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Analysis of Changes in Soil Compaction in The Zone Next to Tracks of Agricultural Tractor Passages

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Abstract: Results of investigations on the effect of multiple passages of tractors of various powers (small-medium-large) on soil compaction within the track and the side zone are presented. Changes in specific pressures as a result of variable support area of considered tractor wheels and their side-compacting action are also presented. There was found statistical significance of the effect of wheel pressures, depth of soil layer and its distance from the track on soil compaction. The investigations were carried out on clayish sand with the use of 3 tractors. Basing on the obtained results a set of empirical equations was developed.

Key words: tractor, tires, contact surface, specific pressures, soil compaction

Tarım Traktörlerinin Tekerlek İzinde Toprak Sıkışıklığı Değişiminin Analizi

Özet: Farklı güçlere sahip traktörlerin (küçük-orta-büyük) birden çok geçiş sonrasında, tekerlek izinde ve izin yanında oluşan toprak sıkışıklığı incelenmiş ve sonuçlar verilmiştir. Ele alınan traktörlerin tekerlek izi alanında ve izin yan alanında özgül basınç değerindeki değişimler de incelenmiştir. Tekerlek basıncının, toprak tabakası derinliğinin ve tekerlek izinden uzaklığın toprak sıkışıklığına etkileri istatistiksel olarak önemli bulunmuştur. Araştırma 3 traktörle, killi-kumlu toprakta yapılmıştır. Araştırma sonuçlarından elde edilen veriler kullanılarak amprik eşitlikler geliştirilmiştir.

Anahtar Kelimeler: traktör, tekerlek, kontak alanı, özgül basınç, toprak sıkışıklığı

INTRODUCTION

Changes in soil properties in the arable and subsoil layers under pressure are considered [Rusanov, 1997] as most important factors in determination of soil productivity. The range of these changes depends on many parameters, namely: vehicle axle loads, type of tires and the wheel specific pressures [Chamen et al., 2003; Gysi, 2001], and overlapping of tracks resulting from multiple running of tractor outfits over the field [Abebe et al., 1989; Buliński, 1995; Buliński, 1998; Chi et al., 1993; Walczyk, 1995]. The last factor is important since stresses in the soil accumulate as a result of multiple running [Alakukku et al., 2003; Horn and Roste, 2000] increasing the profile compaction to a depth often exceeding the level of tillage performed every year. The effects of soil compaction can last several years depending on the stress value occurred [Alakukku, 1996; Etana and Håkansson, 1994].

The wheel pressures of vehicles moving over the field influence also soil properties in the zone next to the track. According to Wiermann et al., (2000), the multi-directional stress under the wheel moving on the field surface creates the shearing forces. The direction of this stress can vary depending on direction of wheel movement, approaching to or going away from the soil particle being considered [Wiermann et al., 2000]. In investigations of Błaszkiewicz [1998] carried out on light soil it was fund that tractor tires caused considerable increase in penetration resistance within the distance of 0.15 m from the track, especially if specific pressures exceeded 0.1 MPa. However, majority of published reports refers to the zone situated directly under the wheel track.

The undertaken investigations aimed at determination of changes in soil compaction caused by multiple running of agricultural tractors.

Material and methods

Investigations were carried out on the soil defined (on the basis of soil grain composition) as clayish sand of fluming content 19% and moisture ranged from 8.9 to 10.4% (on the average 9.6%, standard deviation σ = 0,39). The field was prepared to tests by ploughing to a depth 0.35 m, and then left for 14 days to obtain self-consolidation of soil. The field was divided into measuring lengths of dimensions 20 m x 12 m. The parameters of non-compacted soil were determined on control length. The soil on particular measuring lengths was compacted with the use of agricultural tractors MF 255, Ursus 4512 and Ursus 1234, considered as representative for particular tractor classes used most often in field operations. Selected technical and exploitation data of tractors are listed in Table 1.

