Silage-corn harvesting machinery traffic effects on soil bulk density and water permeability

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Abstract

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Soil compaction caused by machinery traffic affects the growth of agricultural crops and also has environmental effects like soil damage and erosion. Field experiments were conducted to study the effects of repeated silage-corn harvesting machinery traffic on dry soil bulk density and porosity variations at three different sampling depths, moreover average water permeability coefficient of the examined silty clay loam soil was measured using the falling head method of water permeability test. The examined treatments which were applied while harvesting silage-corn with the combination of tractor, chopper and truck were the number of traffic passes and depths of soil sampling. Significant differences between soil compaction treatments were observed in bulk density and porosity of soil. Numerically, 22% increase in soil bulk density and 19% reduction in soil porosity were recorded due to the effect of two passes of the examined machineries over the field terrain comparing to the non-traffic treatment. Moreover; soil sampling at 0–10 cm and 20–30 cm depths resulted in the highest and the lowest soil porosity respectively.

Keywords: repeated traffic passes; silage harvester; soil compaction; soil physical damage; soil porosity

Different aspects related to soil compaction were studied by many researchers. The main results of such studies can be summarized as follows: with increasing soil compaction level, soil bulk density increases (Gomez et al. 2002; Birkás et al. 2008), and soil porosity (Sutherland et al. 2001), O_2 diffusion and microbial activity of soil (Li et al. 2002), root development, plant nutrient uptake and water infiltration rate (Brais 2001), and finally crop yield and quality decrease (Hakansson, Medvedev 1995). Moreover power requirement of tillage for compacted soils is significantly higher than non-compacted soils (Horn et al. 1995; Whalley et al. 1995). Field traffic is considered as one of the main causes of soil compaction especially when soil has higher moisture content than normal (Hakansson et al. 1987). During the harvest period of silage-corn, field terrain is compacted by the wheels of heavy machineries such as tractor, corn chopper and truck, and this compaction causes the average bulk density within the field to increase from 1.14 g/cm^3 to 1.46 g/cm^3 (Aksakal, Oztas 2010). Furthermore silage-corn is harvested in October while the crop leaves shaded the ground, therefore moisture content of the soil is relatively high and these conditions may lead to more severe soil compaction.

In order to evaluate the influence of silage-corn harvesting machinery traffic on soil bulk density and water permeability variations, this study was conducted, and the dependence of soil bulk density variations at different depths to the number of traffic passes was quantified.

Table 1. General specifications of the examined soil

Textural class	Sand (%)	Silt (%)	Clay (%)	pH	EC	Organic matter (%)	Solid density (g/cm^3)
Silty clay loam	18	42	40	6.5	1	1.5	2.74

EC – electrical conductivity

Table 2. General specifications of the wheels of the utilized machinery

Machinery name	Wheel type	Tire inflation pressure (KPa)	Axle load (kg)
Tractor (JD 3350)	front: 10.00–16 rear: 18.40–34	120 85	1,300 2,000
Silage chopper (Kesht Abzar Kar)	11.50/80	115	1,000
Truck (Mercedes-Benz 1983)	front: 14.9 R 28 rear: dual 14.9 R 28	140 140	8,000 10,000

MATERIAL AND METHODS

The study area is located at the Islamic Azad University (IAU) farmland (Khatoonabd, Iran); 5 ha of the farmland was devoted to corn production. General specifications of the examined soil and the utilized machineries are summarized in Tables 1 and 2, respectively.

Silage-corn harvest was performed utilizing a tractor-driven-chopper that cuts and threws the chopped materials into the trailer of a truck; therefore field terrain was affected by the combination of the wheels of tractor (John Deere 3350; John Deere Ltd, Mannheim, Germany), chopper (Kesh Abzar Kar; Isfahan, Iran) and truck (Mercedes-Benz 1983; Mercedes-Benz, Wörth, Germany). In order to quantify the effect of the number of traffic passes on soil bulk density variations, 0, 1 and 2 passes of machinery wheels over the examined field were considered and wet soil bulk density (BD_{sw}) was calculated for soil samples taken from 0–10, 10–20 and 20–30 cm depths. Soil samples were extracted by inserting a ring with 5.3 cm internal diameter and 5.6 cm height into the soil and measuring the weight of the accumulated soil within the ring. Wet soil bulk density (BD_{sw}) and moisture content (MC) can be calculated utilizing the following formulas:

$$BD_{sw} = \frac{M_{sw}}{V_R},\ MC = \frac{M_w}{M_{sd}} = \frac{M_{sw} - M_{sd}}{M_{sd}}$$

where:

M_{sw} – mass of the wet soil sample

M_{sd} – mass of the dry soil sample (the weight of the soil samples after 24 h of oven drying)

V_R – volume of the sampling ring respectively

Furthermore dry soil bulk density (BD_{sd}) and porosity (e) can be obtained using the following formulas:

$$BD_{sd} = BD_{sw}(1 - MV),\ \ e = \left(\frac{BD_s}{BD_{sd}} - 1\right)$$

where:

BD_s – density of the solid part of the soil which was measured using the small pyknometer method which is described in BS standard 1377-2 (1990) (BD_s = 2.74 g/cm^3)

