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Research Article

Effect of Traffic and Tillage on Agriculture Machine Traction and Fuel Consumption in Northern China Plain

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Abstract: Controlled traffic with conservation tillage can reduce soil compaction, thus to improve operation performance and fuel consumption of agricultural machine. Northern Chinese Plain is one of the main agricultural production bases with high level of agricultural mechanization. To explore the effect of wheel traffic on machine traction force and fuel consumption, three treatments were conducted: zero tillage with Controlled Traffic (NTCN), Compacted Treatment (CT) and traditional tillage system with random traffic (CK). Results showed that wheel traffic increased soil bulk density in the top soil layer in both fully compacted and random compacted plots. Controlled traffic system should certain potential on soil compaction amelioration. Controlled traffic system reduced traction force on winter wheat planting by 9.5 and 6.3%, compared with fully compacted treatment and random compacted treatment. Controlled traffic system reduced fuel consumption in both winter wheat planting and sub soiling (significantly), compared with fully compacted treatment and random compacted treatment. Results indicated that controlled traffic system had certain advantages in soil compaction and fuel consumption in this region and with high application potential.

Keywords: Controlled traffic, fuel consumption, soil compaction, traction force

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 ha 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 (He *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).

The region is characterized by high agricultural machinery equipped quantity (6-10 kw/hm^2), which is far above the national average. Due to the high rate on agricultural mechanization, 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). Degradation of the sub-surface soil by wheel traffic induced compaction can also reduce soil permeability, limit the benefits of residue cover and no-tillage and generate major practical problems in conservation tillage (Tullberg *et al*., 2007). Random traffic caused 60% of the ground area being trafficked by wheel using minimum tillage systems and 100% for zero tillage systems (Kingwell and Fuchsbichler, 2011). Soil compaction has adverse effects on soil properties and crop growth. Due to soil compaction, additional effort was required to disturb soil, which significantly increased machine working resistance and fuel consumption, therefore, reduced the economic benefits of conservation tillage (Hamza and Anderson, 2005).

It is well known that optimum conditions for crop production, that is soft, friable and permeable soil, are quite unsuitable for efficient traffic and traction and vice versa. Wheel traffic increases soil strength and the draught requirement of subsequent tillage, while tillage reduces soil strength and the efficiency of subsequent traction (Tullberg, 2000). Wheel traffic effects on crops can be avoided in controlled traffic farming, where crop areas and traffic lanes are permanently separated to provide optimal conditions for crop growth (not trafficked) and traction (compacted). The penalties of wheel traffic compaction and benefits of controlled traffic have been demonstrated by a number of researchers, including Tullberg (2000, 2010), Gasso *et al*. (2013) and Shama *et al*. (2011).

Based on the controlled traffic system on small and medium tractor, series of controlled traffic research has been done on its energy saving character. Huang *et al*. (2007) reported significant reduction on opener

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working resistance. Li *et al*. (1999) and Chen *et al*. (2010) observed significant lower machine rolling resistance in controlled traffic system, which result in obvious fuel saving. Controlled traffic system research in the northern China Plain showed that controlled traffic system reduced annual working fuel consumption by 28.6% (13.53 L/hm^2) (Chen *et al*., 2012) and consequently reduced exhaust gas emission by 20.0, 18.7 and 20.7% in sub soiling, maize and wheat planting, respectively (Chen *et al*., 2009).

The object of this study was to assess the effect of tractor and implement wheels on the traction power and traction force and to use these data to quantify the impact of field traffic on the power requirements of tillage and operations.

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: To explore the effect of wheel traffic on machine traction force and fuel consumption, three treatments were conducted: zero tillage with controlled traffic (NTCN), Compacted Treatment (CT) and traditional tillage system with random traffic (CK).

For NTCN, the layout of the crop and permanent traffic lanes in controlled traffic treatments NTCN and STCN were shown in Fig. 1, designed according to the characteristics of the local tractors and planters. 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.

For CT, the whole plot area was compacted by TL 654 tractor (48 kw) once to simulate the fully compacted treatment.

For CK, no restriction was conducted, in which agricultural machines were randomly wheeled on the plots.

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.

Traction force: The traction force was measured by CTM 2002 B type agriculture comprehend test device. This device consists of fuel sensor, velocity sensor and traction force sensor. The system configuration was showed in Fig. 2. Two tractors were included in the test. The traction force was connected the two tractors, in which the agriculture machine was mounted on the second tractor. During the test, the second tractor was put on neutral position, the first tractor draw the second one. The agriculture machine dig into the soil on actual normal working condition, the second tractor was drawn by the first one, the collected traction force was the actual traction Force (F) and the traction power stored in the main control box of the device.

