TECHNICAL NOTE

Effects of multiple passes of vehicles on clay soil compaction as measured by dry bulk density

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Argaw, F.G., F. Saathoff, A. Woldemichael and A. Gebissa. 2013. **Effects of multiple passes of vehicles on clay soil compaction as measured by dry bulk density**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **55**: 2.17-2.22. Soil compaction caused by machinery traffic on agricultural soil is becoming a problem in all parts of the world. In this experiment, vertical distribution of machinery-induced compaction on clay soil was investigated. The weights of the machineries used during the experiment were 82.80 kN (light vehicle or L) and 132.34 kN (heavy vehicle or H). Both machines passed repeatedly (1, 2, 4, 8 times) on the same track of the soil at two different moisture contents known as dry and wet plots of the farmland. The different parameters measured during the experiment were dry bulk density, vehicle axle load, and track width of the wheel traffic.

The results showed that in a wet soil profile the dry bulk density of the soil taken to a depth of 0.30 m showed a statistically significant difference ($p < 0.05$) relative to the control (zero traffic zone). But it requires at least two passes by the same vehicles to obtain a statistically significant difference ($p < 0.05$) on the dry soil. **Key words:** Repeated traffic, Soil compaction, Axle load

Le compactage du sol causé par la circulation des équipements sur les sols agricoles est devenu un problème dans toutes les parties du monde. Dans cette étude, la distribution verticale du compactage produit par la machinerie a été évaluée dans un sol argileux. Le poids des machines utilisées durant l'expérience étaient respectivement de 82,80 kN (véhicule léger ou L) et 132,34 kN (véhicule lourd ou H). Les deux machines passaient de manière répétitive (1, 2, 4, 8 fois) dans les mêmes voies sur des sols à deux teneurs en eau différentes et déterminées soit des parcelles sèches et humides de terre agricole. Les paramètres mesurés durant l'expérience étaient la densité apparente sèche, la charge sur l'essieu du véhicule et la largeur de l'empreinte de la roue.

Les résultats ont montré que dans un profil de sol humide la densité apparente sèche du sol pris à une profondeur de 0,30 m présentait une différence statistiquement significative ($p < 0,05$) lorsque comparée au témoin (zone sans circulation). Cependant deux passages par le même véhicule étaient nécessaires pour qu'une différence statistiquement significative soit obtenue avec le sol sec. **Mots clés:** circulation répétée, compactage du sol, charge à l'essieu.

INTRODUCTION

In today's mechanized farming where excessive traffic occurs frequently, the loaded wheels of tractors and machineries make contact with a specific point on a soil several times in a single cropping season. It has been estimated that over 30% of ground area is trafficked by the tires of heavy machinery even in a genuine zero tillage system (one pass at sowing). Under minimum tillage (2 to 3 passes) the percentage is likely to exceed 60% and in conventional cropping (multiple passes) it would exceed 100 % during one cropping cycle (Kroulik et al. 2009).

In addition to the wheel ground contact pressure and absolute wheel load, the frequency of wheel passes throughout the life of the crop has a decisive effect on the degree of compaction and the depth to which wheel pressure affects the soil. Studies conducted by Etana and Håkansson (1994) and Arvidsson (2001) have confirmed that compaction by heavy machinery can lead to a compaction in the subsoil to a depth of at least 0.50 m. Since the utilization of heavy agricultural equipment may result in sub soil compaction of arable land soil, their indiscriminate use could be the cause of an agro-ecological problem, which necessitates correction.

Although compaction is regarded as the most serious environmental problem caused by mechanized agriculture (Raper and Kirby 2006) it is the most difficult type of degradation to locate and rationalize, principally as it may show no evident marks on the soil surface.

The effects of soil compaction on crops and soil properties are complex (Bailey et al. 1986) and bulk density becomes the most frequently used parameter to characterize the state of soil compactness. The objective of this study was to quantify and study the relationship between dry bulk density and compacting effort caused by vehicle wheels under repetitive trafficking.

