Effect of Tillage Machinery Traffic on Soil Properties, Corn Root Development and Plant Growth

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ABSTRACT

Tillage traffic is one of the major problems facing modern agriculture. Overuse of machinery, intensive cropping, and short crop rotations, intensive grazing and inappropriate soil management leads to soil compaction. This experiment was conducted on a clay loam soil to study the effect of tillage machinery traffic (TMT) on soil properties, corn root development and plant growth. Tillage machinery (TM) used in experiment was wheel tractor (TW), crawler tractor (TC), and a no compaction (C).

The results showed highly significant differences between treatments. The data on final emergence count did not show significant differences between treatment means when tested at $P \leq 0.05$ levels. However, plant height showed significant differences at $P \leq 0.05$ and $P \leq 0.01$ levels when they were measured at 2, 4, 6, 8 and 10 weeks and at the time of harvest. The TW1, TW2, and TW3 produced taller plants than TC1, TC2 and TC3. The data on root length and density showed significant differences between treatment means at $P \leq 0.05$ and $P \leq 0.01$ levels, with TW1 and TW2 produced the best results while TC3 showed the lowest results.

The machinery passes (MP) significantly influenced growth parameters and gave lower dry matter yield and the other yield components. The soil bulk density, soil resistance, and soil moisture generally increased under machinery passes except under TC3 and TW3 treatments which showed the lowest performance.

Keywords: Corn production, bulk density, tillage traffic, root development, plant growth.

1. INTRODUCTION

Frequent traffic of machinery and equipment, in irrigated field causes a breakdown of soil structure in the topsoil layer, and considerable compaction of the lo wer layers. As a result, it is difficult to prepare a good seedbed which affects germination and consequently irregular stands are obtained. Through the years, the intensive use of the agricultural machinery without moisture control has been causing dissem ination of the soil compaction (Hill and Meza - Montalvo, 1990; Muller et al., 1990), consequently productivity of land in such areas is significantly affected (Barnes et al., 1971; Gupta et al., 1985; Larson et al., 1989; Dias Junior and Miranda, 2000; Hor n et al., 2000). Due to soil compaction root penetration and development becomes pretentious. The root torpor pressure is insufficient to overcome the mechanical resistance of the soil (Gysi, 2001; Smucker and Erickson, 1989; Bicki and Siemens, 1991; Durr and Aubertot, 2000, Arvidsson, 2001; Ishaq et al., 2001) (Arvidsson, 2001; Dauda and Samari, 2002), which result in poor plant emergence and growth ultimately crop yields are decreased. In tropical conditions, the soil compaction process occurs due to till age and harvest operations carried under wetter than the optimal conditions required for wheel movement; in pasture areas, due to the excessive trampling of the cattle (Kondo and Dias Junior, 1999) and in forest areas, due to the traffic of the harvest operations and wood transport under inadequate soil water conditions (Dias Junior et al., 1999). . Thus, in agriculture, application of stress greater than the pre -compression stress should be avoided (Gupta et al., 1989; Lebert and Horn, 1991; Dias Junior, e t al, 1995; Defossez and Richard, 2002). Corn yields are undoubtedly affected by field characteristics and operations such as soil strength, compaction, soil water, tillage and residue practices, time of field operations and soil fertility, which altogethe r influence emergence, root development and nutrient availability. Residues from the previous year left on the soil surface can influence subsequent yields. Therefore, changes in soil physical properties as a function of agricultural machinery traffic is important for root growth and also to assess the load support capacity of the soil.

2. MATERIALS AND METHODS

2.1. Site Description

Study was carried out on a 2.0 ha area during the growing season of 2006. The site is located at the Jiangpu experimental farm of Nanjing Agricultural University, Jiangsu Province of China which is located at Latitude of 32º 3' 4.96" N, and Longitude of 118º 36' 38.78" W). Prior to establishment of this experiment, the site has remained under continuous corn (*Zea mays* L.), since 2002. Surface drains were installed during 2000 within each plot. The soil's organic C, total N, available P, exchangeable K, were 11.34 g kg^{-1}, 27.88 mg kg^{-1}, 13.57 mg kg^{-1} and 31.4 mg kg^{-1}, respectively. The monthly meteorological data was collect ed and is shown in Table 1.

Table1. Meteorological data for the period January to July 2006.

	January	February	March	April	May	June	July
Total rainfall (mm)	117.3	60.2	10.6	113.4	96.9	112.1	191.1

Average temperature(°C)	3.5	4.1	11.2	16.7	20.9	26.2	28.3
Average relative humidity (%)	81	76	65	70	69	73	81
Wind Velocity (m/s)	2.6	3.0	2.7	2.8	2.8	2.3	2.5

Source: Meteorological Station Jiangpu Nanjing Jiangsu Province of China.

