

Effect of wheel passage number and tyre inflation pressure on soil compaction in the wheel track

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Abstract: *Effect of wheel passage number and tyre inflation pressure on soil compaction in the wheel track.* There are presented the results of investigations on determination of the effect of wheel passage number, tyre inflation pressure and wheel load on soil compaction. Investigations were carried out in a soil bin filled with the fine loamy soil layer of dimensions $10 \times 2 \times 1$ m (length \times width \times depth), of moisture content 12%. In investigations there was used the tractor wheel with tyre 7.50 – 16, loaded with axial forces 3,600 and 5,199 N and rolled on the measuring length 1–2–4–8 times at speed 0.82 m/s. The investigations showed a highly significant effect of wheel passage number, tyre inflation pressure and depth of measurement on compaction values in soil profile under the wheel track. In the range of applied wheel loads and tyre inflation pressures, the highest changes in soil compaction were found in the superficial layer – up to 0.05 m.

Key words: tractor wheel, soil compaction, soil bin

INTRODUCTION

The observed for many years trend towards introduction of tractor field outfits that are wider, more effective and heavier results in the increased wheel pressures in soil and its compaction [Keller et al. 2002]. The wheel passage over the loosened soil creates the track of strongly compacted bottom layer. The subsequent passages of wheels over the same track increase the track depth and

stress values in subsurface layer. After 2–4 wheel passages, the ground contact area and specific pressure value are similar to that on the hard surface [Grečenko 2003]. According to Håkansson and Medvedev [1995], Dawidowski et al. [2001], Canillas and Salokhe [2002], the wheel axle load, number of passages over the same track, the soil state during passage execution, and particularly soil moisture content, significantly affect soil compaction in the zone of passage. Becera et al. [2010] who investigated the changes in soil compaction (cone penetrometer resistance), its density and porosity, reported that up to the fifth tractor passage over the same track, the ground pressure values were the main factor that shaped compaction of the top soil layer (0–200 mm). A series of investigations [Bell 1994, Dawidowski 1995, Walczyk 1995, Buliński 1998, 2000, Pytka 2005, Jurga 2008] pointed out that the first 2–4 passages over the loosened soil (according to Canillas and Salokhe [2001] – the first three passages) led to highest changes in soil properties. Owsiak and Lejman [2008] that investigated compaction of light clay in the track under tractor wheel, reported that an increase in soil compaction was found up to the fourth passage of front wheel and up to

the fifth passage of rear wheel and both wheels together.

Some reduction of soil compaction can be achieved by appropriate adjustment of vehicle technical and exploitation parameters (mass distribution, speed of passage) or of wheeling system (tyre dimension and inflation pressure, type of tyres, dual wheels, caterpillar mechanisms). Ansorge and Godwin [2007] found in investigations carried out in the soil bin on caterpillar and wheel system, that a tyre loaded with 4.5 t force caused similar soil deformation as a caterpillar loaded with 12 t. Besides, a decrease in tyre inflation pressure from 2.5 to 1.25 bar caused substantial decrease in soil compaction (cone penetrometer resistance), depth of wheel track, soil displacement and soil bulk density.

The effect of wheel load (11, 15 and 33 kN) and tyre inflation pressure (70, 100 and 150 kPa) was investigated by Arvidsson and Keller [2007]. They found that tyre inflation pressure had the greatest influence on stress values under wheel to a depth of 0.1 m, and small influence at depth of 0.3 m and deeper – as opposed to loading that significantly changed the stress values in deeper layers. Similar results were reported by Carman [2002, 2008], who found that soil density in the tyre passage track at depth 0.2 m increased with an increase in wheel loading and inflation pressure; it decreased with an increase in the speed of passage. According to this author, loading was the main factor of soil compaction when compared to tyre type and wheel passage speed. The highest soil compaction expressed with density and compaction index occurred at depth 0.7 m. Rather narrow range of possible