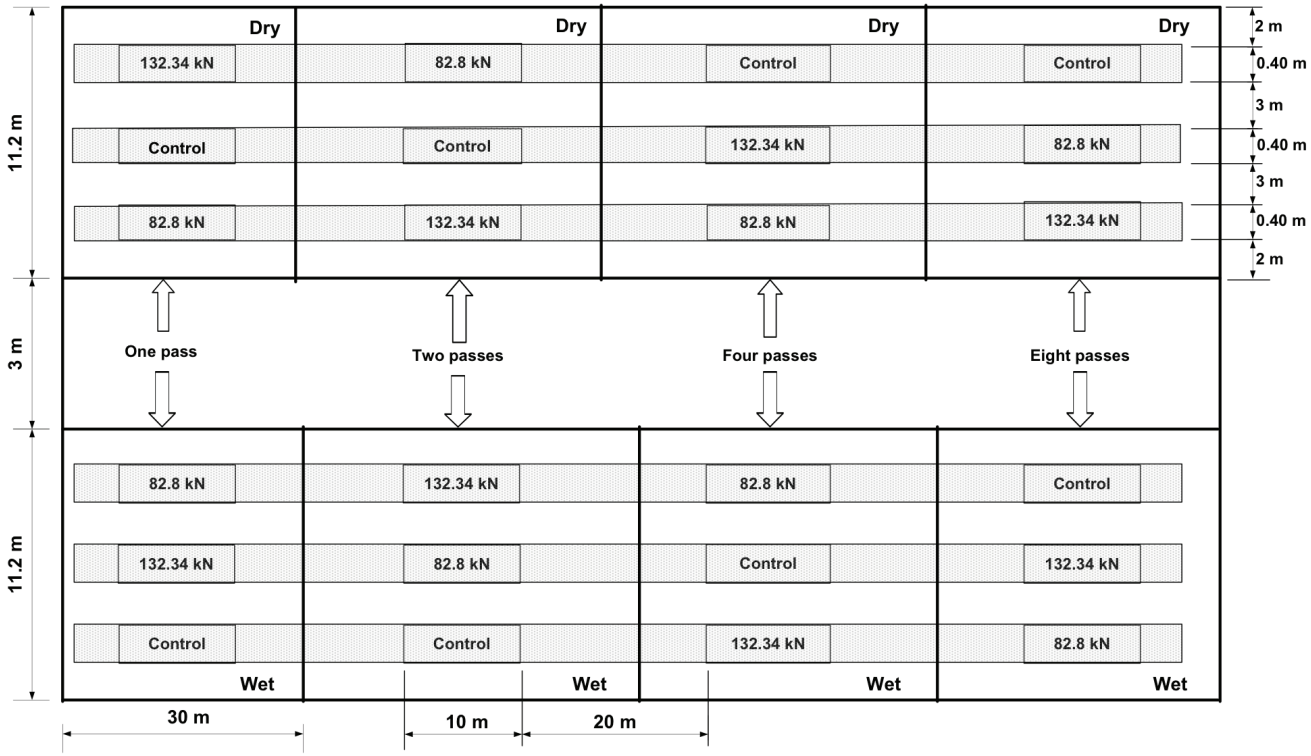

Fig. 1. Layout of the experimental design.

MATERIALS AND METHODS

Experimental site and design

The experiment was carried out on Hawassa University farmland located at (7° 02' 50.63" N) and (38° 29' 54.13" E) in Hawassa, southern Ethiopia, and 1715 m above sea level. The area has a well-drained clay soil of volcanic ash origin (Andisols) with organic matter content varying from 0.56% (w/w) on the surface to 0.19% (w/w) at a depth of 0.90 m (Table1). The area (farmland) has been plowed once a year with mouldboard plow to a depth of 0.25 m. This plowing has been done continuously for the past 25 years for maize (*Zea mays L.*) plantation. The farm used rubber-wheeled agricultural machines for the primary and secondary tillage as well as big trucks to carry out the product to a storage facility.

