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Research paper

Measuring soil compaction and soil behavior under the tractor tire using strain transducer

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Abstract

Soil compaction can occur due to machine traffic and is an indicator of soil physical structure degradation. For this study 3 strain transducers with a maximum displacement of 5 cm were used to measure soil compaction under the rear tire of MF285 tractor. In first series of experiments, the effect of tractor traffic was investigated using displacement transducers and cylindrical cores. For the second series, only strain transducers were used to evaluate the effect of moisture levels of 11%, 16% and 22%, tractor velocities of 1, 3 and 5 km/h, and three depths of 20, 30 and 40 cm on soil compaction, and soil behavior during the compaction process was investigated. Results showed that no significant difference was found between the two methods of measuring the bulk density. The three main factors were significant on soil compaction at a probability level of 1%. The mutual binary effect of moisture and depth was significant at 1%, and the interaction of moisture, velocity, and depth were significant at 5%. The soil was compressed in the vertical direction and elongated in the lateral direction. In the longitudinal direction, the soil was initially compressed by the approaching tractor, then elongated, and ultimately compressed again.

Keywords: Soil compaction; Bulk density; Strain transducers; Tractor traffic

1. Introduction

Evaluation of soil compaction due to its negative effect on the rate of agricultural production and plant growth is important because soil compaction can easily reduce yield up to 10% through destruction of soil structure and reduction of water flow into the soil, which can lead to soil degradation (Duiker, 2002). Though precision farming methods that restrict traffic can reduce soil compaction, modern tractors are heavier than in the past with higher capacity of traction and carting resulting in a greater potential for compaction (Mohsenimanesh and Shane, 2010). Soil compaction and degradation may be visible due to the deformation of the upper surface of the soil or it may be hidden within deeper layers. The vehicle traffic can have a negative impact on crop production which is caused by soil compaction. The effects of soil compaction can last for years and may not be eliminated by tillage or freezing and thawing (Raper, 2005).

Most researchers measure soil stress under vehicle traffic by placing load cells in the soil, and soil stress data has been used to predict soil strain. However the relation between soil stress and its strain has not been defined very well (Erbach et al., 1991). Therefore, predicted strain from stress data may differ significantly from the actual soil strain. Simple stress–strain relationship based on linear elastic theory cannot predict soil compaction accurately from the applied stress (Kinney et al., 1991). Measurement of soil strain in different directions of x, y and z would therefore be useful.

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Erbach et al. (1991) used a rectilinear potentiometer to measure soil vertical strain. Soil compaction was measured using six soil-strain gages under tires of a tractor with a mass of 6000 kg, where 4200 kg was distributed on the rear axle. Four gages were positioned vertically and spaced 150 mm apart and with endplate distances of 250 mm. Their top endplate was 50, 100, 150 and 200 mm beneath the soil surface. Two gages also were place 150 and 300 mm from the centerline of rear tire with their top endplates 50 mm beneath the soil surface. The result of field tests showed that soil strain decreased with the depth increment. Maximum strain of 17.6 and 3.2% occurred under the rear tire when the strain gages were 50 and 200 mm under the soil surface, respectively.

To measure soil strain and clarify soil behavior in three mutual directions of x, y and z, three strain transducers were inserted in the soil with their initial lengths (Way et al., 2005). The experiments were conducted by NSDL (National Soil Dynamics Laboratory) within Norfolk sandy loam soil. The initial depth of each transducer midpoint was 220 mm beneath the undisturbed soil surface. The initial lengths of the three mutually orthogonal soil strain transducers were considered as the length, width and height of a right hexahedron sample within the soil, and the initial volume of the hexahedron soil sample was calculated from the strain gage lengths. After tire passes, the current volume was computed using the final values of the strain transducer lengths. Kinney et al. (1991) used similar strain transducer layouts to measure strain and compaction under tractors equipped with single rear wheel, dual rear wheels and steel track.

Way et al. (2005) found that soil in the vertical direction always compressed and maximum vertical strain occurred when the axle was about 0.1 m rearward of the transducer. In the longitudinal direction, the soil was initially compressed when the approaching tire was 0.75 to 1 m rearward of the transducer, then the strain increased to a positive value indicating soil elongation, and ultimately the soil was compressed again after the tire had completely passed. Maximum soil strain occurred in the vertical direction. The magnitude of the mean final lateral natural strain was 0.127, which was 64% of the final vertical natural strain of −0.2. The magnitude of the mean final longitudinal natural strain was −0.027, which was 13% of the vertical one. The mean volumetric strain was −0.099, which was 35% of the mean volumetric strain from the soil core samples of −0.286. They related this difference to the greater lateral dimension of the strain transducer (117.5 mm) relative to the lateral dimension of the soil core of 69 mm (Way et al., 2005). Kinney et al. (1991) showed that in the depth of 100–240 mm, the final vertical strain created by the single rear wheel was 55% more than that of the inside dual rear wheel and 70% more than that of the track. Magnitudes of bulk density change were similar to those of vertical soil strain. It was found that the single rear wheel created the deepest soil depression and the steel track made the shallowest.

Applying the dynamic load to the soil surface induces stress to the soil along with soil strain. Hence, a coupled soil stress and strain measurement is required so that the compaction process fully understand (Wiermann et al., 1999). They conducted indoor tests at the NSDL in which a stress state transducer system (SST) was connected to a displacement transducer system (DTS) to measure the displacement of the SST in vertical and horizontal directions. The effect on compaction of three different dynamic loads and tire inflation pressure combinations at two passes of a tire was investigated. The vertical displacement increased significantly with increasing dynamic load and inflation pressure. There was no significant difference between the first and second pass in terms of vertical displacement, while horizontal displacement increased significantly for the second pass. The results showed more deformation of soil in deeper layers and in the horizontal direction for the second pass.

The objectives of these trials were to confirm displacement gauges as a tool to measure soil compaction and to investigate the effects of tractor traffic on compaction. The trials also addressed the effects of a set of parameters on soil compaction and characterized soil deformation behavior during the compaction process for the particular soil conditions investigated.

2. Materials and methods

Experiments were conducted in Loam soil with a content of 25% clay, 29.34% silt and 45.66% sand. For these tests, a MF285 tractor equipped with single rear wheels (18.4R30 radial-ply) and a weight of 1694 kg on the rear axle was used. During the tests, a moldboard plow was on a three point hitch, and that increased the weight on the rear axle to 2086 kg. The front wheels were closed to the minimum setting, and spacers were used on the rear wheels so that the rear wheel track was separated from the front wheel track by 180 mm. The inflation pressure of the rear wheel was 100 kPa during all tests. Experimental runs were randomised and blocked to control variation. For this, treatments at 3 replications were arranged in a complete randomised block design. MSTAT-C software was used to analysis the data.

A first series of experiments were conducted to examine the effect of tractor traffic on soil compaction and compare strain transducer results with cylindrical cores as a reference. Soil volumetric moisture content was 11%, tractor forward velocity was 1.7 km/h, and the depth for measuring density was 40 cm. Three displacement transducers were placed in 3 directions of x, y and z, and 15 cylindrical cores with diameter of 10 cm and height 20 cm were placed in a profile with length, depth and width of 3, 0.7 and 0.4 m, respectively (Fig. 1). The strain transducers were mutually orthogonal and were located directly beneath the centerline of the rear tire path during the tractor movement.