: zero tillage with Controlled Traffic (NTCN), zero tillage with random Traffic (NT) and traditional tillage treatment with random traffic (CK). All treatments consisted of zero tillage with full residue retention for both wheat and maize.

NTCN: Winter wheat was no-till planted at early October. Three times of irrigation were applied in late November, next March and middle May. Winter wheat was harvested at early June. Then, summer maize was no-till planted at middle June and harvested at late September. Before winter wheat planting, the maize residue was chopped. All residues were return to the filed. All traffic was controlled to the permanent wheel track.

NT: Winter wheat and summer maize was growing follow the same procedure as NTCN. The only difference was that the traffic was not controlled. Random traffic was applied in the field.

CK: Rotary tillage was applied before wheat planting. The winter wheat was planted at early October. Same irrigation procedure was applied. Wheat was harvested by harvester with all the residue return to field. Then, maize was no-till planted at middle June. After maize harvesting, 20-30 cm residue was left in the field.

The layout of crop and permanent traffic lanes in controlled traffic treatment NTCN was shown in Fig. 1, designed according to local tractors, planters and harvester. Seven rows of winter wheat and two rows of maize were planted in 1.5 m beds. The width of each wheel track was 0.45 m, occupying 30% of the ground area. In NT treatment, there was no permanent track lane. Wheat and maize were uniformly planted in each plot, 20 and 75 cm, respectively. The plot was 9 m wide and 90 m long. The experimental design was a random block with 4 replications.

Winter wheat was Jingdong-6 at a seeding rate of 120 kg/ha and summer maize was Jingyu-13 at a seeding rate of 37.5 kg/ha, both of which were the most widely used varieties in the region. Urea ($CO [NH_2]_2$), $(NH_4)_2 HPO_4$ and KCl (K_2O content: 60%) were applied to provide 95 kg N/ha, 75 kg P/ha and 40 kg K/ha as the basal N, P, K fertilizer at planting time. An additional 50 kg N/ha was applied at first-node stage for winter wheat. Summer maize sowing density was seven plants per m^2 and a complete fertilizer (N-P_2O_5-K_2O) was applied at the rate of 85 kg N/ha, 45 kg P/ha and 40 kg K/ha at planting. Roundup (glyphosate, 10%) was used for weed control during summer maize growing season. Same amount of seeds, fertilizers and herbicides were applied to get more comparable results.

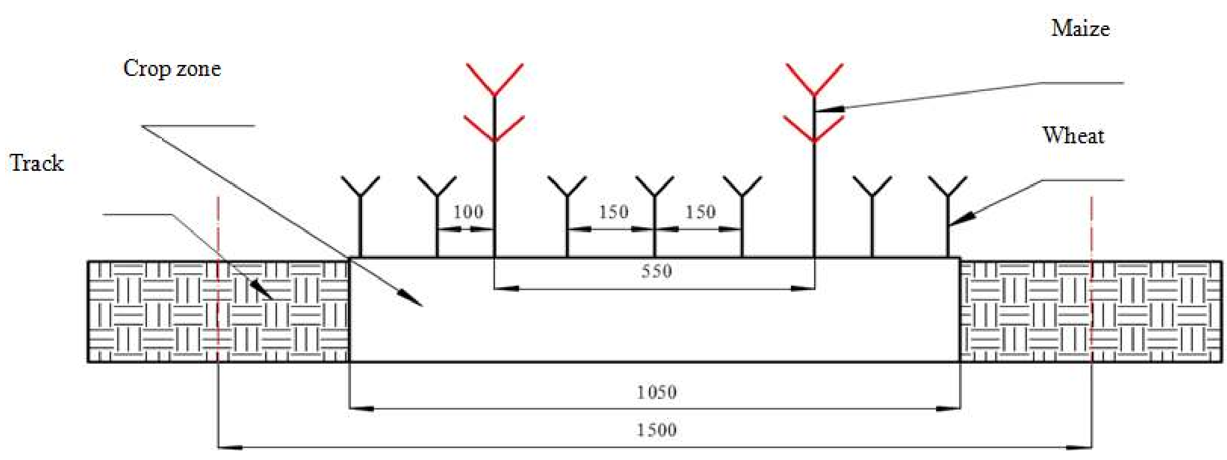

Fig. 1: Traffic lanes and crop layout for wheat and maize on NTCN (units, mm)

Soil bulk density: Soil samples were collected before force test. In each plot, one soil sample was formed by 6 sub-samples for soil bulk density. The spatially replicated samples were individually analyzed for each treatment. In each plot, six random soil samples were taken using a 54-mm-diameter steel core sampling tube, manually driven into a 50-cm depth. The soil cores were split into ten sections: 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40-45, 45-50 cm, respectively. These samples were then weighed when wet, dried at 105°C for 48 h and weighed again to determine bulk density.

Plant growth characteristics: The winter wheat plant samples taken at the jointing, booting and filling stages were oven dried at 65°C to constant weight and weighed to calculate plant dry weight. Summer maize plant samples were taken at harvest and dried at 65°C to constant weight and weighed to calculate plant dry weight.

