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RESEARCH ARTICLE

PREDICTION OF SOIL/TIRE INTERFACE CONTACT PRESSURE AND THE ASSOCIATED DRY BULK DENSITY CHANGE ALONG SOIL PROFILE CAUSED BY WHEEL TRAFFIC BY USING THE FEM PLAXIS CODE

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ABSTRACT

Research results have shown that soil compaction caused by agricultural machinery traffic can have an adverse effect on crop production. Various authors have tried to numerically model and investigate the degree of compaction in relation to machinery axle load, traffic, and the mechanical characteristics of the soil. Assuming a uniform soil/tire interface contact pressure distribution is one of the main problems with most of the FEM-based numerical models. Soil/tire interface contact pressure is not uniformly distributed; it varies depending on the soil properties and tire characteristics. We used PLAXIS to numerically model the soil/tire interface contact pressure perpendicular to the vehicle movement direction. The soil/tire interaction was modeled with a PLAXIS beam element of varying flexural rigidity placed on the soil surface loaded with a uniform pressure intended to simulate the load on the soil from the tire. Depending on the mechanical parameters of the specific soil and flexural rigidity of the beam element, different types of contact pressure distribution were obtained. A U-shaped soil/tire interface contact pressure distribution was obtained for a soft beam element while a parabolic type of distribution was observed for a rigid beam element. The results agree with what we have found in the literature. We also determined the dry bulk density profile in the soil caused by compaction using the PLAXIS simulation technique. These simulation results were compared to the measured field data available and it was found that the two are in agreement. Hence, beam elements with appropriate flexural rigidity can be used in machinery-traffic-based compaction modeling.

INTRODUCTION

In today's mechanized farming excessive traffic occurs frequently. In a single cropping season, the loaded wheels of agricultural machines such as tractors and self-propelled harvesters as well as other equipment used in agro-technical operations are in repeated contact with each point of an arable land. 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 tillage (multiple passes) it would exceed 100% during one cropping cycle (Kroulik *et al*., 2009). In addition to the soil/tire interface 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. Generally, the degree of soil compaction on farm land depends on the following two parameters:

1) Soil mechanical strength, which is influenced by intrinsic properties such as texture, soil organic matter content, and structure of the tilled layer at wheeling (Horn *et al*., 1994) and
2) Its water content (Guierif, 1984) and loading, which depends on axle load, tire dimensions, and velocity. Compaction degrades soil by decreasing water infiltration and increasing runoff, resulting in increasing crop production problems, thereby decreasing crop yields and the profitability of farming systems (Way *et al*., 2004). Furthermore, the increase in the dry bulk density of the soil which results from compaction raises the strength of soil and consequently decreases the penetrability of soil by plant roots. This results in a reduction in the yield of the field (Radford *et al*., 2000). Soil compaction by machinery traffic in agriculture can be considered as one of the most important physical limiting factors for plant root growth and decreasing crop production and it is a well-recognized problem in many parts of the world (Chan *et al*., 2006, Gysi, 2000). Different models are currently used for predicting the degree of compaction by machinery traffic on arable land. These models usually contain two basic components: 1) Predicting the soil/tire interface contact pressure distribution and contact area which is taken as the fundamental input parameter to predict the compaction of subsurface soil; and 2) Predicting the stress distribution/propagation through the soil profile and the associated strain which results in predicting the degree of compaction through the stress–strain relationship obtained from the mechanical parameters of the soil. These parameters are obtained through laboratory tests. These models in soil compaction can be divided into two fundamental groups: analytical and numerical finite element models (Defossez *et al*., 2002). The analytical method is usually suited for homogeneous materials, but soil in general and agricultural soil in particular is not homogeneous and the mechanical properties of the soil vary both horizontally and vertically along the profile of the soil.