soil density changes under loading was proved by investigations, where an increase in wheel load by 100% caused an increase in soil density only by 23%. Changes in tyre inflation pressure forecasted by tyre manufacturers for field conditions, i.e. for deformable surfaces, result in lower penetration of tyres in soil and shallower tracks, as well as the increased wheel rolling resistance [Wong 2001]. A decrease in tyre inflation pressure by 28 kPa in relations to factory recommendations increased the rolling resistance by 5%; further pressure reduction by 55 kPa caused the increased resistance by about 10% [Elwaleed et al. 2006]. Kurjenluoma et al. [2009] reported that type of tyre significantly affected the rolling resistance and wheel track creation; the decreased pressure in radial-ply tyre decreased rolling resistance by 20% and the track depth by 15% when compared to bias-ply tyre, but only on soft loosened soil.

The undertaken investigations aimed at determination of the effect of wheel technical and exploitation parameters (load, tyre inflation pressure) and number of passages over the same track on the changes in soil compaction and their distribution in the wheel track.

MATERIAL AND METHODS

The investigations were carried out in a soil bin filled with fine loamy soil of the following composition: sand 61.5%, dust 22%, fluming particles 16.5%. The soil moisture content during investigations amounted to 12% (± 0.5). The loosened soil was compacted with tractor wheel

with tyre 7.50 – 16, loaded with vertical forces 3,600 and 5,199 N and rolled on the measuring length 1–2–4–8 times at speed 0.82 m/s. Three tyre inflation pressures were applied during investigations: $P_1 = 140$, $P_2 = 180$, $P_3 = 220$ kPa.

The soil compaction was measured with the use of two probes (Fig. 1) placed crosswise at distance of 50 mm to the right and 50 mm to the left from the track axis; the probes were equipped with cone tips of diameter 20.27 mm and apex

after soil preparation, and then for each measuring variant (speed \times wheel load \times tyre inflation pressure) at three places of measuring length: 1 m from the beginning, in the middle, and 1 m from the end, at depth ranged from 0 to 350 mm.

The index of carriage setting enabled to maintain the same position of probes in relation to longitudinal axis of the bin in subsequent repetitions.

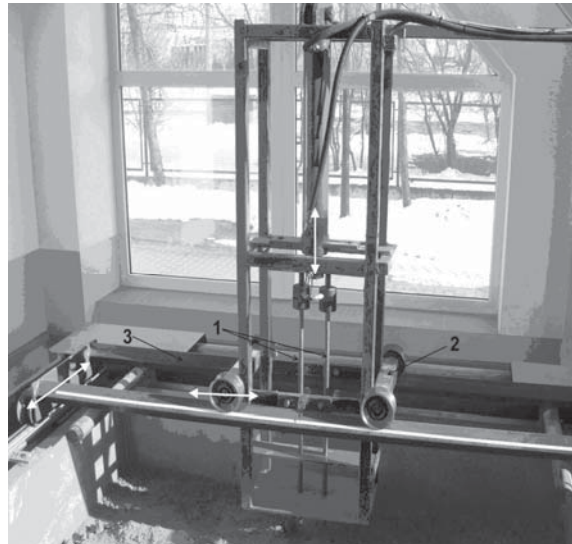


FIGURE 1. Frame with probes for soil compaction measurements; 1 – probes, 2 – carriage, 3 – transverse frame