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 4 replications. Seasonal Evapotranspiration (ET) for individual plots was determined for each growing season using soil water balance equation:

$$ET = P + I - \Delta W \quad (1)$$

where, ET was the evapotranspiration of the growing season, P was the total growing seasonal rainfall, I was the irrigation and ΔW was the soil water change (final minus initial) from planting to harvesting which was calculated by subtracting the total soil water content at 100 cm depth of soil profile. Total Water Use Efficiency (WUE) was calculated as the winter wheat yield (t/hm^2) divided by the growing season Evapotranspiration (ET).

Statistical analysis: Mean values and Standard Deviations (S.D.) were calculated. All data were subjected to analysis of variance using ANOVA to assess the effects of traffic management and tillage on the measured variables. When ANOVA indicated a significant F-value, multiple comparisons of annual mean values were performed by the Least Significant Difference method (LSD). The SPSS analytical software package (2003) was used for all of the statistical analyses.

RESULTS

Soil bulk density: After 2 years of experiment, controlled traffic treatment NTCN showed lower soil bulk density in 0-30 cm soil layer and with significant difference in 0-20 cm soil layer (p<0.05), shown in Table 1.

Table 1: Soil bulk density for each treatment and track (g/cm^3)

	0-10 cm	10-20 cm	20-30 cm	30-40 cm
NTCN	1.25^a	1.32^a	1.45^a	1.47^a
Track	1.45^b	1.48^b	1.53^a	1.49^a
NT	1.34^{ab}	1.43^b	1.50^a	1.48^a
CK	1.38^b	1.45^b	1.51^a	1.46^a
S.D. (total)	0.11	0.09	0.04	0.07
S.E. (total)	0.03	0.03	0.01	0.02

Means within the same column in the same soil profile followed by the same letters are not significantly different at p<0.05; S.D.: Standard deviation; S.E.: Standard error

Table 2: Winter wheat dry mass for treatments (g/10 plants)

	NTCN			
	Side row	Center row	NT	CK
Jointing	4.32^a	3.60^b	3.73^b	3.60^b
Filling	25.43^a	23.14^b	23.64^{ab}	23.32^b
Harvesting	32.35^a	26.67^b	27.85^b	26.83^b

Means within the same column followed by the same letters are not significantly different at p<0.05

In 0-10 cm soil layer, obvious soil compaction effect was observed due to wheel traffic, in which track had the highest value of soil bulk density. Controlled traffic treatments averagely reduced soil bulk density by 9.6%. Compared to CK, NTCN showed significantly lower value (9.3%) (p<0.05). Compared to NT, NTCN reduced bulk density by 6.7% without significant difference.

In 10-20 cm, significantly difference were observed between NTCN and both random traffic treatments (NT and CK), averagely reducing 9.2 (p<0.05).

As depth went, bulk density difference reduced, with slightly lower in 20-30 cm layer in NTCN, compared with NT and CK.

Random traffic in both conservation tillage and conventional tillage systems caused soil compaction in field.

Crop growth performance: Table 2 was the winter wheat dry mass after two years. Higher value was observed in NTCN, compared with NT and CK. Compared with CK, NTCN increased above ground dry mass by 10.0, 4.1 and 9.9% in jointing stage, filling stage and harvesting, respectively. And certain side row benefits were observed. Significantly higher values was observe in the side row of NTCN, 20.0% in jointing stage, 9.1% in filling stage and 20.6 at harvesting. Similar result was shown between NTCN and NT. Slightly higher value was got in NT, compared with CK, without significant difference.

For summer maize, the above ground dry mass for NTCN, NT and CK were 307.50, 258.05 and 256.12 g/plant, respectively (Fig. 2). NTCN showed significantly higher value than NT and CK (p<0.05). Compared with CK and NT, NTCN increased summer maize dry mass by 20.1 and 19.2%. NT showed slightly higher value than CK, without significant difference.

Table 3: Winter wheat yield for different treatments

	Position	Spike length/cm	Fertile spikelets	Kernels/spike	Thousand kernel weight/g	Yield/t/hm^2
NTCN	Side rows	8.8^a	16^a	34^a	44.87^a	4.7^a
	Center rows	8.4^a	15^a	31^b	42.67^b	
NT		8.5^a	15^a	32^{ab}	42.13^b	5.0^a
CK		8.4^a	15^a	31^{ab}	41.84^b	4.9^a

Means within the same column followed by the same letters are not significantly different at p<0.05

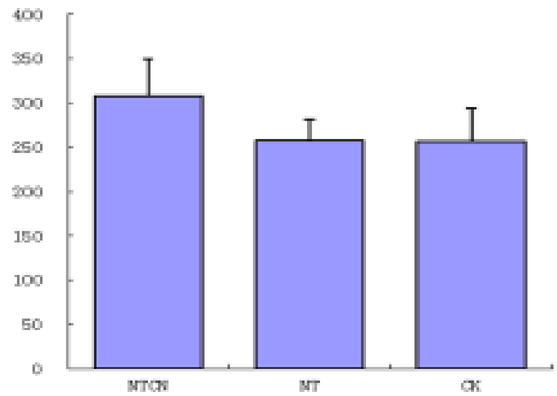

Fig. 2: Above ground dry mass for summer maize (g/plant)