Table 1. Selected technical and exploitation data of tractors used in investigations

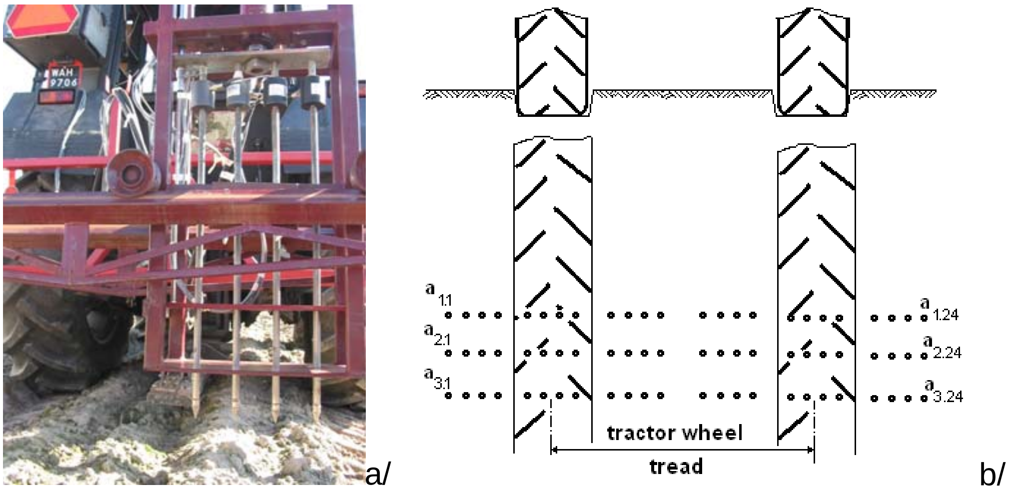
Item		Unit	Tractor		
			MF255 (**A**)	Ursus 4512 (**B**)	Ursus 1234 (**C**)
Class (draw-bar pull)		kN	0,9	1,4	2,0
Engine power		kW	35	49	72
Totral weight		kN	22,98	31,77	57,42
Axle load	front	kN	8,68	12,28	23,58
	rear	kN	14,30	19,49	33,84
Tire size	front	cal	6.00-16 (**O$_1$**)	7.50-16 (**O$_2$**)	14.9-24 (**O$_3$**)
	rear	cal	12.4-32 (**O$_4$**)	13.6/12-36 (**O$_5$**)	18.4 R34 (**O$_6$**)
Inflation pressure	front	kPa	210		120
	rear	kPa	120		120

Each tractor made 1-2-4-8 compacting runs over the same track at speed 5 km/h (± 0.1 km/h). After each series of measurements the soil compaction was measured in the layer of 0-300 mm across the track every 100 mm and in the side zones at distance 100-200-300-400 mm on the left and on the right of the tracks.

Soil compaction was measured with the use of a set consisted of 4 penetrometer probes fixed to a special frame mounted on tractor hydraulic lift. The probes were situated crosswise to direction of tractor motion at distance 100 mm and were equipped with cones of diameter 20.27 mm and apex angle 30º, according to ASAE Standard, 1993.

Resistance of each probe was recorded with the use of electric resistance force transducers CL14, while the depth of probes with capacitive displacement sensor CL-70-500. The probe resistances were recorded in the range of 0-300 mm every 1 mm with accuracy 5 N, with the use of digital computer set for measurements and recording DMCplus.

In order to determine the specific tractor wheel pressures, during each tractor run over the measuring length tractor was stopped and the wheel-soil contact area was measured. The tractor wheel tire was impressed on a paper sheet and the print area was measured with the use of a planimeter with accuracy 1 cm^2, while the print length and width were measured with accuracy ±0,5 mm.



a/ b/

Fig. 1. Probes for soil compaction measurements;
a/- set of penetrometers, b/- distribution of measurement points