In this study average water permeability coefficient (K) of the examined soil samples was calculated too, the value of K was measured utilizing the falling head method of water permeability test which is described in the standard of BS 1377-5 (1990). This

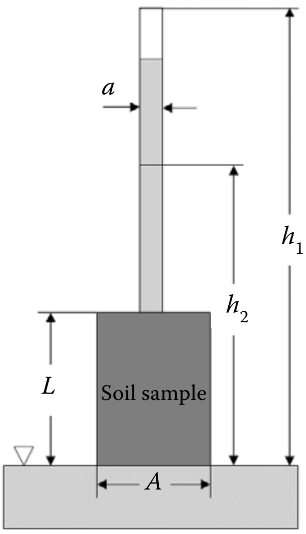

Fig. 1. Falling head permeameter

a – thin pipe cross section; A – soil sample cross section; h_1 – height of water at time t_1; h_2 – height of water at time t_2; L – length of the soil sample

Table 3. Dry soil bulk density and porosity as affected by the number of traffic passes and soil sampling depth

Treatment	Dry soil bulk density (g/cm^3)	Porosity (%)
No. of traffic passes		
0	1.278^a	53.3^a
1	1.456^b	46.9^b
2	1.564^c	42.9^c
Soil sampling depth (cm)		
0–10	1.378^a	49.7^a
10–20	1.457^b	46.8^b
20–30	1.464^b	46.6^b

means followed by the same letter are not significantly different at $P < 0.05$ according to LSD test

method is suitable for water permeability measurement in fine-grained soils. Calculation formula of K is presented here and a falling head permeameter is schematically shown in Fig. 1:

$$K = \frac{2.3\,a\,L\log\left(\frac{h_1}{h_2}\right)}{A(t_2 - t_1)}$$

where:

L – length of soil sample

A – cross section of the soil sample

h_1 – height of water in the thin pipe at time t_1

h_2 – height of water in the thin pipe at time t_2

a – cross section of the thin pipe

Therefore the examined independent parameters of this study were the number of traffic passes (factor A) and depths of soil samples (factor B), and the dependent parameters were the dry soil bulk density (BD_{sd}), and soil porosity (e); furthermore, average water permeability coefficients of soil samples with the same number of traffic passes were reported, too. The experimental design consisted of a split-plot arrangement of a completely randomized design with three replications. Statistical analysis of the obtained data was performed utilizing the Mstat software (Mstat 5.4.2; University of Wisconsin, Madison, USA).

RESULTS AND DISCUSSION

Effects of the examined factors on dry soil bulk density and porosity

Analysis of variance of the obtained data showed that both factors (number of traffic passes and depth of soil samples) had significant effects in 5% probability level on the dependent variables (dry soil bulk density and porosity). Field terrain without any traffic pass had the highest porosity and the lowest dry soil bulk density and two passes of traffic over the field terrain resulted in the lowest porosity and the highest dry bulk density among the treatments (Table 3).

Numerically, 22% increase in dry soil bulk density and 19% reduction in soil porosity was recorded due to the effect of two passes of the examined machineries over the field terrain compared to the non-traffic treatment. This result is in agreement with the results obtained by Aksakal and Oztas (2010), which was about the changes in distribution patterns of soil bulk density and penetration resistance within a silage-corn field following the use of heavy harvesting equipment. They concluded that average bulk density within the field increased from 1.14 to 1.46 g/cm^3 due to the effect of machinery traffic treatment, which is similar to the results acquired in this study. In another study Kaspar et al. (2001) found that dry bulk density of soil located below the wheel traffic tracks was higher than the value of this parameter obtained from soil samples extracted from non-traffic strips. Hamlett et al. (1990) reported the values of 1.1 and 1.4 g/cm^3 for soil bulk densities of samples extracted from non-traffic soil strips and with wheel traffic tracks, respectively. In another study, Voorhees and Lindstrom (1984) obtained the bulk density value of silty sand loam soil of Minnesota state fields at 20 cm depth equal to 1.1–1.4 g/cm^3 and 1.4–1.65 g/cm^3 below non-traffic strips and with traffic tracks, respectively. Moreover; soil sampling from 0–10 cm and 20–30 cm depths resulted in the highest and the lowest soil porosity respectively; however, a reverse trend was observed with regard to the parameter of dry soil bulk density. Numerically, the increase of sampling depth from 0–10 cm to 20–30 cm depth led to 6.65% reduction in average soil porosity and 5.8% increase in dry soil bulk density.