The wheeling experimental design (Fig. 1) was a split-split plot type full factorial design where soil moisture (two levels: wet and dry) was considered to be the whole plot factor and the number of passes (four levels: one pass, two passes, four passes, and eight passes) was considered to be the sub plot factor and axle weight (two levels: heavy and light) was considered as the sub-sub plot factor. The split-split plot arrangement taken (Fig. 2) is specially suited for three factor experiments.

<table>
<tr><td colspan="4">A1 Whole plot

Where: A1 : Dry A2 : Wet
B1 : One pass B2 : Two passes B3 : Four passes B4 : Eight passes
C1 : No load C2 : Light load C3 : Heavy load

A : Whole plot treatment
B : Sub plot treatment
C : Sub-sub plot treatment</td></tr>
<tr><td rowspan="3">A2B1
Sub plot</td><td rowspan="3">A2B2
Sub plot</td><td rowspan="3">A2B3
Sub plot</td><td>A2B4C1
Sub-sub plot</td></tr>
<tr><td>A2B4C2
Sub-sub plot</td></tr>
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Sub-sub plot</td></tr>
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Fig. 2. Split-split plot arrangement.

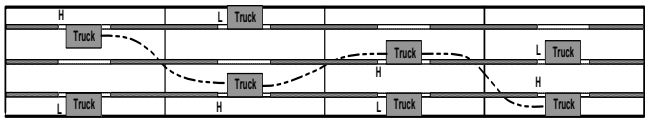

Fig. 3. Vehicle movement pattern, diagram to scale.

One of the wheeling tests was done during a rainy period, where the soil moisture content was 21% (wet) and the other was conducted after the rainy period when the average moisture content of the soil was 16.5% (dry). The moisture content was measured by gravimetric method (oven drying technique). The experiment was done in three replications. Moisture content, number of passes, and axle loads are randomly assigned to the farm plots. In order to avoid interaction between the sub-sub plots, a minimum distance of 3m was kept between two sub-sub plots.

The statistical analysis was performed using the SPSS 16.0 program. The List Significant Difference (LSD) posthoc analysis was used to compare differences between group means of the dependent variable (dry bulk density). The soil response variable, dry bulk density was measured at different depths (0.10 m, 0.30 m, 0.60 m and 0.90 m) in four replicates for each depth immediately following the traffic treatments after 0 (control), 1, 2, 4, and 8 vehicle passes over the same track. In all experiments the vehicle speed was approximately one m/s and there was no hitch load attached to the vehicle. The truck movement pattern on the field is shown on Fig. 3.

Wheeling machine properties

The weights on the front and rear axle and the wheel contact pressure of the vehicle used during the experiment when it is not loaded as well as when it is partially loaded with a payload of weight 49.541kN are shown in Table 2. For both wheeling experiments (heavy weight and light weight) we have used the same rear wheel driven machinery (Table 2).

The average contact vertical stress between the tire and the ground surface was estimated as the weight (kN) on the axle divided by the tire-surface contact area of all wheels on the axle. The contact area between the tire and the ground was approximated as a rectangular shape and hence measurement of both dimensions (along and perpendicular to the vehicle motion) taken in the field under working conditions was enough to approximate the contact area.

RESULTS AND DISCUSSION

The modified proctor test result on the soil at different profile showed that the maximum density of the soil at a layer [0 – 0.50 m] was 1.48 × 103 kg/m3 and the optimum moisture content was 20% (Fig. 4). Therefore, it is expected that agricultural traffic near this moisture content produces significant compaction or soil damage. The average dry bulk densities of the soil after wheeling by a heavy and light load at different number of passes and moisture contents of the soil are shown in Table 3.

Table 1. Profile characteristic of the soil.