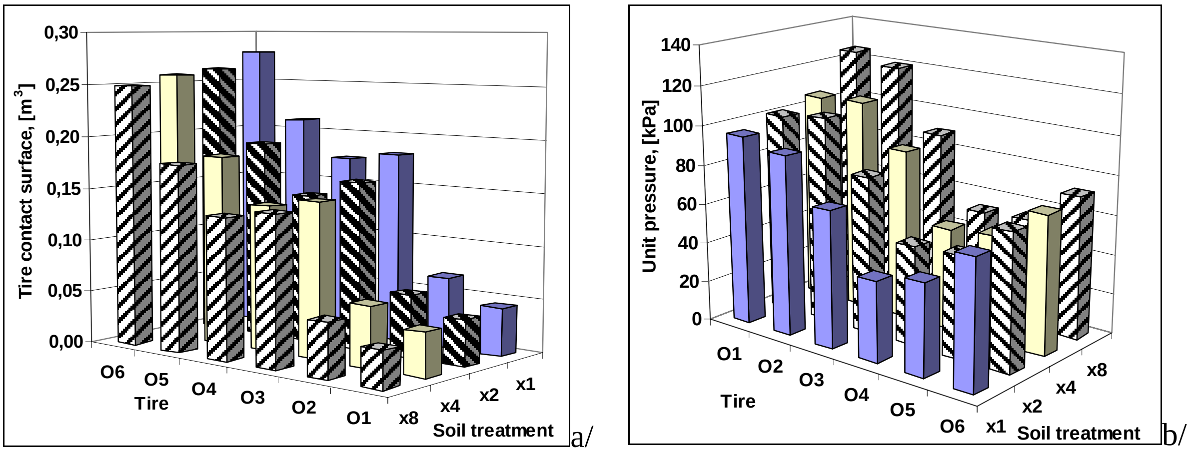


Fig. 3. Changes in tire-soil contact area (a) and specific pressure values (b) in particular measurement variants

Results of investigations

Results of measurements on tire-soil contact area for investigated tractors are presented in Fig. 3a.

Measurements on contact area showed that degree of ground compaction during overlapping of the tracks, which occurs often on natural fields, affected significantly the size of tractor wheel support area. This is an important factor in determination of specific pressures exerted on soil by the wheels. Analysis of tire-soil contact area showed that this area decreased with soil compaction and amounted to 5.7% - 18% after the second pass, 1.8% - 9,0% after four passes, and 2 - 6% after eight passes, depending on tire size. The total change in tire contact area after eight passes amounted to 10.6% - 23.44%, when compared with the first tractor pass. This change was variably influenced by tire size. The highest area differences were found for front tires of tractors O_{1-3} moving over pulverized soil, while lower changes in contact area after subsequent tractor passes were found for rear tires O_{4-5}, which traveled partially over the front wheel tracks. It means that predicting of stresses created in soil under the tractor wheel calls for consideration of soil condition during tractor pass and the resulted specific pressure values. These values, determined on the basis of tractor mass distribution between particular axles, are presented in Fig. 3b.

The obtained values of tire specific pressures indicate that front wheels of the smallest tractor (A) of the least weight transferred to the soil the highest pressures. Depending on number of compacting runs they were higher by 4% - 7% than front tire pressures of the medium-size tractor (B), and by 41% - 46% than front tire pressures of the largest and heaviest tractor (C). These differences can be explained by tractor mass distribution and also by the tire-soil contact area, resulting mainly from tire size. The total pressures calculated for front and rear tires of particular tractors are presented in Table 2.

Table 2. Total pressures of tractor wheel on soil in particular measurement variants

Number of compacting runs	Total tractor wheel pressures[1/], [kPa]		
	A	**B**	**C**
x1	137.36	132.73	125.54
x2	293.22	282.23	264.21
x4	621.52	598.59	551.29
x8	1318.08	1269.15	1152.05

[1/] Designations of tractors see Table 1.

It is evident from the presented values that total pressures of the front and rear wheel of the smallest tractor (A) were higher by 3.5% - 3.9% than the respective values for the medium-size tractor (B), and by 9,4% - 14,4% for the heaviest tractor (C). These differences increased with number of passes. With respect to constantly increasing soil compaction within the track, the dependence between wheel pressures and number of passes was not linear. As a result of changes in tire contact area caused by the increased soil compaction after eight passes over the same track, the accumulated wheel pressure values of the smallest tractor (A) increased by 219.2 kPa, the medium-size tractor (B) by 207.3 kPa, and the heaviest tractor (C) by 147.7 kPa.

The stresses accumulated in the layer under the track as a result of multiple tractor passes over the same track lead to soil compaction also in the adjacent zones. The mean soil compaction values in the layer 0 - 300 mm (Fig. 4) were determined for the track (K) and for the side profiles within the distance 100 – 200 – 300 - 400 mm from the track edge, after subsequent passes of tractors (A, B, C) of total specific pressures 125,54 – 1318.08 kPa (see Table 2).