Six treatments that included; Crawler TC1 (one pass), TC2 (two passes), and TC3 (four passes); Wheel tractor TW1 (one pass), TW2 (two passes), and TW3 (four passes) were replicated three times in a randomized complete block design (RCBD). The parameters such as; soil structure, bulk density, soil moisture content, and soil strength were studied.

2.2 Instruments and Machines Used

A two wheel driven (2D) Tractor Model 1995 (power 35.3 kW, weight 2500 kg) and a Crawler Tractor Model 1982 (power 50 kW, weight 4500 kg) Manufactured by Shanghai Tractor International Combustion engine Corporation, R,P. China (Fig.1 & 2) were used in this study. The other equipment included core soil sampler, soil sample containers, balance, penetrometer and an oven were used.

Fig.1 wheel tractor TW

Fig.2 crawler tractor TC

2.3. Experimental Design and Treatment Applications

The experiment was laid out in a randomized complete block design with a factorial arrangement of treatments consisting of (a two wheel driven tractor and crawler tractor) and three pass levels (one pass, two passes, and four passes), replicated in three blocks, resulting in a total of 18 plots. Each plot measured 4 m X 120 m. The plots were separated by 1 m wide buffer strips. Wheel tractor (TW) with rubber tires and Crawler tractor (TC) with chain were used after rotary tillers operation before planting.

Corn seed (Baiyu109 variety) was planted using a planter (double-disk seed and fertilizer opener) with a density of 141751 seeds ha^{-1} (45 kg^{-ha}). A compound fertilizer (N 8%, P 8%, and K 9%) at a rate of 750 kg ha^{-1} was applied with the seed at planting. N, P and K application rates were selected on the basis of soil tests (for plant extractable K and P) using the Melich III test, which is the standard fertilizer test in Jiangsu Province of China. Nitrogen 46 (urea only 450 kg ha^{-1}) was applied 2–5 weeks later, and at the 8th week of sowing second dose at 300 kg ha^{-1} was applied.

2.4 Herbicide

After three weeks of planting a commonly used herbicide Thifensul Furon-methyl was applied at a rate of 1350 g^{-ha}.

2.5 Soil Sampling

The core samples were randomly taken at each sampling location to determine the bulk density using a core sampler (0.5 cm diameter by 0.5 cm height). Three sub-samples were taken, from wheel tracked and three from chain tracked plots. The soil cores were taken at 0–5 cm, 5–10 cm, and 10 – 15 cm depths. The bulk density measurements were made at different times during the growing season depending on the objectives, convenience and climatic conditions.

2.6 Crop Data Collection

Emerging seedlings were counted at 10 randomly selected rows in each plot in 1-m long sections. The seedlings were counted between 2 and 4 weeks following planting. Plant significant difference were obtained after 2, 4, 6 and 8 weeks and at the time of harvest., The dry matter yield was determined by hand harvesting six randomly selected corn plants in an experimental plot. Since there wasn't any differentiation between treatments at the time of harvest hence, the maturity differences between corn treatments was beyond the scope of this study. During harvest, the stalks and cobs were collected and counted, and stored to be dried later. After drying at 70 °C for a period of 2 to 3 days, the Stover (stalks, leaves and husks) from each sample location were weighed and a sub-sample was collected and kept for drying at 70 °C at least for 48 hours. Once the Stover sub-sample was dried it was reweighed and the Stover yield was determined. Dry matter yield was determined by adding both Stover and grain yield.

2.7 Statistical Analyses

The analysis of variance (ANOVA) was done using depth as a repetition factor to evaluate effects of depth on bulk density. For each depth, treatment differences were evaluated using the Student–Newman–Kuels (SNK) test at a 0.05 level of probability.

Corn emergence data and dry matter yields were analyzed for each sampling period using the general linear model Analysis of Variance. The SNK test at 0.05 level of pr obability was used to determine treatment differences. The entire analyses were performed using a SAS Statistical Software.

3. RESULTS

3.1. Bulk Density

Dry bulk density values mostly varied at the 0–15 cm depth and fluctuated between 1.28 and 1.67 g cm^{-3} (Table 2). Bulk densities varied at the deeper depth, bulk density values ranged between 1.48 and 1.57g cm^{-3}. Some variations were likely due to different timings of soil sampling.

Average bulk density was lower at 0–5 cm than in the underlying layer. Differences in bulk density between the shallow and deeper depths were quite clear, with higher bulk density values in the deeper layer. A significant depth–compaction interaction was found in (TW) and (TC), which is attributed to the tillage operations which predominately take place in the top soil layers (Table 3).