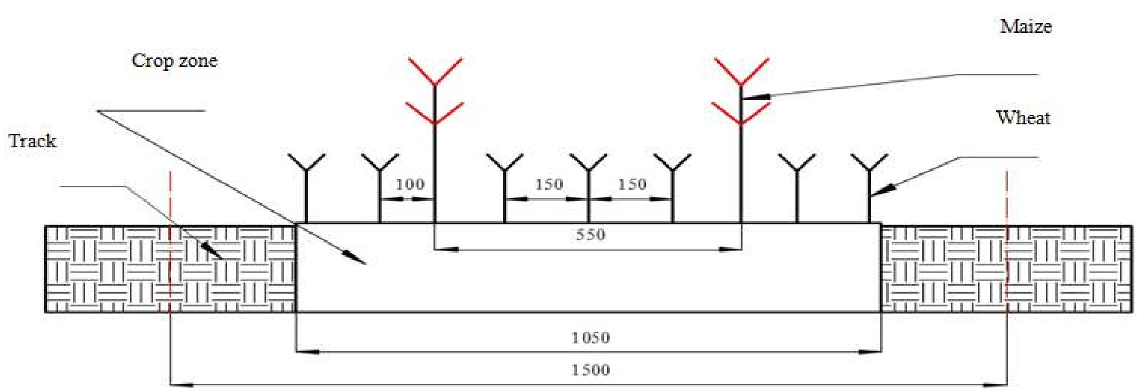

Fig. 1: Traffic lanes and crop layout for wheat and maize on NTCN (units, mm)

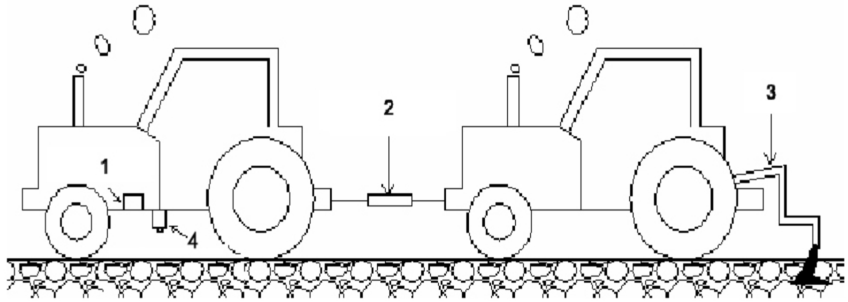

Fig. 2: Traction force measurement of agricultural machine drafted by tractor
1: Fuel sensor; 2: Force sensor; 3: Machinery; 4: Velocity sensor

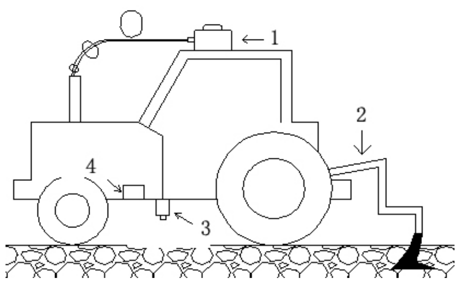

Fig. 3: Fuel consumption test of agricultural machine
1: Emission tester; 2: Machine; 3: Velocity sensor; 4: Fuel sensor

The mounted machine was 2BMFS-2/7 no-till wheat-maize seeder, matched with a 48 kW tractor, with the total weight of 500 kg. The seed planting depth was 4-5 cm and fertilizer depth was 9-10 cm. During the test, operation kept constant speed. For each test, the effective operation distance was beyond 80 m. Six replications were conducted for each treatment.

Fuel consumption: The fuel consumption was measured by CTM 2002B type agriculture comprehend test device. The test system configuration was showed in Fig. 3. The fuel consumption test was done in sub-soiling and wheat planting.

For sub-soiling, the sub-soiler was 120 kg, with 30 cm working depth and 1.4 m working width. For wheat planting, the 2BMFS-2/7 no-till wheat-maize seeder was used. During the test, operation kept constant speed. For each test, the effective operation distance was beyond 80 m. Six replications were conducted for each treatment.

Actual fuel consumption was derived from the fuel consumption per hour and fuel consumption per 100 km data in the CTM2002B test device. The fuel consumption can be calculated by the following equations.