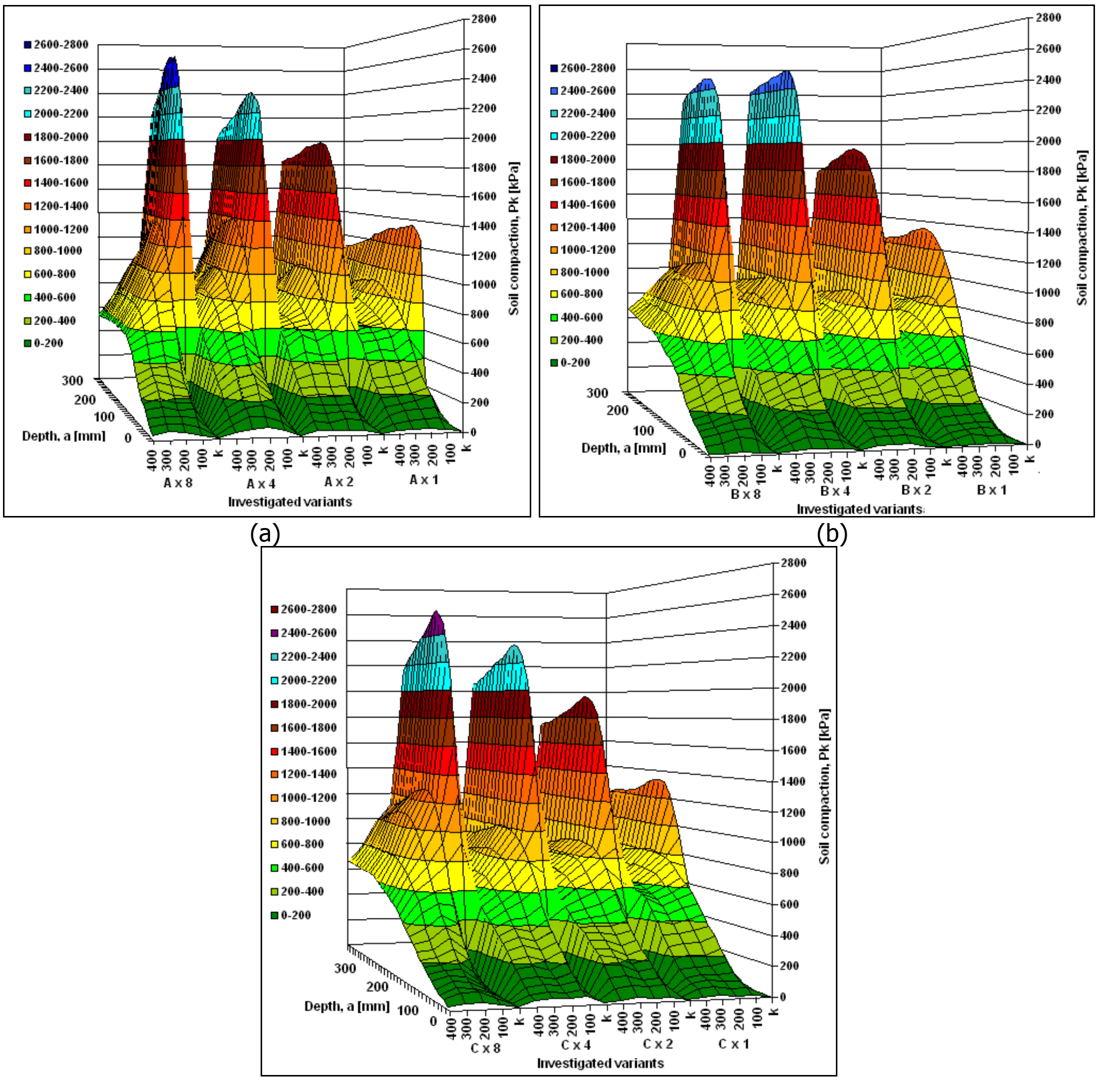
Basing on the obtained soil compaction measurements it was fund that soil compaction within the track increased with specific wheel values: the maximal values amounted to about 1336 kPa after single pass of tractor (C) of pressure 126 kPa, and to about 2644 kPa at pressure 1318 kPa after eight passes of tractor (A) over the same track. Such compaction was found at the depth 50 – 100 mm, while in the deeper layers compaction was lower by about 7 - 16%. In surface track layers of depth 0 - 30 mm, directly contacting the tire, and considerably pulverized as a result of shearing forces coming from tire tread ribs, the soil compaction values were scattered and had a random nature.

