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Assessing of Soil Compaction Using Some Soil Properties Caused By Agricultural Machinery Traffic

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Abstract: The purpose of this experiment was to asses the soil compaction caused by agricultural machinery traffic using some soil properties. The study was conducted on a silty clay loam soil at the experimental farm of Nanjing Agricultural University, China. The soil surface was compacted by passing tractors once, twice and four times. The soil was silty clay loam and its water content was approximately at field capacity. Penetration resistance and some other soil properties were measured in the soil profile in order to determine their interactions. The obtained results showed a positive relationship between penetration resistance and bulk density and negative relationships between penetration resistances. Correlation coefficients of those relationships were 0.42448**,-0.65726**,-0.64677**,-0.51499** and-0.61283**; respectively.

Key words: Penetration resistance · bulk density · air porosity · soil compaction · soil structure · agricultural machinery

INTRODUCTION

Recently, heavier and more powerful tractors and machins have been used on farms throughout the world [1, 2]. Aiming to reduce the human labor and a corresponding increase in farm size with a need to increase individual operator productivity. However, problems have been noted due to increased loads on the soil surface. Some of the most serious problems resulted by the increased machinery size resides in the soil deformation, compaction and destruction of established soil structure [3-5]. The degree of soil compaction refers to the axle load [3]. Vehicles with high axle loads have reduced yield crop and caused in many detrimental environmental effects as reported by [3, 6] on a compaction amelioration study that used a tandem axle liquid manure tank with a 6.4-Mg-per-axle load to compact some field plots that were subsequently seeded to barley (*Hordeum vulgare* L.) and alfalfa (*Medicago sativa* L.) on a clayey soil. The compaction treatment significantly decreased yield crop, increased cone penetration resistance and increased dry bulk density. Wheel traffic of agricultural prime movers is well recognized as a major contributor to detrimental soil compaction [7-9]. Soil penetration resistance, bulk density and pore size distribution have been used for determination of soil compaction [10, 11]. The resistance of soil penetration may vary rapidly depending on the changes of soil water content and soil structure and texture of soil [12, 13]. Soil penetration resistance readings those need to be compared are often taken at different soil water contents. Because, soil water changes may significantly affect soil penetration resistance, it is almost difficult to determine the penetration resistance differences caused by water content or treatment [14]. To be able to compare penetration resistance readings, it would be necessary to adjust for differences of water content changes [14]. The relationship between penetration resistance and soil water content depends on soil physical properties, such as bulk density, soil porosity, texture and structure [11, 14, 15]. Calibration of soil penetration resistance readings with regard to soil water content changes takes a long time and is difficult. The purposes of this article are to develop relationships between soil penetration resistance readings and bulk density. Under tropical conditions, the soil compaction process occurs due to tillage and harvest operations carried out under wetter conditions the optimal required for wheel movement; while in pasture areas, it refers the excessive trampling of the cattle [16] and in forest areas, due to the traffic of the harvest operations

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and wood transport under insuitable soil water conditions [17] and to estimate soil compaction from cited soil properties if soil conditions are different such as soil water content, soil structure and stoniness.

MATERIALS AND METHODS

Site description: This study was carried out on 20 hectares at the Jiangpu experimental farm of Nanjing Agricultural University, Jiangsu Province of China which is located at (Latitude of 32° 3' 4.96" N and Longitude of 118° 36' 38.78" W), during the growing seasons of 2005-2007.

Table 1 shows some of the meteorological data such as average rain, temperature, humidity and wind velocity in this region.

Soil: The topsoil and subsoil texture of this loess-derived soil is similar (silty clay loam). There is also no significant spatial variability of soil texture in the surface 0.5 m of the 20-ha field in which these trials were conducted. Prior to establishment of experiments, the site has remained under continuous corn (*Zea mays* L.), since 2002. Surface open drains were installed during 2000 within each plot. The soil's organic C, total N, available P, exchangeable K, were 11.34, 27.88, 13.57 and 31.4 mg kg^{-1}, respectively. Particle size distribution was determined by the hydrometer method [18, 19]; clay (<2 m): 24 %; silt (2-50 m): 26 % and sand (50-2000 m): 50 %. Water content as a percentage of dry weight representing field capacity (25 %, w/w) and permanent wilting (12 %, w/w) was determined according to [20]. Soil pH and electrical conductivity in water (1:2.5) was 7.78 and 192 dS/m, respectively [21, 22]. Organic matter content of the soil was 2.25 % [23]. The $CaCO_3$ equivalent of the soil was 29 % [23]. Particle density was 2.65 g cm^{-3} [24]. Bulk density and total porosity, void ratio, air porosity, drainage porosity were measured according to [25, 26], respectively. All measurements were made at three different soil layers (0-5, 5-10 and 10-15 cm) and replicated thrice. Experimental plots (6x30 m) were tilled to a depth of 10 cm. When the soil water content was about the field capacity, the soil surface was compacted by passing a wheel tractor, crawler tractor and holder/walking tractor.