Fuel consumption calculated from fuel consumption per hour was in the formula (1):

$$F_{ca} = \frac{F_{ch}}{A} = \frac{F_{ch} \times 10000}{v \times B \times 1000} = \frac{F_{ch} \times 10}{v \times 1.5} \quad (1)$$

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

Soil depth (cm)	CT	CK	Track	NTCN
0-5	1.294	1.183	1.297	1.162
5-10	1.386	1.346	1.409	1.202
10-15	1.347	1.361	1.378	1.321
15-20	1.519	1.349	1.379	1.304
20-25	1.391	1.394	1.406	1.377
25-30	1.421	1.378	1.351	1.322
30-35	1.418	1.384	1.377	1.341
35-40	1.440	1.459	1.397	1.277
40-45	1.389	1.392	1.395	1.290
45-50	1.385	1.412	1.381	1.229

In which F_{ca} was fuel consumption per hectare (L/hm^2), F_{ch} was fuel consumption per h (L/h), A was working area (m^2), B was working width per operation (1.5 m), v was velocity (km/h).

Fuel consumption calculated from fuel consumption per 100 km was shown in formula (2):

$$F_{ca} = \frac{F_{c100}}{A} = \frac{F_{c100} \times 10000}{100 \times B \times 1000} = \frac{F_{c100}}{15} \quad (2)$$

In which, F_{c100} was fuel consumption per 100 km (L/100 km).

The fuel consumption per hectare can be calculated from the average value for formula (1) and (2).

RESULTS

Soil bulk density: Soil bulk density in 0-50 cm soil layer was shown in Table 1. Controlled traffic treatment NTCN showed the lower soil bulk density value in the whole 50 cm soil layer, without significant difference. In the track of NTCN, the bulk density was higher in 5-10 cm layer, compared with CT and CK. Obvious soil compaction was observed in compacted treatment CT, in which the highest soil bulk density was in 15-20 cm soil layer. CT, CK and track showed similar value.

Traction force: Traction force was measured for winter wheat planting, shown in Fig. 4. The average traction force for NTCN, CT and CK were 5210, 5707 and 5536 N, respectively. Compared with compacted treatment CT, NTCN reduced traction force by 9.5%, without

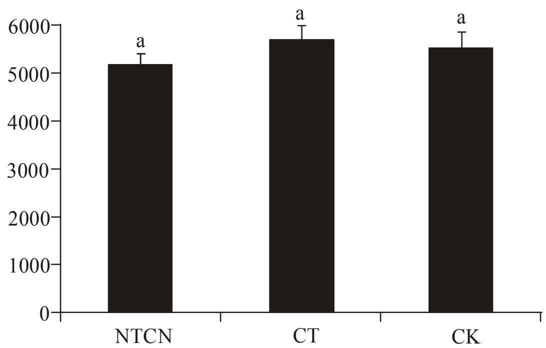

Fig. 4: Traction force t in winter wheat planting/N

Table 2: Fuel consumption at wheat planting and sub-soiling for different treatments (units, L)

	Wheat planting			Sub-soiling		
	F_{ch}	F_{c100}	F_{ca}	F_{ch}	F_{c100}	F_{ca}
NTCN	4.14[a]	225.3[a]	15.40[a]	5.57[a]	347.9[a]	23.21[a]
CT	4.39[a]	231.5[a]	15.85[a]	6.50[b]	393.2[b]	27.55[b]
CK	4.57[a]	238.7[a]	15.97[a]	5.81[a]	358.2[a]	24.05[a]

Values in the same column with the same letter are not significantly different at p<0.05

significant difference. Compared with random traffic treatment CK, NTCT reduced the value by 6.3%. CT showed slightly higher value than CK (3.1%).

Fuel consumption: Table 2 was the fuel consumption at wheat planting and subsoiling for NTCN, CT and CK. At wheat planting, CK showed highest value in both hourly and 100 km fuel consumption, while NTCN showed the lowest value. Consequently, the average fuel consumption per hectare for CK was 3.7% higher than that of NTCN. CT was 2.9% higher than NTCN. But no significant difference was observed among the three treatments.

For subsoiling, CT showed the highest value in fuel consumption, with significant difference with CK and NTCN. For hourly and 100 km fuel consumption, NTCN reduced by 16.7 and 11.9% and CT reduced by 13.0 and 9.8%, compared with CT. Therefore, the average fuel consumption per hectare were significantly higher than CK (14.6%) and NTCN (18.7%) ($p<0.05$). CK was 3.6% higher fuel consumption than NTCN, without significant difference.