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As a result it becomes necessary to use numerical FEM models to simulate soil compaction. Although numerical FEM models require more mechanical input parameters, they are more accurate in describing the mechanical behavior of soil and predicting the associated degree of compaction. However, it has been found that it is difficult to measure and obtain the vertical contact pressure distribution on the soil/tire interface as the surface features of the tire as well as rough soil surfaces prevent accurate measurement. Some authors tried to overcome these difficulties by taking stress measurement at 0.1m below the surface of the soil (Keller 2005; Keller *et al.*, 2002). Some have tried to do the experiment on paved roads (Koolen *et al*., 1992) and by imbedding a pressure gauge directly in the tire (Way *et al*., 2004). For different types of soils, loads, and tires a U-shaped or a parabolic type of contact stress distribution has been observed (Keller *et al*., 2007). In this paper we used the finite element code PLAXIS to numerically generate the distribution of vertical contact stress (contact pressure) at the soil/tire interface. With the introduction of a beam element of varying stiffness on the soil surface, we are able to simulate the actual soil/tire interaction so that we are able to generate the soil/tire interface contact pressure distribution, stress-strain propagation, and the associated rise in the dry bulk density across the soil profile. These simulation results are then compared to the field data of dry bulk density obtained through a wheeling test. The aim of this paper is to predict the contact pressure distribution at the soil/tire interface of machineries on agricultural soil at Hawassa Ethiopia and the resulting dry bulk density change across the profile utilizing the FEM modeling of PLAXIS code.

MATERIALS AND METHODS

Field experiment and machinery used

The wheeling test/experiment was carried out at Hawassa University farm plot located at (7^0 02′ 50.63″ N) and (38^0 29′ 54.13″ E) in Hawassa, southern Ethiopia, 1715 m above sea level during March 2011. The vehicle used for the wheeling (compaction) experiment was a 2WD dual rear wheel drive truck which has the characteristics as shown in Table 1. The magnitude of the soil/tire interface contact pressure was varied by using the same vehicle with varying pay-loads on it. The first wheeling test was carried out by the truck with no pay load on it and the second test was carried out with a payload of 5050 kg (49.54 kN) loaded on the truck. We used the same truck for both wheeling experiments (heavy load and light load). The truck is a highway vehicle used for the removal of the final product out of the farm field. Both the front and rear wheels of the truck were fitted with a Dunlop Radial tire of size 11R × 20 (section width is 11 inches or 27.9 cm while the rim diameter is 20 inches or 50.8 cm; R indicates that the tire is radial) and inflation pressure was 750kPa. The traction surface of all tires has a V-groove tread. Since the rear wheel of the truck has a dual type of tire, the track covered by the front and rear wheel is slightly displaced to each other and consequently the track covered on the ground by the rear wheel is bigger than the individual tire section width. The driving speed of the vehicle was maintained at approximately 3.6 km/h (1m/s).

Soil profile and field experiment

The wheeling experiment was executed at Hawassa University farm plot six months after maize harvesting. The farm was not tilled again after the harvest untill the date of the experiment. The area has a well-drained clay soil of volcanic ash origin (Andisols) with low organic matter content varying from 0.56 % (w/w) on the surface to 0.19 % (w/w) at a depth of 90 cm. It is not stony (Table 2). The area (farm land) has been plowed once in a year with a moldboard plow to a depth of 25 cm. 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. One of the wheeling tests was done during a rainy period, where the plot's moisture content was 21%, and the other was conducted after the rainy period when the average moisture content of the plot was 16.5%. The moisture content was measured by gravitation method (oven-drying technique). Soil core samples at different depths (10 cm, 30 cm, 60 cm, and 90 cm) were collected with a standard cylindrical core sampler of 50 mm diameter and 100 cm^3 volume. This was done after 0 (control), 1, 2, 4, and 8 vehicle passes over the same track in three replications. In all experiments the vehicle speed was approximately 1 m/s and there was no hitch load attached to the vehicle. The soil response variable dry bulk density was measured from the collected samples. The modified proctor density of the soil was measured at different layers (Table 2). This measurement was done with a motorized impact machine utilizing a hammer of 4.5 kg mass dropped from a height of 45.7 cm. Five specimens at varying moisture contents were used to generate the curves for each layer.