Horizon depth (m)	Modified Proctor: Optimum water content (%w/w)	Modified Proctor: Max dry bulk density (kg/m^3)	Organic carbon (%w/w)	Clay percentage (< 2×10^{-6} m)	Silt percentage (2×10^{-6} - 50×10^{-6} m)	Sand percentage (50×10^{-6}– 2×10^{-3} m)	Plastic Index (PI)	Color of the dry soil	Texture
[0 – 0.50]	20	1.48×10^3	0.56	41	28	31	10.1%	Brown	Clay
[0.50 – 0.70]	21	1.49×10^3	0.41	46.3	26	27.7	11.2%	Light gray	Clay
[0.70 – 1.00]	22.5	1.51×10^3	0.19	51.6	12	36.4	18.7%	Light yellowish brown	Clay

Table 2. Machinery used during the experiment.

Machine Type	Net machine weight (kN)	Front axle weight (kN)	Front wheel contact area (m^2/tyre)	Front wheel contact pressure (kPa)	Rear axle weight (kN)	Rear wheel contact area (m^2/tyre)	Rear wheel contact pressure (kPa)
Daewoo (Novus) 2WD Dual rear wheel (not loaded)	82.8	44.5	0.078	285.5	38.3	0.068	141.5
Daewoo (Novus) 2WD Dual rear wheel (loaded)	132.3	62.0	0.081	384.3	70.4	0.073	241.7

Table 3. Dry bulk density [× 10^3 kg/m^3] measured at the center of the wheel track for heavy and light vehicles at 21% moisture content and multiple passes (ANOVA significant levels).

Depth [m]	Control plot	Vehicle one pass		Vehicle two passes		Vehicle four passes		Vehicle eight passes	
		Heavy	Light	Heavy	Light	Heavy	Light	Heavy	Light
[0–0.20]	0.97 a	1.11 e	1.05 e	1.12 e	1.06 e	1.14 e	1.10 e	1.14 e	1.13 e
[0.20–0.40]	1.04 b	1.11 e	1.08 e	1.12 e	1.10 e	1.13 e	1.11 e	1.14 e	1.13 e
[0.40–0.80]	1.11 c	1.14 c	1.13 c	1.15 e	1.14 c	1.15 e	1.14 c	1.16 e	1.15 e
[0.80–1.00]	1.12 d	1.14 d	1.14 d	1.15 d	1.14 d	1.15 d	1.14 d	1.16 d	1.15 d

The dry bulk densities of the soil at zero pass (control) increases (Table 3) with depth of the soil profile. This is partially attributed to the weight of the overlying soil, change of texture along the profile and compaction caused by traffic during earlier field operations.

For both light and heavy weight machinery treatment, until a depth of 0.30 m along the wet soil profile, the measured value of dry bulk density shows that there is a statistically significant difference ($p < 0.05$) compared to the non-trafficked (zero pass) soil. But on the dry soil and to the same depth of 0.30 m a minimum of two and four passes were required with the light and heavy machine respectively to obtain a statistically significant difference on dry bulk density compared to the non trafficked (zero pass) soil. This is directly attributed to the decrease in the susceptibility of soil for compaction, as it gets drier.

Furthermore, for both weights (heavy and light) there is a strong positive relationship between number of passes and measured dry bulk density on the topsoil. This is similar to the result shown by (Smith and Dickson 1990) which confirms the direct relationship between wheel contact pressure and topsoil compaction. On the dry soil, the light machine could not produce a significant compaction in deeper layers (greater than 0.30 m), but on the wet soil the same machine was observed to produce a statistically significant difference in the dry bulk density at a depth of 0.60 m after two wheel passes. Beginning from 0.60 m depth, there is no statistically significant difference ($p > 0.05$) between the treatments obtained from light and heavy vehicle on both wet and dry soil.

The percentage increase in dry bulk density (Fig. 5) of the soil after wheeling with light and heavy vehicles decreases as the number of repeated wheel passes increases i.e. the greatest proportion of the compaction occurs on the first pass of the vehicle. This is in agreement with the results obtained by Etana and Håkansson (1994). Furthermore, the percent-increase in dry bulk density of the soil caused by the wheel traffic decreases as we go deeper into the soil profile.

As shown in Fig. 6, the dry bulk density of the soil along the profile did not show a step rise immediately beneath the topsoil indicating that no plow layer was formed as a result of previous year's agricultural operations. This indicates that although the area has been plowed with tractors weighing approximately 30 kN for decades, plow pan was not formed in the soil.