DISCUSSION

Due to the wheel traffic, bulk density increased in nontrolled traffic treatments and track. Even with one complete compaction in the field, CT showed higher soil bulk density in 20 cm soil layer. This result was consistent with Seker and Isildar (2000) and Hartmann *et al*. (2012) that the first passes of tractor will cause surface soil compaction. The soil bulk density should quite similar value between CT and track in the top soil layer. Controlled traffic system can reduce soil bulk density in crop zone than CK and CT, due to the using of permanent traffic lane. 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 dry land areas of Chinese Loess Plateau (Chen *et al*., 2008; Bai *et al*., 2009) and Australia have solid evidence on this result (Tullberg *et al*., 2007).

As different character on soil compaction, traction force showed different pattern among the three treatments. Compared with CK and NTCN, fully compacted treatment CT should higher traction force in wheat planting, as the whole plot had been completely compacted. The higher bulk density in the 0-10 cm soil layer (Table 1) in CT transferred into higher traction force. This can be explained by the previous study on controlled traffic system in annual two-crop region by Huang *et al*. (2007) illustrated that soil compaction increased opener working resistance, thus the traction force increased significantly after several years of experiments.

Random traffic treatment CK also showed higher traction force, compared with controlled traffic treatment NTCN. Controlled traffic treatment not only reduced opener working resistance in crop zone, but also has profound advantage in traffic due to the permanent traffic lane. Tullberg (2000) reported 30% of draught reduction due to the traffic penalty. Chen *et al*. (2010) pointed out that controlled traffic system can significantly reduce rolling resistance through the permanent track and result in significantly lower traction force. As the short experiment time, controlled traffic system just show some advantage in permanent track firmness and crop zone softness, thus, CK only showed limited disadvantage on traction force. Continuous conventional tillage and random traffic will result in significant soil compaction in the tillage layer and this compaction may expand to the whole field area, which would increase soil working parts resistance. And due to the conventional tillage in CK, surface soil is soft, which increased rolling resistance, may cause more than 50% of tractor power used for traffic (Tullberg *et al*., 2007). Therefore, traction force will be further increased in conventional tillage system for long run.

As traction force increased in compacted plots, both fully compacted CT and random traffic CK, higher fuel consumption was induced in both winter wheat planting and sub soiling. As the winter wheat planting working depth was 10 cm, both soil bulk density and traction force were not significantly higher in CK and CT, controlled traffic treatment illustrated in low fuel consumption. Even this effect was not obvious, but the results showed the potential of fuel consumption on controlled traffic system. Previous study conducted by Chen *et al*. (2012) confirmed the energy saving capacity after years of controlled traffic system experiment, which reported 28.6% of fuel reduction in controlled traffic system compared with non-controlled traffic system. Soil compaction effect showed obviously on sub-soiling fuel consumption. As shown in Table 1 fully compacted treatment CT showed highest soil compaction in 15-20 cm soil layer, which was in the range of sub soiling depth (30 cm). Thus, significant higher fuel consumption was induced in CT, as fuel consumption was positive related to soil bulk density (Du and Zhou, 1999).

Even with short experiment time, soil compaction and its potential on consequent traction force and fuel consumption were observed in controlled traffic and non-controlled traffic system. Controlled traffic system showed certain benefits on traction force reduction and energy saving. The capacity of controlled traffic system on traction force and fuel consumption reduction can be further enhanced through permanent firm traffic lane and un-compact crop zone. Further research should be conducted on the systematic draught and energy consumption, to reveal its advantage in energy saving, thus to promote its application in this area.

CONCLUSION

Controlled traffic system showed certain advantages in soil compaction and fuel consumption in the annual two crops region of Northern Chinese 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 reduced traction force on winter wheat planting by 9.5 and 6.3%, compared with fully compacted treatment and random compacted treatment.
- Controlled traffic system reduced fuel consumption in both winter wheat planting and sub soiling (significantly), compared with fully compacted treatment and random compacted treatment.

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REFERENCES

Bai, Y.H., J. He, H.W. Li, Q.J. Wang, H. Chen, N.J. Kuhn, H. Hikel, F. Chen and Y.S. Gong, 2009. Soil structure and crop performance after 10 years of controlled traffic and traditional tillage cropping in the dryland loess plateau in China. Soil Sci., 74: 113-119.