Table 4. Number of traffic passes × soil sampling depth interaction effect on dry soil bulk density (g/cm^3)

No. of traffic passes	Soil sampling depth (cm)		
	0–10	10–20	20–30
0	1.239^a	1.348^{bc}	1.249^a
1	1.363^{bc}	1.509^d	1.495^d
2	1.531^d	1.514^d	1.647^e

means followed by the same letter are not significantly different at $P < 0.05$ according to LSD test

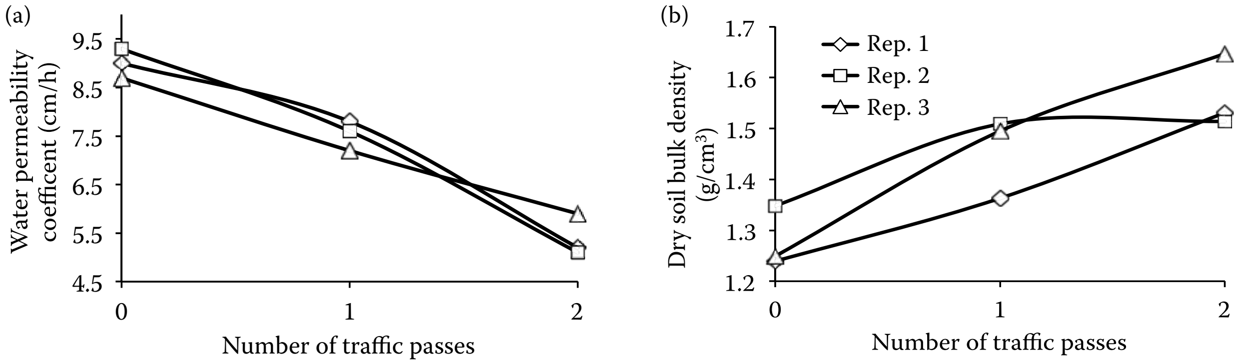

Fig. 2. Variation of average water permeability coefficient (a) and dry soil bulk density (b) as functions of the number of traffic passes
Rep. – replication

These results are in agreement with the results presented by Taser and Kara (2005) which was about the effects of different soil compaction treatments and contact pressures on silage-corn emergence under clay-loam soil conditions. They concluded that the soil bulk density and penetration resistance values increased with the depth of soil samples. Precise inspection of the results showed that the treatment with 0.025 MPa soil contact pressure, caused penetration resistance and soil bulk density of less than 1.10 MPa, and 1.33 g/cm^3 at 0–10 cm soil depth, and less than 1.70 MPa and 1.43 g/cm^3 at 10–20 cm soil depth. However, the obtained results are not similar to the results obtained from classical soil mechanics studies (Tsytovich 1976), where the value of the equipotential bulbs assumed to be located below the ground of a surface loading, gradually decreases with increasing depths. Maybe due to this fact the theories of soil mechanics were developed for studying the behaviour (gradual dissipation of surcharge pressure with depth) of compacted soil under the foundation of buildings, with loadings that are far more than the pressures applied from the wheels of agricultural machineries to the non-compacted soil of agricultural fields. Moreover, the examined depths in civil engineering studies are deeper (with the scale of several meters) than depths considered in agricultural engineering studies (with the scale of several centimetres); therefore, it is not rational to compare the results obtained from these two separate branches of science, in spite of their common concern which is the soil.

Table 5. Number of traffic passes × soil sampling depth interaction effect on soil porosity (%)

No. of traffic passes	Soil sampling depth (cm)		
	0–10	10–20	20–30
0	54.8^{e}	50.8^{d}	54.4^{e}
1	50.3^{d}	44.9^{bc}	45.4^{bc}
2	44.1^{bc}	44.7^{bc}	39.9^{a}

means followed by the same letter are not significantly different at $P < 0.05$ according to LSD test

The number of traffic passes × depth of soil samples interaction was significant ($P < 0.05$) for dry soil bulk density and soil porosity; furthermore, the highest soil porosity and the lowest dry soil bulk density resulted from soil samples taken from 0–10 cm depth and with non-traffic treatment, and the lowest soil porosity (the highest dry soil bulk density) was obtained from soil samples taken from 20–30 cm depth and with two passes of machinery traffic (Tables 4 and 5).

Effect of the number of traffic passes on average water permeability of soil

Another result that can be inferred from this study is that with an increase of the number of traffic passes over the soil from zero to two passes, average water permeability coefficient of the examined soil reduces from 9.0 to 5.4 cm/h, that means 40% reduction in the value of this coefficient. Trend of variation in water permeability coefficient of the examined soil is summarized in Fig. 2a.

This result is similar to the result obtained by Ersahin (2003). He studied the spatial relationship between infiltration rate and some soil properties. The author reported a strong negative relationship between infiltration rate and bulk density of subsoil (30–60 cm). Simultaneous comparison of the two parts of Fig. 2 will lead to the same result as stated by Ersahin (2003).

CONCLUSION

The results of the present study indicate that soil compaction caused by the traffic of silage-corn harvesting machineries leads to a significant increase in dry soil bulk density and a decrease in soil porosity and water permeability coefficient. To reduce the negative effects of this phenomenon, farmers should take the following precautions:

(1) reduction of the weight of the utilized machineries,

(2) utilization of the harvesting machineries equipped with dual wheels arrangement and wider wheels, especially when silage-corn is harvested in farm fields with soil having high moisture content.

However, it is recommended to conduct experiments in order to find the effect of the level of moisture content on the severity of soil compaction. These experiments can provide guidelines for farmers to help them answer whether it is suitable to start silage harvesting in farm field with soil having certain moisture content.

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