PLAXIS and the field experiment

PLAXIS is a finite element package intended for the two-dimensional analysis of deformation and stability in geotechnical engineering (PLAXIS, 2006). We used this package to numerically generate the distribution of soil/tire interface contact pressure (vertical stress), stress-strain propagation along the soil profile, and the resulting change in the dry bulk density profile after the wheeling test under the drained mode of PLAXIS. In this mode no pore water pressure is developed in the soil. This assumption is justified by the low water content in the soil and the short duration of the applied load. PLAXIS also permits the full automatic mesh generation with updated mesh analysis based on the triangulation principle, i.e. the geometry of the mesh is continuously updated during the calculation. PLAXIS includes several constitutive models of varying complexity and areas of application. The most commonly used models are the soft soil model and Mohr/Coulomb model developed for modeling the elasto-plastic behavior of soil (Wood, 1994). The soft soil model is a modified cam-clay type model that can be used to simulate the behavior of soft soils like normally consolidated clays. The model performs best in primary compression situations. The main characteristics of this model are: (1) stress-dependent stiffness, (2) distinction between primary loading and unloading–reloading, (3) memory for pre-consolidation, and (4) failure behavior according to the Mohr/Coulomb criterion (PLAXIS, 2006). We introduced a beam element (Figure 1) at the soil surface onto which a constant uniform vertical stress (σ_0) is applied. This stress is the average contact stress (σ_0) applied by the wheel on the soil. It was estimated as the load on the axle divided by the tire-surface contact area of all wheels on the axle as shown in equation (1).

$$\sigma_o = \frac{Axle\ weight}{Tyre\ soil\ contact\ area\ of\ all\ tyres\ on\ the\ axle} \quad (1)$$

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 used to approximate the contact area.

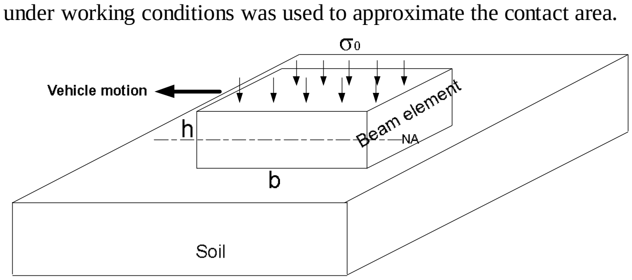


Figure 1. Beam element

The distribution of the vertical stress between the beam element and the soil (soil/tire interface contact pressure) depends on the magnitude of the vertical stress (σ_0), the deflection of the beam element, and on the soil resistance. PLAXIS calculates beam deflection using the concepts developed in the mechanics of beams (Gere *et al.* 1997). The flexural rigidity as well as its dimensions characterizes the beam element. The flexural rigidity is a measure of the resistance of a beam element to bending and it is given by equation (2):

$R = E \times I$(2)

where E is the Young's modulus of the beam (k Pa) and I is the area moment of inertia (m^4) of the cross-section with respect to the neutral axis (NA).

Therefore, for the beam element with a rectangular cross-section shown in Figure 1, R is given by equation (3):

$R = E \times \frac{Ah^2}{12}$(3)

where A is the cross-sectional area of the beam (A = bh).

A wheel can be represented by a cylinder with a circular cross-section of diameter D (Figure 2).

Figure 2. Cylinder with a circular cross-section

The flexural rigidity of the circular cylinder can be calculated using equation (4).

$R = E \times \frac{\pi D^4}{64}$(4)

The above equations (3 and 4) indicate that the flexural rigidity R increases as the Young's modulus E and other geometric dimensions increase. However, measuring the wheel flexural rigidity directly is complex as its value depends upon various parameters like tire structure, inflation pressure, material type, etc. The variation of the contact stress perpendicular to the driving direction was studied as a function of the wheel flexural rigidity, soil mechanical properties, and the uniformly applied stress (σ_0). Furthermore, we used the PLAXIS software to generate the dry bulk density profile of the soil caused by the soil/tire interface contact pressure distribution on the soil surface induced by machinery traffic. During the study we assumed a fully drained plain strain condition and the simulation was done with the soft soil model of PLAXIS with soil mechanical parameters as shown in Table 3. A two-dimensional cross-section of (10m width × 1m depth) with 327 elements (Figure 3) was used for the calculation. The boundary conditions, contact stress and beam, and the finite element mesh are shown in Figure 3.

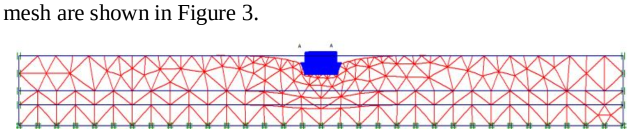


Figure 3: Finite element mesh (deformation magnified 5 times)

The soil interface at 1 m depth is assumed to be rigid.