In order to compare the effect of different wheel pressures on soil compaction within the track, the values of the entire profile obtained for particular passes are presented as mean values (Fig. 5).

The highest increase in soil compaction in the investigated profiles was found at depth of 150 - 220 mm; the measured value exceeded more than twice the initial state (130-150%). Similar values of maximal soil compaction were obtained also under the track, when sinking depth of wheel was taken into consideration.

In deepest layers (200 - 300 mm) the soil compaction was lower than in middle layers by about 13%.

In order to compare the effect of variable wheel pressure on soil compaction in particular layers, the values obtained for entire profile were presented as the mean values of measurements at distances 100 – 200 – 300 – 400 mm (Fig. 6). It was fund that in relation to non-compacted field (horizontal broken line), an increase in soil compaction in profile closest to the track ranged from about 115 kPa (25%) at wheel pressure 126 kPa (tractor C, single pass) to about 367 kPa (80%) at wheel pressure 1318 kPa (tractor A, eight passes). The respective values for the profile at distance 200 mm from the track ranged from 49 kPa (11%) to 231 kPa (50%), while in the profile at distance 300 mm ranged from 10 kPa (2.3%) to 100 kPa (21%). Changes in soil compaction in the most remote profile were not consistent and ranged from -39 kPa to +34 kPa. An increase in soil compaction at pressures 264, 293, 622 and 1318 kPa corresponds to the value obtained from pass of tractor (A) of the highest specific wheel pressures.



(a)

(b)

(c)

Fig. 4. Changes in soil compaction under the track (k) of tractors A (a/), B (b/), C (c/) and at distance 100 - 400 mm from track edge.

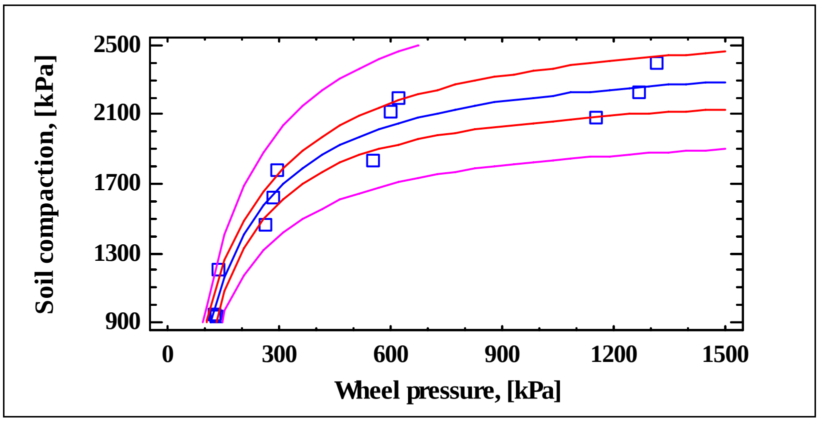


Fig. 5. Changes in mean specific soil compaction under the track at various wheel pressures (Pk)