Tractor and machines used: Field tests were performed during 2005, 2006. Experiments were completed and are described below. The Wheel tractor (WT) 35.3 kW (50 hp), DFH75 track tractor (CT) 55.9 kW (75 hp) and (HT) 11.2 kW (15 hp) were used for these experiments.

Table 1: Meteorological data for growing season

Month	Total rainfall (mm)	Av. Temperature (C°)	Av. Humidity (%)	Wind velocity (m s^{-1})
January	117.3	3.5	81	2.6
February	60.2	4.1	76	3.0
March	10.6	11.2	65	2.7
April	113.4	16.7	70	2.8
May	96.9	20.9	69	2.8
June	112.1	26.2	73	2.3
July	191.1	28.3	81	2.5

Table 2: Experiment coding system for treatments

Treatment	Code	Treatment	Code
T1-Wheel tractor	WT1	T2-Wheel tractor	WT2
T3-Wheel tractor	WT3	T4-Crawler tractor	CT1
T5-Crawler tractor	CT2	T6-Crawler tractor	CT3
T7-Holder/Walking tractor	HT1	T8-Holder/Walking tractor	HT2
T9-Holder/ Walking tractor	HT3	C-No compaction	C

The wheel tractor has a mass of 2000 kg, DFH75 has a mass of 3075 kg and Holder/ Walking tractor has a mass of 900 kg. Tires on the WT were inflated to 400 kPa. The rear wheel diameter is 96 cm and the front wheel diameter is 64 cm, wheel tire on (HT) width is 22 cm. The total ground contact area of Chain tracks was calculated to be 4.3 m^2 (2×3.1×0.7 m) resulting in an average ground stress of 43 kPa. Weight distribution for WT tractor was 60% on the rear axle and 40% on the front axle. Ground pressure for the WT was about 175 kPa and weight on CT was distributed equally. The tractors passed the field one, two and four times, correspondingly, by single tires. On such background corn and wheat was sown.

Penetration measurement: In selected experiments, soil penetration resistance (R_p), bulk density (ρ_b), soil moisture, porosity (Tp), void ratio (Vr), air porosity (Ap) and the drainage porosity (Dp) were measured. Penetration resistance was measured with a TE-3 penetrometer made in Nanjing, China. The penetrometer had a drive mechanism powered by hand crank, allowing insertion at a constant rate. The cone had a 108 angle with a cone base cross-sectional area of 1 cm^2. The penetrometer was pressed into the soil at a constant rate of 0.02 m s^{-1}. The measurement range of the penetrometer was 0.2 to 8.0 MPa with a precision of 0.04 MPa. All measurements were performed at three different soil layers (0-5, 5-10, 10-15 cm) and replicated thrice. Data were subjected to correlation and regression analyses by using SPSS software [27].

Experimental design: The experiment was established at site. Ten treatments including control were set up in a replicated randomized complete block design (RCBD) resulting in a total of 30 plots. The treatments and their labels are shown in Table 2.

RESULTS AND DISCUSSION

The effects of different passing number of a wheel tractor on soil cone penetration resistance are shown in Fig. 1-3. Passes of the tractor on the soil surface increased cone penetration resistance. Maximum increase of cone penetration resistance occurred with CT at the soil surface (5-10 cm). Bulk density, total porosity, void ratio, air porosity and drainage porosity of the un-trafficked soil and of the soil after 1, 2 and 4 passes of the tractors are illustrated in Table 5.