Table 2. Dry bulk density (ρ_b) prior to experiment. (g/cm^3)

Observation	0-5 cm depth	5-10 cm depth	10-15 cm depth
1	1.31	1.38	1.68
2	1.38	1.68	1.49
3	1.77	1.65	1.55
Average	1.48	1.57	1.57

Table 3. Average dry bulk density (ρ_b) after compaction operations. (g/cm^3)

Depth (cm)	C*	TW1	TC1	TW2	TC2	TW3	TC3
0-5	1.28	1.40	1.44	1.38	1.42	1.50	1.54
5-10	1.41	1.43	1.51	1.44	1.65	1.51	1.53
10-15	1.49	1.52	1.52	1.51	1.61	1.643	1.67

TW = Wheel tractor
TC = Crawler tractor
C* = no compaction

3.2. Corn Emergence Rates

Emergence showed significant interaction between treatments. Generally, TW3 and TC3 showed slower emergence percent than the other treatments. TW2 had the highest emergence rate (Table 4) while, TC3 had the lowest emergence rate per square meter. TW treatments had a higher emergence than TC, which was again attributed to compaction Table 5.

Table 4. Plant emergent rate (%)

Dated	TW1	TC1	TW2	TC2	TW3	TC3	C*
2006.4.20	47.85	42.14	54.28	45.71	35.71	32.86	72.14

TW = Wheel tractor
TC = Crawler tractor
C* = no compaction

Table 5. Number of plants emerged / m^2

S.No.	C*	TW1	TC1	TW2	TC2	TW3	TC3
1	11	8	6	7	7	10	9
2	12	8	9	10	9	5	6
3	11	7	8	10	10	6	6
4	10	9	9	9	5	3	4
5	8	7	7	6	4	4	3
6	9	6	5	7	3	2	4
7	7	5	3	8	5	6	2
8	12	6	4	6	4	4	3
9	11	5	3	6	6	7	4
10	10	4	5	7	7	3	5
Average	10.1	6.7	5.9	7.6	6.4	5	4.6

3.3 Plant Status

3.3.1 Effect on final emergence count: The treatments did not show any high significant differences when tested at $P \leq 0.05$ level as shown in Table 6.

3.3.2 Effect on plant height: Differences were obtained between plant heights measured during 4, 6,8,10 weeks and at the time of harvest time. The TW1, TW2, and TW3 produced taller plants as compared to than TC1, TC2 and TC3; however, plant heights were shorter under TW3 and as compared to rest of the treatments (Table 7). Figure 3 and 4 shows the corn crop grown in the field both under wheel (TW) and crawler (TC) tractors.

3.3.3 Effect on root length and root density: Differences were obtained between plant root measured during 4, 6,8,10 weeks and at the time of harvest time. TW1 and TW2 showed the best results while, TC2 showed the lowest results (Table 7). The differences in root development are shown in Figure 5 and 6. The data were taken during 8th week of sowing.

Table 6. Field traffic effects on plant emergent rate

ANOVA

Treatments	Source of Variation	SS	DF	MS	F Value	P Value
C VsTW1	Between Groups	64.8	1	64.8	24.60759	0.000101
	Within Groups	47.4	18	2.633333		
C Vs TC1	Between Groups	88.2	1	88.2	22.11142	0.000178
	Within Groups	71.8	18	3.988889		
C Vs TW2	Between Groups	31.25	1	31.25	11.89218	0.002866
	Within Groups	47.3	18	2.627778		
C Vs TC2	Between Groups	84.05	1	84.05	21.3385	0.000213
	Within Groups	70.9	18	3.938889		
C Vs TW3	Between Groups	130.05	1	130.05	31.25367	2.63E-05
	Within Groups	74.9	18	4.161111		
C Vs TC3	Between Groups	151.25	1	151.25	44.41272	2.98E-06
	Within Groups	61.3	18	3.405556		

Fig.3 Crop planted under TW2

Fig.4 Crop planted under TC2

Fig.5 Root development in TW2

Fig.6 Root development TC2

Table 7. Average Plant height and root development (cm)

S.NO	TW1		TC1		TW2		TC2	
WEEK	R.L	P.H	R.L	P.H	R.L	P.H	R.L	P.H
2	2.7	14.3	3.5	12.4	2.4	8.5	2.4	10.3
4	14.2	17.3	13.7	16.3	11.6	15.3	13.2	14.3
6	15.3	58.1	14.6	50.6	12.1	48.3	13.1	47.6
8	17.4	114.2	16.8	113.9	13.3	114.8	13.6	111.3
10	18.0	188.1	17.6	165.8	14.1	166.7	13.2	173.5
Harvest	22.65	215.67	18.98	211.67	24.30	230	20.29	210