CONCLUSION

The results from the experiment indicate that the compaction obtained on a dry soil with the light machinery was insignificant. Significant compaction was mainly observed on the wet topsoil. But most of the fieldwork practice in the area is done during the rainy season on wet soils, when the soil is more susceptible to compaction. It has been also shown that no plow pan was observed in the soil profile. This could be attributed to the lightweight of the tractors used for farm operations during the past decades.

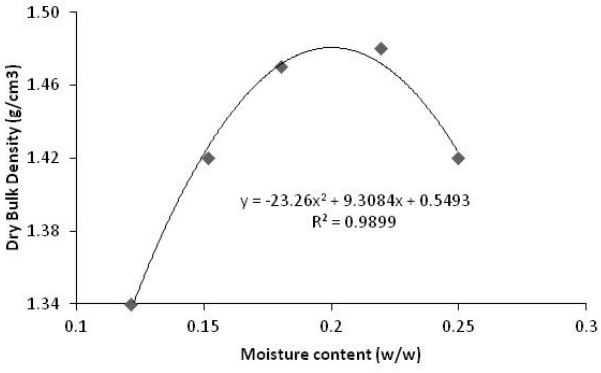

Fig. 4. Moisture density relationship modified proctor test (layer 0 - 0.50 m).

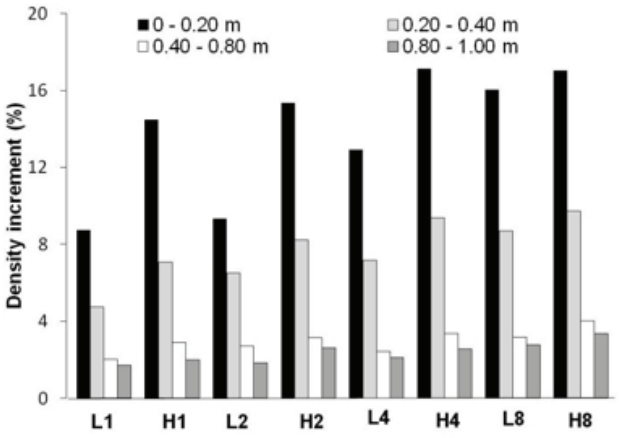

Fig. 5. Increase in dry bulk density caused by Light (L) and Heavy (H) wheel traffic on wet agricultural soil with respect to the control measured in four depth ranges after one, two, four, and eight passes.