The PLAXIS software was used to calculate the volumetric strain and hence the change in the dry bulk density profile induced by the soil/tire interface contact pressure associated with the weight of the machinery used during the wheeling test. The dry bulk density data obtained during the wheeling test are compared with the results of the PLAXIS simulation. PLAXIS calculates only the stress and strain in the soil profile so we used equation (5) to calculate the final dry bulk density (ρ_f) from the change in the volumetric strain ($\Delta\varepsilon_v$) obtained from PLAXIS and initial dry bulk density (ρ_i) obtained from field measurements.

$\rho_f = \rho_i \left(\frac{1}{1 + \Delta\varepsilon_v}\right)$ (5)

PLAXIS needs the following cam–clay type parameters: modified compression index (λ^*), modified swelling index (k^*), cohesion (c), angle of internal friction (φ), and dilatancy angle (ψ). From a uniaxial compression test on an oedometer we found the compression index(C_c) and the swelling index (C_s) of undisturbed samples taken from the field. Both parameters are defined in a one-dimensional compression test graph of void ratio (e) versus $log\sigma_1$ (Wood 1994). But PLAXIS considers parameters obtained from a vertical strain (ε) versus $log\sigma_1$ graph and therefore defines a modified compression index λ^* and a modified swelling index k^* as shown in equations (6 and 7).

$\lambda^* = \frac{C_c}{2.3(1+e)}$ (6)

$k^* \approx \frac{2C_s}{2.3(1+e)}$ (7)

Where C_c and C_s are the compression and swell index of the soil respectively.

Despite the fact that the void ratio (e) changes during compression, PLAXIS recommends a constant value for the void ratio in equations (6 and 7). The value for the void ratio can be the average value or just the initial value prior to compression. Furthermore, for the type of materials which can be described by the soft soil model, the dilatancy angle can generally be ignored. A dilatancy angle of zero degrees is considered in the standard settings of the soft soil model. Actually, apart from heavily-over- consolidated layers, clay soils tend to show no dilatancy at all (i.e. ψ = 0). The cohesion (c) and the angle of internal friction (φ) were estimated from a shear box test. In the soft soil model the Poisson ratio (ν) will usually be in the range between 0.1 and 0.2. For the loading of normally consolidated materials Poisson ratio plays a minor role but it becomes important in unloading problems (PLAXIS 2006).

Wheeling test simulation

The PLAXIS soft soil model used to determine the dry bulk density profile permits us to take into account the effect of the passage of the front wheel prior to the rear wheel by the preconsolidation of the soil using the Pre-Overburden Pressure (POP) as defined by equation (8). It takes into account the soil's stress history.

$POP = |\sigma_p - \sigma'^0_{yy}|$(8)

where σ_p is the preconsolidation pressure (the greatest vertical stress reached previously) and σ'^0_{yy} is the in-situ effective vertical stress at the soil surface. But at the soil surface the value for σ'^0_{yy} is zero. Therefore, the value for POP is estimated by the preconsolidation pressure. A comparison of the soil/tire interface contact pressure was made based on the following two assumptions:

1)Rigid beam element or cylinder (R = 8500 kN m^2)
2)Very soft beam element or cylinder (R = 0.01 kN m^2)

In PLAXIS very soft materials are assumed to have a flexural rigidity value of R = 0.01 kN m^2 while rigid materials are assumed to have a flexural rigidity R = 8500 kN m^2.

Table 1. Characteristics of machinery used during the experiment

Machine type	Net machine weight (kN)	Front axle weight (kN)	Front wheel contact area (m^2/tire)	Front wheel contact pressure (kPa)	Rear axle weight (kN)	Rear wheel contact area (m^2/tire)	Rear wheel contact pressure (kPa)
Daewoo (Novus) 2WD truck dual rear wheel (not loaded)	82.80	44.54	0.078	285.49	38.26	0.068	141.49
Daewoo (Novus) 2WD truck dual rear wheel (loaded)	132.34	61.95	0.081	384.31	70.39	0.073	241.71

Table 2. Profile characteristics of the soil

Horizon depth (cm)	Modified proctor		Organic carbon (%age w/w)	Clay percentage (< 0.002 mm)	Silt percentage (0.002-0.05 mm)	Sand percentage (0.05 –2 mm)	Plastic Index (PI)	Color of the dry soil	Texture
	Optimum water content (%age w/w)	Max dry bulk density (gm/cm^3)							
[0 – 50]	20	1.48	0.56	41	28	31	10.1 %	Brown	Clay
[50 – 70]	21	1.49	0.41	46.3	26	27.7	11.2 %	Light gray	Clay
[70 – 100]	22.5	1.51	0.19	51.6	12	36.4	18.7 %	Light yellowish brown	Clay