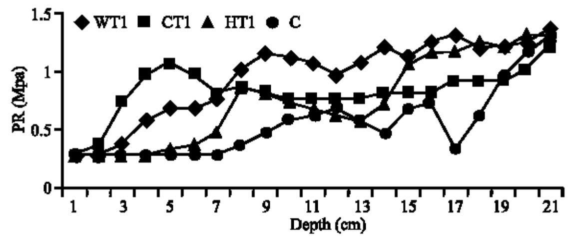

Fig. 1: Effect of cone penetration resistance (PR) in soil profile one pass of tractors

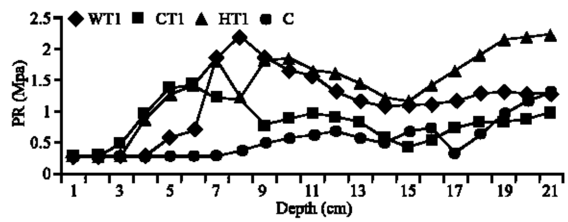

Fig. 2: Effect of cone penetration resistance (PR) in soil profile two passes of tractors

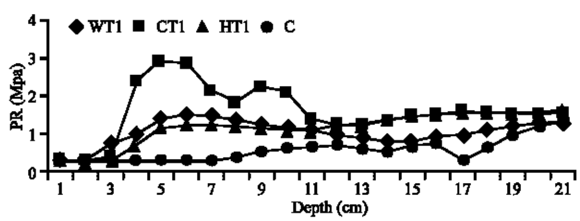

Fig. 3: Effect of cone penetration resistance (PR) in soil profile four passes of tractors

Statistical analysis: Analysis of correlation was done to determine the relationships between cone penetration resistance and bulk density, total porosity, void ratio, air porosity, drainage porosity and available water porosity (AWP; size of between 8.6m-0.2m) Correlation coefficients

Table 3: Effect on soil moisture in soil profile passing numbers by tractors(%)

Depth (cm)	T1	T2	T3	T4	T5	T6	T7	T8	T9	C
0-5	16.55	18.20	19.55	18.20	17.92	16.73	18.22	18.48	19.38	20.98
5-10	16.36	17.36	19.61	21.99	18.48	16.31	17.36	18.48	19.12	20.98
10-15	15.38	15.83	18.38	24.37	16.82	19.42	17.92	17.09	13.63	21.25

Table 4: Effect on bulk density (ρ_b) in soil profile passing numbers by tractors g cm^{-3}

Depth (cm)	T1	T2	T3	T4	T5	T6	T7	T8	T9	C
0-5	1.75	1.75	1.70	1.67	1.70	1.77	1.49	1.48	1.47	1.63
5-10	1.88	1.76	1.66	1.54	1.70	1.73	1.72	1.66	1.68	1.77
10-15	1.81	1.80	1.81	1.61	1.69	1.62	1.71	1.71	1.72	1.63

Table 5: Effect on total porosity (Tp), void ratio (Vr), air porosity (Ap), drainage porosity (Dp) in soil profile passing numbers by tractors

Treatments	Tp (%)	Vr	Ap (%)	Dp (%)
T1	46.42	0.87	6.85	8.62
T2	43.9	0.78	5.09	7.92
T3	42.52	0.74	3.82	5.84
T4	44.4	0.80	8.73	7.80
T5	38.99	0.64	3.82	5.40
T6	39.37	0.65	3.73	5.58
T7	45.41	0.84	8.87	8.43
T8	41.13	0.70	5.77	6.12
T9	44.78	0.81	7.32	7.08
C	57.73	1.33	19.82	9.52

Table 6: Correlation coefficients between penetration resistance and measured soil properties

Soil properties	PD (MPa)	BD (g.cm^{-3})	TP (%)	VR	AP (%)	DP (%)	AWP (%)
PR	1.000						
BD	0.42448**	1.000					
TP	-0.65726**	-0.13313**	1.000				
VR	-0.64677**	-0.1197**	0.971003**	1.000			
AP	-0.51499**	-0.24562**	0.933812**	0.96525**	1.000		
DP	-0.61283**	-0.1068**	0.829778**	0.816418**	0.776141**	1.000	
AWP	-0.20316ns	-0.4194ns	0.69883ns	0.64828ns	0.647ns	0.277ns	1.000

** p< 0.01 ns: not significant statistically of relationships between penetration resistance and measured soil properties are given in Table 6. The relationships between penetration resistance and total porosity, void ratio, air porosity and drainage porosity were found take negative and statistically significant at the 1% level. Correlation coefficients of these relationships were -0.65726**, -0.64677**, -0.51499** and -0.61283*, respectively.

CONCLUSION

Penetration resistance was strongly affected importantly by soil water content. Therefore, there were various difficulties to compare all the penetration resistance readings at different soil conditions such as soil water content and soil structure. There were statistically significant relationships between penetration resistance and bulk density, total porosity, void ratio, air porosity and drainage porosity. Bulk density, total porosity, void ratio and air porosity which have high coefficients of determination with penetration resistance could be used to compare the soil compaction under different soil conditions. The obtained results indicate that the soil compaction resulting from traffic with the tracked tractor was generally more pronounced than that with the wheeled tractors.

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