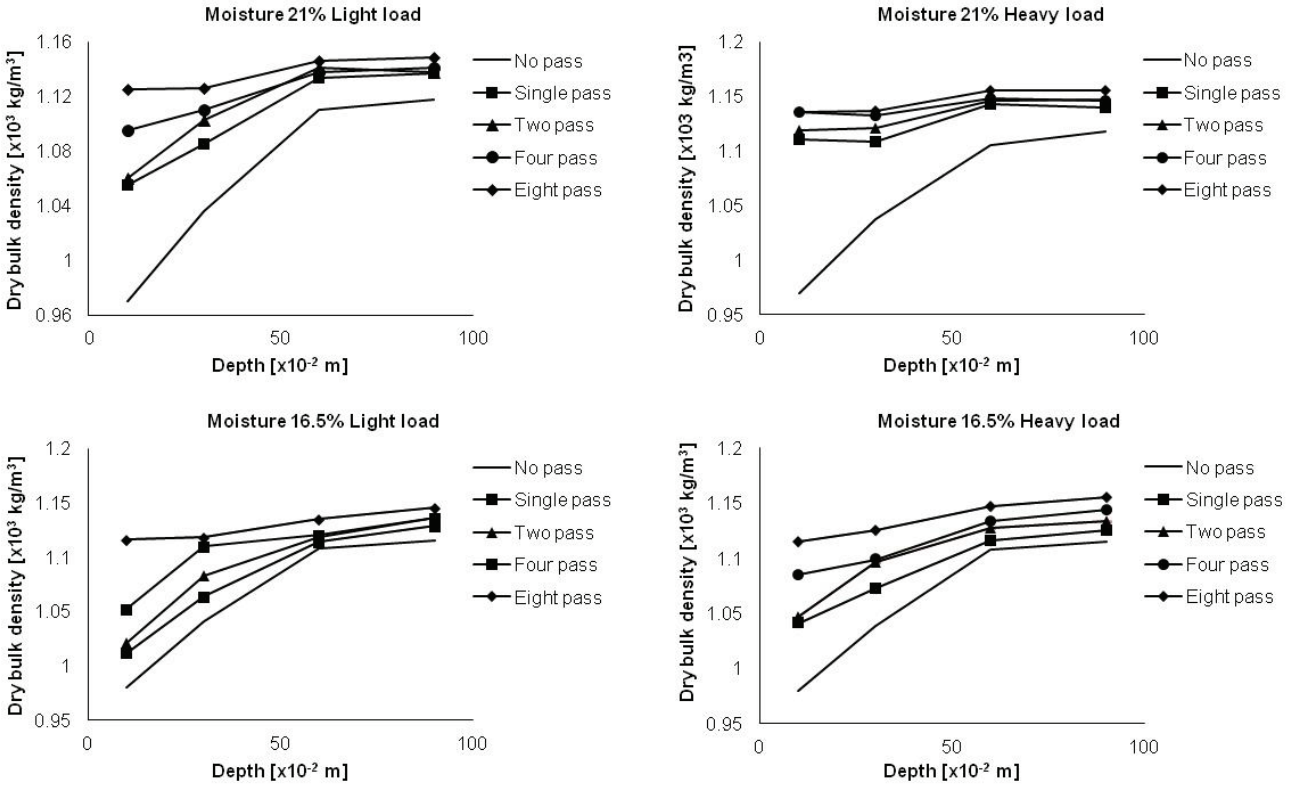

Fig. 6. Relationship between dry bulk density and number of passes of heavy and light vehicle on dry and wet soil against soil depth.

Furthermore, the rapid growth of highly mechanized farms results in the introduction of farm machineries with heavier axle load working on wet soils. The common practice in the prevailing conventional farming systems is the use of uncontrolled traffic, but the introduction of heavy weight farm machinery in clay soils with low organic matter content augmented by field operations during the wet season necessitates the use of a controlled traffic system (separate the wheel and crop zone in the field), for sustainable soil management.

REFERENCES

Arvidsson, J. 2001. Sub soil compaction caused by heavy sugar beet harvesters in southern Sweden I. Soil physical properties and crop yield in six field experiments. *Soil and Tillage Research* 60: 67-68. http://dx.doi.org/10.1016/S0167-1987(01)00169-6

Bailey, A.C., C.E. Johnson, and R.L. Schafer. 1986. A model for agricultural soil compaction. *Journal of Agricultural Engineering Research* 33: 257-262. http://dx.doi.org/10.1016/S0021-8634(86)80040-3

Etana, A., and I. Håkansson. 1994. Swedish experiments on the persistence of subsoil compaction caused by vehicles with high axle load. *Soil and Tillage Research* 29: 167-172. http://dx.doi.org/ 10.1016/0167-1987(94)90053-1

Kroulik, M., F. Kumhala, J. Hula, and I. Honzik. 2009. The evaluation of agricultural machines field trafficking intensity for different soil tillage technologies. *Soil and Tillage Research* 105: 171-175. http://dx.doi.org/10.1016/j.still.2009.07.004

Raper, R.L., and J.M. Kirby. 2006. Soil Compaction: How to do it, Undo it, or Avoiding Doing it. ASAE distinguished lecture # 30, pp. 1–14. Agricultural equipment technology conference, 12-14 February 2006, Louisville, Kentucky, USA.

Smith, D., and J. Dickson. 1990. The contributions of vehicle weight and ground pressure to soil compaction. *Journal of Agricultural Engineering Research* 46: 13-29. http://dx.doi.org/ 10.1016/S0021-8634(05)80110-6