Table 3. PLAXIS parameters of the soil profile (moisture content w = 21%)

Soil parameters	Unit	Horizon depth (cm)		
		[0 – 50]	[50 – 70]	[70 – 100]
Cohesion (c)	kPa	41.2	40.5	50.6
Angle of internal friction (φ)	(^{0})	25.92	26.6	24.94
Poisson's ratio (ν)	(-)	0.15	0.15	0.15
Dilatancy angle (ψ)	(^{0})	0	0	0
Modified compression index (λ^*)	(-)	0.255	0.254	0.255
Modified swelling index (κ^*)	(-)	0.091	0.091	0.091

The value of the stresses (σ_o) applied on top of the beam element is calculated using equation (9).

$$\sigma_o = \frac{W}{A} \quad (9)$$

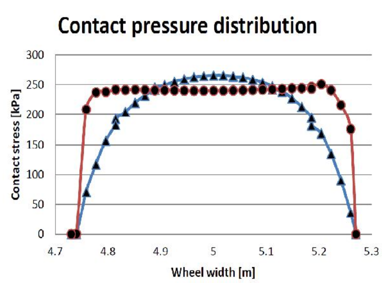
where w is weight on the tire (kN) and A is the tire–surface contact area (m^2).

Accordingly, the front wheel is simulated with a vertical contact stress of σ_o = 285.49 kPa and σ_o = 384.31 kPa for light and heavy loads respectively and the rear wheel is simulated with a contact stress of σ_o = 141.49 kPa and σ_o = 241.71 kPa for light and heavy loads respectively.

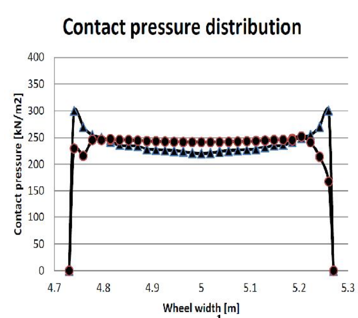
RESULTS

Soil/tire interface contact pressure

Flexural rigidity R of the beam element used to simulate the tire is one of the main factors that affect the soil/tire interface contact pressure. Its value increases with inflation pressure and other tire parameters. Considering that our tire or beam element is very soft (R = 0.01 kN m^2), then the vertically applied load through the wheel is assumed to act directly on the soil surface. Therefore, we expect a U-shaped contact pressure distribution possibly affected by the mechanical characteristics of the soil as shown in Figure 4. On the other hand when we consider an infinite value of R = 8500 kN m^2, the beam element is very rigid and it is expected that the contact pressure distribution is possibly parabolic as shown in Figure 4. The use of PLAXIS allowed us to investigate the effect of soil properties and tire stiffness on the soil/tire interface contact pressure distribution. The result of the study indicated that the contact pressure distribution is influenced by the externally applied load, properties of the soil, and the mechanical characteristics of the beam element (tire characteristics). The indicated contact pressure distribution is in agreement with Craig (2004) on foundation problems in the field of geotechnical engineering. Craig indicated that the contact pressure under rigid foundations is not uniformly distributed. We also examined the effect of change in moisture content of the soil on the resulting soil/tire interface contact pressure distribution. Moisture content is one of the main factors that change the plastic behavior of a soil (Terzahgi *et al*., 1996). Therefore, a change in the moisture content of a soil could also change the distribution of the contact pressure between the wheel and the ground surface. The simulation was performed for clay soil at two different levels of moisture content, namely 16.5% (called dry soil) and 21% (called wet soil) under the same applied load. The resulting contact pressure distribution is shown in Figure 4.



a) Wet soil



b) 16.5 % ($g\,g^{-1}$) dry

Figure 4. Calculated vertical contact stress distribution for the heavy load on the clay soil using a soft plate (●) and a very rigid plate (▲) at two different values of moisture content: a) 21% ($g\,g^{-1}$) wet and

As the soil gets drier it becomes stiffer/stronger and difficult to deform, and as a result there will be stress (pressure) concentration at the edges of the beam element Figure 4. This result agrees with Johnson's (1985) contact mechanics, where for perfectly elastic bodies subjected to indention by a flat plate the stresses will be at their maximum at the edge of the punching plate. Furthermore, PLAXIS allows us to visualize points/locations where the stress exceeds its plastic threshold value. There are a wide variety of soil/tire interface contact pressure distributions available in the literature but in particular the U-shaped distribution is usually expected for clay soils but not for sandy soils.