Chen, H., Y.L. Yang, H.W. Li, 2009. Effect of controlled traffic with conservation tillage on tractor exhausting gas emission in the field. J. Agr. Mech. Res., 31(12): 208-211, (In Chinese).

Chen, H., W.W. Wu, X.T. Liu and H.W. Liu, 2010. Effect of wheel traffic on working resistance of agricultural machinery in field operation. T. Chin. Soc. Agric. Mach., 41(2): 52-57, (In Chinese).

Chen, H., Y.H. Bai, Q.J. Wang, F. Chen, H.W. Li, J.N. Tullberg, J.R. Murray, H.W. Gao and Y.S. Gong, 2008. Traffic and tillage effects on wheat production on the Loess Plateau of China: 1. Crop yield and SOM. Aust. J. Soil Res., 46: 645-651.

Chen, H., Y.L. Yang, J. He *et al*., 2012. Effect of wheel traffic on fuel consumption of agricultural machinery in field operation. T. Chin. Soc. Agric. Mach., 43(2): 37-42, (In Chinese).

Du, B. and X.X. Zhou, 1999. Energy saving of controlled traffic tillage. J. China Agr. Univ., 4(2): 63-66, (In Chinese).

Gasso, V., Claus A.G. Sørensen, F.W. Oudshoom and O. Green, 2013. Controlled traffic farming: A review of the environmental impacts. Eur. J. Agron., 48: 66-73.

Hamza, M. and W.K. Anderson, 2005. Soil compaction in cropping systems: A review of the nature, causes and possible solutions. Soil Till. Res., 82: 121-145.

Hartmann, P., A. Zink, H. Fleige and R. Horn, 2012. Effect of compaction, tillage and climate change on soil water balance of Arable Luvisols in Northwest Germany. Soil Till. Res., 24: 211-218.

He, J., Q.J. Wang, H.W. Li, L.J. Liu and H.W. Gao, 2009. Effect of alternative tillage and residue cover on yield and water use efficiency in annual double cropping system in North China plain. Soil Till. Res., 104(1): 198-205.

He, J., H.W. Li, R.G. Rasaily, Q.J. Wang, G.H. Cai, Y.B. Su, X.D. Qiao and L.J. Liu, 2011. Soil properties and crop yields after 11 years of no tillage farming in wheat-maize cropping system in North China plain. Soil Till. Res., 113(1): 48-54.

Huang, H., X.Y. Wang, H.W. Li, H. Chen and X. Zhang, 2007. Experimental investigation on energy saving of controlled traffic conservation tillage. Trans. CSAE, 23(12): 140-143, (In Chinese).

Kingwell, R. and A. Fuchsbichler, 2011. The whole-farm benefits of controlled traffic farming: An Australian appraisal. Agr. Syst., 104(7): 513-521.

Li, R.X., S.Y. Chi, Y. Shi *et al*., 1999. Soil compaction and tillage energy consumption cased by tires of agricultural machines. T. Chin. Soc. Agric. Mach., 30(2): 12-16, (In Chinese).

Li, L.L., G.B. Huang, R.Z. Zhang, B. Bill, L. Guangdi and Y.C. Kwong, 2011. Benefits of conservation agriculture on soil and water conservation and its progress in China. J. Integr. Agric., 10(6): 850-859.

Seker, C. and A.A. Isildar, 2000. Effects of wheel traffic porosity and compaction of soil. Turk. J. Agric. For., 24: 71-77.

Shama, P., V. Abrol and R.K. Shama, 2011. Impact of tillage and mulch management on economics, energy requirement and crop performance in maize-wheat rotation in rainfed subhumid inceptisols, India. Eur. J. Agron., 34(1): 46-51.

Sun, H.Y., X.Y. Zhang, S.Y. Chen, D. Pei and C.M. Liu, 2007. Effects of harvest and sowing time on the performance of the rotation of winter wheat-summer maize in the North China plain. Soil Till. Res., 25: 239-247.

Tullberg, J.N., 2000. Wheel traffic effects on tillage draught. J. Agr. Eng. Res., 75: 375-382.

Tullberg, J.N., 2010. Tillage, traffic and sustainability: A challenge for ISTRO. Soil Till. Res., 111(1): 26-32.

Tullberg, J.N., D.F. Yule and A.D. McGarry, 2007. Controlled traffic farming from research to adoption in Australia. Soil Till. Res., 97: 272-281.