S.NO	TW3		TC3		C	
WEEK	R.L (cm)	P.H (cm)	R.L (cm)	P.H (cm)	R.L (cm)	P.H (cm)
2	2.31	11.5	1.73	8.2	2.3	12.4

4	11.13	10.6	10.5	13.0	13.8	14.9
6	13.92	47.9	12.7	45.0	16.0	64.3
8	14.3	100.0	14.2	92.3	19.4	118.5
10	12.6	126.3	11.4	115.0	21.0	200.3
Harvest	27.79	209	25.05	203.33	26.40	249.33

R.L = Average Root length (cm)

P.H = Average Plant height (cm)

3.3.4 Dry matter: Average dry matter yields were affected by traffic compaction. The lowest yields (14.208 tones ha^{-1}) were observed at TW3 while the highest yields (34.399 tones ha^{-1}) were recorded at C treatment (Table 8). The combination of two passes under TW2 and TC2 treatments had comparably higher dry matter yields than TW1, TC1, TW3 and TC3 treatments. The soil texture and soil drainage characteristics were consistent within individual plots.

Lower emergence rates did not translate into lower yields in TW3 and TC3. There was a significant tractor × passes interaction, where TW3 and TC3 had a significantly lower total dry matter yield than TW1, TC1, TW2, and TC2 (Table 8). The climatic conditions of 2006 were wetter than normal; thus, less warming and evaporation of water from these sites may have contributed to their lower yield. TC has a smaller total dry matter yield than other treatments. This was attributed to difficulty in seeding through residue from the previous years and the large amount of precipitation received 2–3 days before planting that created a poor seedbed conditions.

Table 8. Average dry matter yield (tones^{-ha})

S.No.	C*	TW1	TC1	TW2	TC2	TW3	TC3
1	40.444	24.707	23.307	34.399	31.387	14.208	19.074

C*= no compaction

4. DISCUSSION

Results of this study reveal that tillage had a greater influence on bulk density of the sandy loam soil. Similar results have been reported in other studies; for example, (Kushwaha et al. 2001), compared the effects of no-till, conventional tillage and residue practices, found that CTNR had a significantly lower bulk density (1.27 g cm^{-3}) than NTR (1.40 g cm^{-3}) on a sandy loam site. Da Silva et al. (2001) found a significantly higher bulk density in TC; the bulk density varied from 0.96 to 1.71 Mg m^{-3} on a loam soil. Kushwaha et al. (2001) observed that tillage practices had the largest impact on bulk density. The tillage practices have also affected the emergence, growth and the dry matter yield. In a study conducted in Northern New York Cox et al. (1990) slow emergence of corn plants. They further pointed that the emergence differences did not necessarily translate into lower total dry matter yield, but climatic conditions over the entire season could have affected the total yield. Under drier than average conditions during a 20-year study, noticed that corn yields were greater, probably because of the higher amount of soil moisture held in plots where compaction is reasonable.

Kelvin et al., (2001) conducted research in sandy soil by rubber tracked and tired vehicles and found that heavy vehicle effects penetration resistance after more discriminating indistinguishing soil physical changes among the trafficked and un trafficked treatments than bulk density.

Ruijun Qin et al. (2004) compared the results of root length, density, length, and mean root diameter under different tillage systems and found that under no tillage and conventional tillage the root length, diameter was higher in upper soil layer (0-5 cm), similar from (5-10 cm) and lower from (10-30 cm).

Chaudhry and Sandhu (1983) studied the impacts of compaction and observed that the compacted soil restricts the root development which effects the yield.

Tsimba et al., (2002) compared tillage practices and partial tillage disrupts root restricting consolidated soil zones and improve rooting capacity-disruption tillage increase costs of farm operations because of need for more powerful tractors and greater fuel use.

Chan (1992) observed that soil compaction significantly affects crop quality and the yield. Soil compaction affects plant growth by causing increased resistance to root penetration and decreased uptake of water, Muhammad Saqib et al., (2004).

5. CONCLUSIONS

The following conclusions were drawn from this study:

I. Bulk density was affected by tillage practices, but only within the first 10 cm both under TW and TC treatments.
II. Tractor × passes interactions affected corn emergence. Poor emergence was found under TW3 and TC3 treatments.
III. There was long-term tillage effect on dry matter yields, and differences were attributed to climatic variation over plant growth and root development.
IV. Higher bulk density in some treatments (TW2 and TC2) may have increased the ability of the soil to retain water during seasons with less than average precipitation, which may have contributed to higher dry matter yields.
V. Plant height was found better in slight compacted plots. Thus TW2 is recommended as a sustainable tillage practice on a clay loam, loam and sandy loam soil in a temperate climate.

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