We also observed that a change in the applied load and hence σ_o does not affect the shape of the soil/tire interface contact pressure Figure 5. It only changes the magnitude of the difference between the maximum and minimum values. This agrees with Keller's (2005) statistical analysis which shows that the shape of contact pressure distribution is not dependent on the magnitude of the applied load.

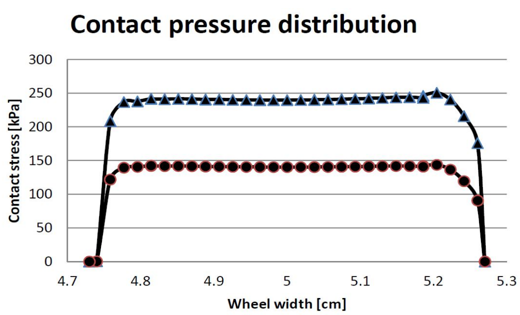
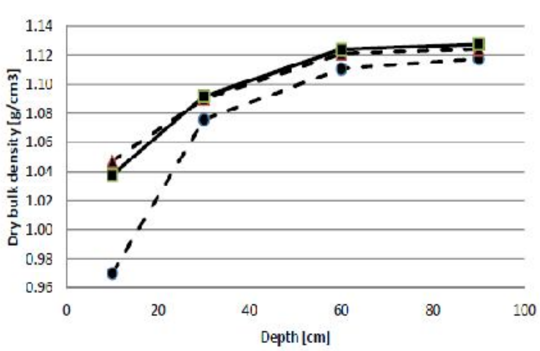


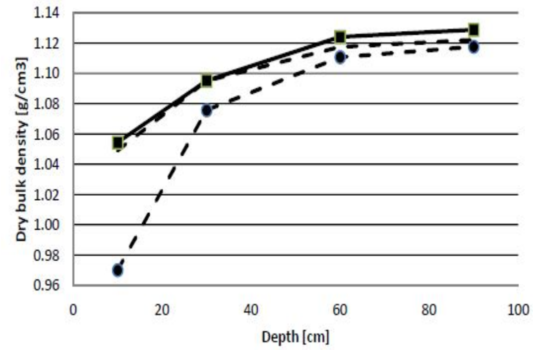
Figure 5. Calculated vertical contact stress distribution with varying applied loads on a wet (21% g g^{-1}) clay soil using a soft plate and hard plate. $\sigma_o = 241.71\ kN$ (▲) and $\sigma_o = 141.49\ kN$ (●).

Dry bulk density profile

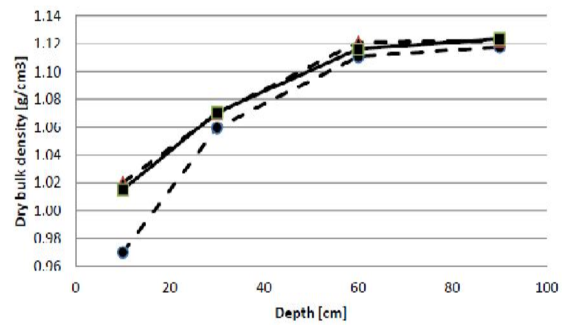
We used PLAXIS to determine the stress and strain distribution along the soil profile as a function of tire parameters (flexural rigidity) and soil parameters. Accordingly, the associated volumetric strain and hence the resulting change in the dry bulk density along the soil profile was also calculated. As shown in Figures 6 and 7, the value of the dry bulk density obtained from field measurements always fell between the simulated values found using a rigid plate (maximum flexural rigidity) and a soft plate (minimum flexural rigidity) up to a depth of 30 cm in the soil profile. Hence, giving a value between the zero and infinite value of flexural rigidity for our tire seems to be more appropriate and, therefore, having a good estimate of the input parameters used in PLAXIS could improve the calculation significantly. It is also observed that the dry bulk density obtained from a soft plate is always greater than that obtained using a rigid plate. This could be due to the higher estimate of the soil/tire contact pressure at the center of the wheel for the soft tire (beam element) compared to that obtained using a hard tire.