Table 4: Summer maize yield for different treatments

	Spike length/cm	Kernel rows per spike	Kernel per row	Hundred kernel weight/g	Yield/t/hm^2
NTCN	20.3^a	13.5^a	38.3^a	31.37^a	7.5^a
NT	19.9^a	12.9^a	37.8^a	29.65^a	7.0^a
CK	19.8^a	13.0^a	37.3^a	29.35^a	6.9^a

Means within the same column followed by the same letters are not significantly different at p<0.05

Table 5: Annual yield and WUE for different treatments

	P (mm)	I (mm)	ET (mm)	Annual yield (t/hm^2)	Annual WUE (t/hm^2/mm)
NTCN	507.4	296.6	713	12.2^a	0.0171
NT	507.4	296.6	769	12.0^a	0.0155
CK	507.4	296.6	745	11.8^a	0.0159

Means within the same column followed by the same letters are not significantly different at p<0.05

Crop yield: Table 3 was the winter wheat yield after two years experiments. Certain side effect was observed in NTCN. The side row in controlled traffic had significantly higher yield component values in kernel per spike and thousands kernel weight, compared with NT and CK and the center row in NTCN (p<0.05). However, Due to the 30% of land occupation for permanent track in NTCN, the overall winter wheat was slightly lower than that of NT and CK. Similar values were observed in NT and CK.

Table 4 was the summer maize yield after two years. All yield component values were higher in NTCN. Consequently, higher yield was observed in NTCN, 7.1 and 8.7% higher than those of random traffic treatment NT and CK, without significantly difference.

Consequently, the deficit in wheat yield due to wheel track can be compensated by the increase of maize yield in one growing year. NTCN showed higher annual yield than NT and CK (Table 5).

DISCUSSION

Random traffic in both conservation tillage and conventional tillage systems caused soil compaction in field. Previous study (Seker and Isildar, 2000; Hamza and Anderson, 2005) showed that the first passes of tractor will cause surface soil compaction and this effect would be constraint to the surface soil layer. As experiment time was only 2 years, the soil compaction observed in NT and CK were only in 0-20 cm soil layer. While in controlled traffic systems, soil compaction can be avoided by permanently separating crop areas and traffic lanes, providing optimal conditions for crop growth in the nontrafficked zones between the traffic lanes. However, controlled traffic system did not illustrate profound advantage over CK on soil compaction amelioration, due to the short experiment time. This advantage will gradually build up along with time. Continuous controlled traffic system research in the dryland areas of Chinese Loess Plateau (Bai *et al*., 2009) and Australia have solid evidence on this result (Tullberg *et al*., 2007).

As the soil compaction was eliminated in the crop zone, better soil and water conservation were observed in the previous study (Hamza and Anderson, 2005; Gasso *et al*., 2013). However, due to the short experiment time, the advantage from soil compaction avoiding in crop zone cannot overcome the deficit from 30% field occupation by permanent track, for the narrow row crop winter wheat in this study. Along with the experiment time, the effectiveness of yield improvement can be further enhanced in controlled traffic system and the deficit will be further reduced and offset eventually. That was confirmed by Chen *et al*. (2008b) who reported more than 10% winter wheat yield increase for controlled traffic system after 8 years compared to random traffic system and similar results were observed in arid farming system in Australia (Tullberg, 2010; Gasso *et al*., 2013).

For summer maize, permanent track showed no adverse effect on the wide row production. The advantage of controlled traffic system on soil and water conservation was translated into better crop performance.

Consequently, the winter wheat yield deficit can be compensated by the summer maize yield increase, thus to achieve annual yield increase. It was indicated that the controlled traffic system can overcome the adverse effect of permanent track in the field and ensure the crop production annually, even with short experiment time. Similar results was also observed in the two year permanent raised bed system experiment in the North China Plain, conducted by He (2007), which reported annual crop yield increase for wheat-maize production by traffic control. As experiment time went, the effect of controlled traffic system on crop performance would be further enhanced. For the long run, the gradually improved soil in NTCN may compensate the winter wheat yield loss on track (Chen *et al*., 2008b; Bai *et al*., 2009). Combined with the obvious increase in summer maize, the advantage on yield increase will be further enhanced in controlled traffic system.

CONCLUSION

Controlled traffic system showed certain advantages in soil compaction and crop performance in the annual two crops region of North China Plain:

- Wheel traffic increased soil bulk density in the top soil layer. Controlled traffic system should certain potential on soil compaction amelioration.
- Controlled traffic system improved winter wheat and summer maize yield component by reducing soil compaction in crop zone.
- Even 30% of the field was occupied by the permanent track, controlled traffic still increased total annual yield by compensating yield loss in winter wheat from the yield benefit in summer maize.

Although these results were preliminary, it was indicated that controlled traffic is an improvement on the current conservation farming system in the North China Plain and may enhance its sustainable development. Further long-term research on the relationships between controlled traffic, soil structure, productivity and environmental conditions are needed to provide rational foundation for implementation of controlled traffic system for small and medium machine condition in China.

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