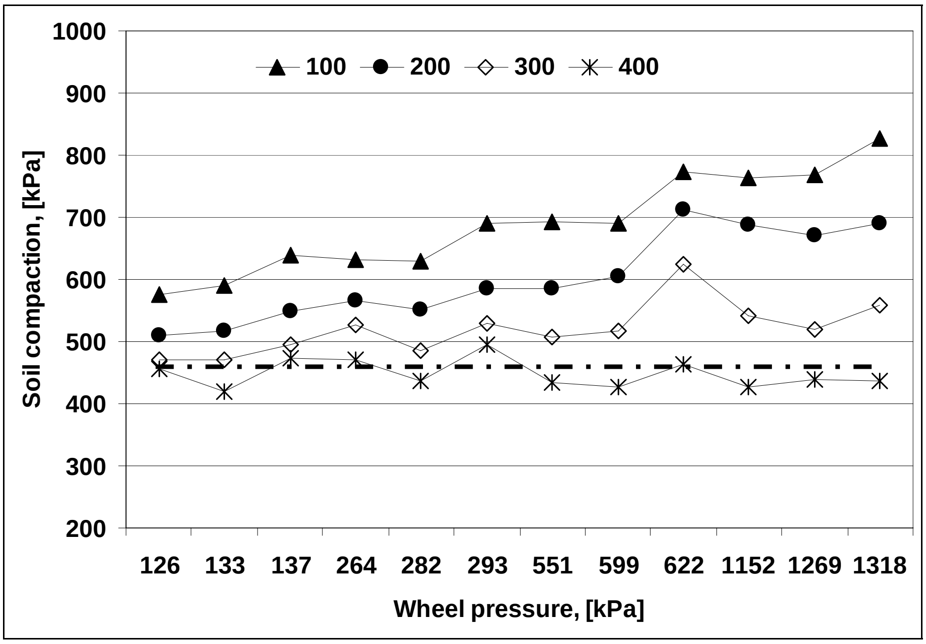


Fig. 6. Changes in mean soil compaction in the profiles aside of track at various wheel pressure (broken line – soil compaction on non-compacted field)

It is evident from presented diagram that the biggest changes were found within distance of 300 mm from the track edge. Taking into consideration the width of wheel track one can find that the zone of highly compacted soil covered at least 900 mm along the track axis. Thus, with application of agricultural vehicles the zone width of compacted soil can totally amount to at least 1.8 m along tractor pass over the field.

In order to determine significance of the effect of considered factors, i.e. depth of layer (a), distance from track (b) and value of total specific pressure (P_k), all the results were subjected to multifactor variance analysis (Multifactor ANNOVA) of Statgraphic package.

The obtained values of statistics point out that all factors considered separately and their interactions have statistically significant effect on soil compaction in the arable layer, with confidence level 95,0%.

Table 3. Results of statistical analysis on investigated factors

Source	Sum of squares	Df	Mean square	F-Ratio	P-Value
Main effects					
P_k	3,73379E6	11	339435,0	150,46	0,0000
b	1,25464E7	3	4,18213E6	1853,79	0,0000
a	1,00476E8	30	3,34919E6	1484,58	0,0000
Interactions					
P_k x b	2,06694E6	33	62634,5	27,76	0,0000
P_k x a	3,73828E6	330	11328,1	5,02	0,0000
a x b	5,45198E6	90	60577,6	26,85	0,0000
Residual	2,23343E6	990	2255,99		
Total (Corrected)	1,30247E8	1487			

All F-ratios are based on the residual mean square error.

In order to find functional dependences between investigated factors, the results of measurements for the track and the side zones were subjected to regression analysis. As a result there was developed the following dependence between mean soil compaction values in the track (k_s) and wheel pressures (P_k) expressed in kPa:

$$K_s = 2{,}718^{(7{,}8147 - \frac{117{,}19}{P_k})}$$

R = -0,974

SEE = 0,0775%

The following equation for soil compaction in side zones (K_s) depending on the depth of layer (a) in mm, its distance from the track (b) in mm, and the wheel pressures was developed:

$$K_s = 32{,}2572 * \frac{a^{0{,}7794}}{b^{0{,}2526}} * P_k^{0{,}0572}$$

In the above equation R = 0,941, and SEE = 0,246%.

The presented dependences can be used in predicting of changes in soil compaction in mechanized field operations performed under conditions similar to conditions of these investigations. However, it should be noted that limitations assumed in these investigations do not take into account the effects of various moisture content and soil conditions, which can significantly influence the soil reactions to stresses.

Conclusions

- The carried out laboratory and field investigations proved that changes in soil compaction within the track during multiple passes of wheels influenced the wheel contact area and specific pressure values.
- Basing on the obtained measurement values one can find that distribution of tractor weight and tire size had a bigger effect on the wheel pressure values than the total weight of tractor.
- Range of changes in soil compaction in the zone adjacent to the track covered the field strip of width about 400 mm. The highest compaction in the investigated profiles was found at depth 150-220 mm, where an increase In soil compaction in relation to initial state was more than double.
- An increase in soil compaction in the profile closest to the track amounted to 115 - 367 kPa. The respective values for the profile at distance 200 mm from the track ranged from 49 kPa to 231 kPa, in the profile at distance 300 mm from 10 kPa to 100 kPa, while in the most remote profile from -39 kPa do +34 kPa.

- The regression equations developed on the basis of investigation results enable to combine the soil compaction with wheel pressures and position of considered soil layer, with a high level of equation fitting to the measured values.

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