(a)



(b)



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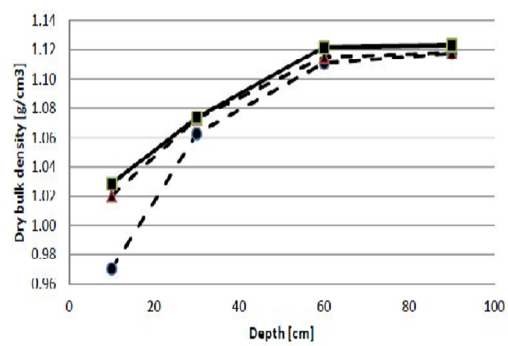
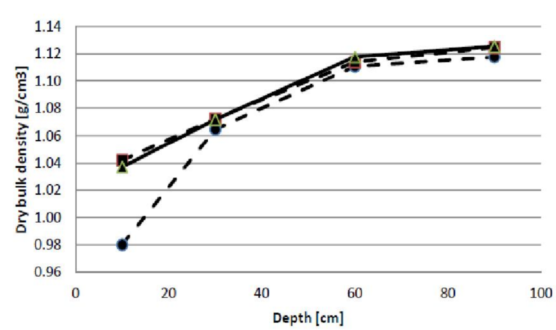


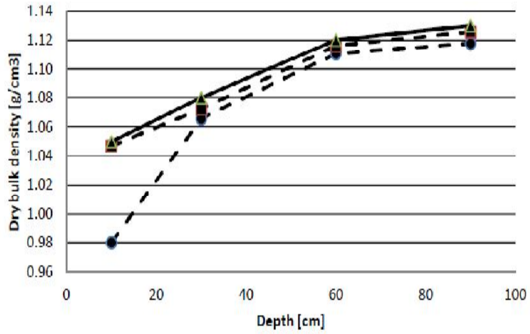
(d)

Figure 6. Dry bulk density profile at the tire center after single pass with: Initial value (broken line with dark circles (●)), one pass measured value (broken line with dark triangles (▲)), and calculated or simulated value (solid line with dark rectangles (■)) on wet soil at moisture content of 21% (g g^{-1}) with a) heavy load and hard plate, b) heavy load and soft plate, c) light load and hard plate, and d) light load and soft plate.

The simulation for the dry bulk density profile agrees with the observation from the field wheeling test. However the difference seen between the simulation and observation is perhaps is the result of non-optimum mechanical parameters of the soil.



(a)



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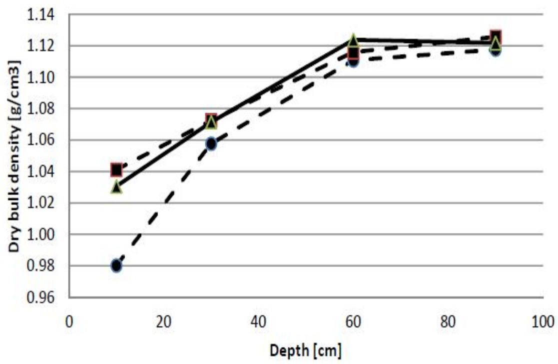

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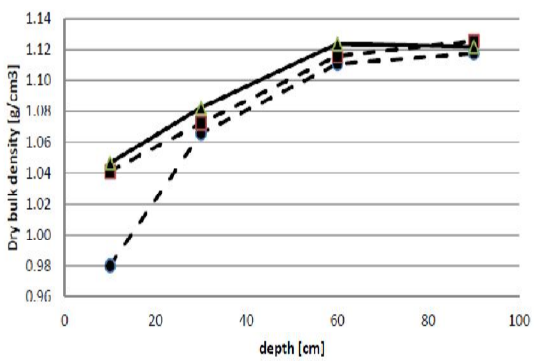

(d)

Figure 7. Dry bulk density profile at the tire center after single pass with: Initial value (broken line with dark circles (●)), one pass measured value (solid line with dark triangles (▲)), and calculated or simulated value (solid line with dark rectangles(■)) on dry soil at a moisture content 16.5 % (g g^{-1}) with a) heavy load and hard plate, b) heavy load and soft plate, c) light load and hard plate, and d) light load and soft plate.

A good estimate of tire flexural rigidity and input parameters could improve PLAXIS simulation results. Considering the fact that the field measurements of the dry bulk density profile were roughly between those obtained with rigid and soft beam elements, giving an intermediate value of the flexural rigidity (R) between R = 0.01 kN m^2 and R = 8500 kN m^2 seems more appropriate for our wheel. Our expectation here is that tire characteristics (flexural rigidity) affect the contact stress/pressure distribution.

Conclusion

It has been shown that using PLAXIS together with the concept of a beam with a certain magnitude of flexural rigidity and subjected to a uniform pressure can be used to numerically simulate the soil/tire interface contact pressure and dry bulk density profile during compaction with machinery traffic in agriculture. Our results indicate that the use of PLAXIS enables us to numerically simulate soil compaction based on measured values of soil mechanical properties, assumed tire flexural rigidity, and the applied vertical load from the weight of the machinery. Tire flexural rigidity is a complex parameter as it is dependent upon tire characteristics like tire structure, inflation pressure, material type, etc. But using PLAXIS allows us to approximate its value between two extreme values for soft and rigid plates. Establishing a quantitative relationship between tire flexural rigidity and its material and geometrical parameters like inflation pressure, structure, material, dimensions, etc. will enable us to improve our approach in modeling soil compaction.

REFERENCES

Chan, K.Y., Oates, A., Swan, A.D., Hayes, R.C., Dear, B.S., Peoples, M.B., 2006. Agronomic consequences of tractor wheel compaction on a clay soil. Soil and Tillage Res.89: 13-21.

Craig, R.F., 2004. Craig's Soil Mechanics. Spon Press, New York.

Defossez, P., Richard, G., 2002. Models of soil compaction due to traffic and their evaluation. Soil and Tillage Res.67: 41-64.

Gere,J.M.,Timoshenko,S.P., 1997. Mechanics of Materials. PWS Publishing company, Boston.

Guerif, J., 1984. The influence of water-content gradient and structure anisotropy on soil compressibility, J. Agric. Eng. Res. 29: 367-374.

Gysi, M., Klubertanz, G., Vulliet, L., 2000. Compaction of an Eutric Cambisol under heavy wheel traffic in Switzerland. Soil and Tillage Res. 56: 117-129.

Horn, R., Taubner, H., Wuttke, M., Baumgartl, T., 1994. Soil physical properties related to soil structure. Soil and Tillage Res. 30: 187-216.

Johnson, K.L., 1985. Contact Mechanics. Cambridge University Press, Cambridge.

Keller, T., Trautner, A., Arvidsson, J., 2002. Stress distribution and soil displacement under a rubber-tracked and a wheeled tractor during ploughing, both on-land and within furrows. Soil and Tillage Res. 68: 39-47.

Keller, T., 2005. A Model for the Prediction of the Contact Area and the Distribution of Vertical Stress Below Agricultural Tires from Readily Available Tire Parameters. Biosystems Engineering J. 92: 85-96.

Keller, T., Defossez, P., Weisskopf, P., Arvidsson, G., 2007. SoilFlex: A model for prediction of soil stress and soil compaction due to agricultural field traffic including a synthesis of analytical approaches. Soil and Tillage Res. 93: 391-411.

Koolen, A.J., Lerink, P., Kurstjens, D.A.G., Van den Akker, J.J.H., Arts, W.B.M., 1992. Prediction of aspects of soil-wheel systems. Soil and Tillage Res. 24: 381-396.

Kroulik, M., Kumhala, F., Hula, J., Honzik, I., 2009. The evaluation of agricultural machines field trafficking intensity for different soil tillage technologies. Soil and Tillage Res. 105: 171-175.

PLAXIS, 2006. Finite element code for soil and rock analysis. Balkema, Rotterdam, Nertherlands.

Radford, B.J., Bridge, B.J., Davis, R.J., McGarry, D., Pillai, U.P., Rickman, J.F., Walsh, P.A., Yule, D.F., 2000. Changes in the properties of a vertisol and responses of wheat after compaction with harvester traffic. Soil and Tillage Res. 54: 155-170.

Terzaghi, K., Ralph B. P., Mesri, G., 1995. Soil Mechanics in Engineering Practice. John Wiley and Sons, INC. New York.

Way, T., Kishimoto, T., 2004. Interface pressures of a tractor drive tire on structured and loose soils. Biosystems Eng. J. 87: 375-386.

Wood, D.M., 1994. Soil behavior and critical state soil mechanics. Cambridge university press, New York.

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