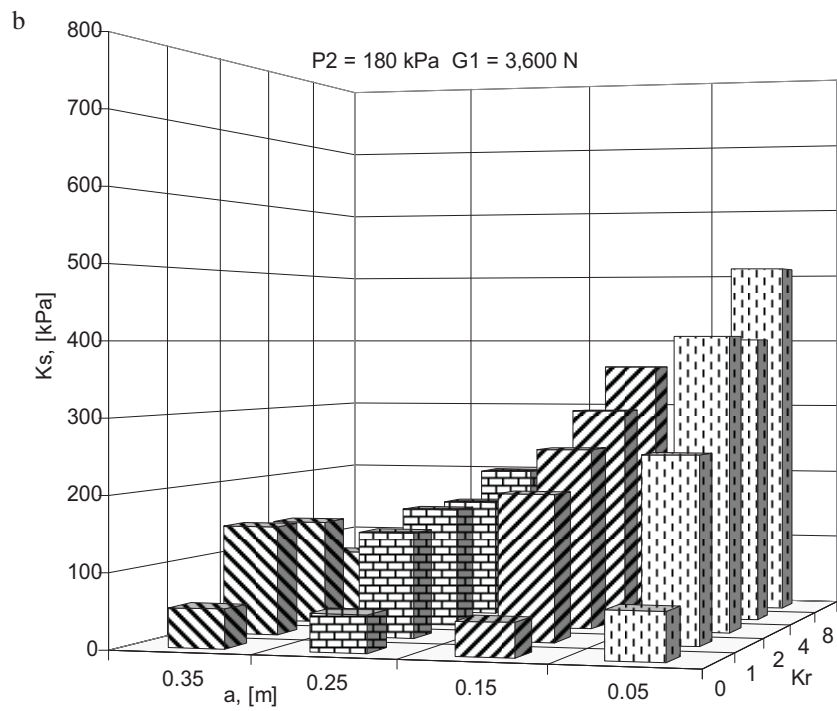
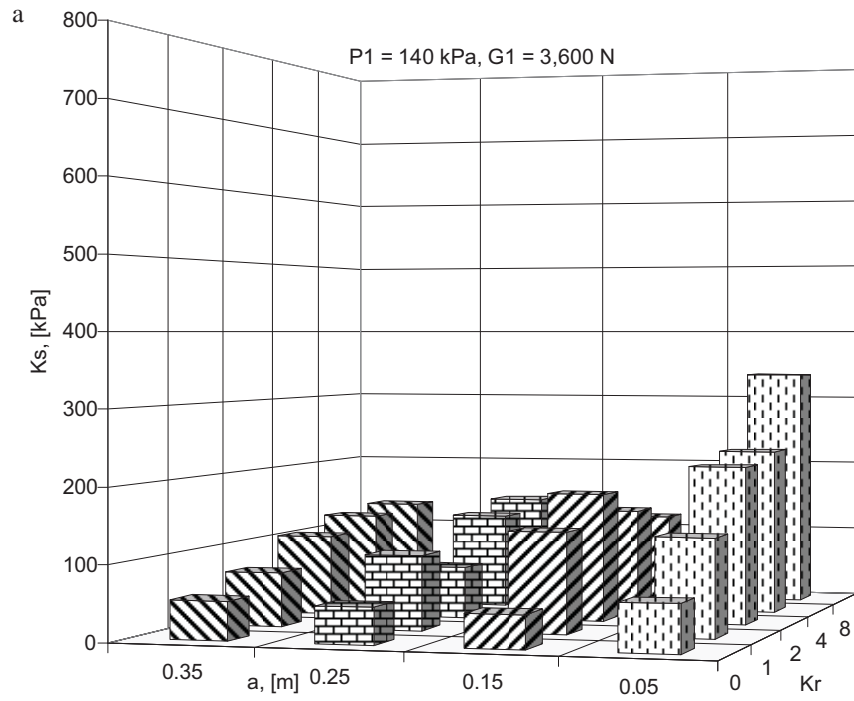
angle 30° , according to ASAE Standards [1993]. The probes were mounted on a special carriage (2) supported on transverse frame (3), that was moved along the bin on guide bars of the tool carriage (Fig. 1). Mounting of probes enabled to make measurements on entire length and width of the soil bin. The probes were moved at constant speed of 0.03 m/s.

The soil compaction was determined for not compacted length, i.e. directly

RESULTS AND DISCUSSION

Figure 2 presents the results of soil compaction measurements (K_s) for particular depths (a), various tyre inflation pressure (P) and number of passages (K_r) at axle load $G = 3,600$ N.

Considering the presented value one can find that in the range of applied wheel loads and tyre inflation pressures the highest soil compaction changes occurred in



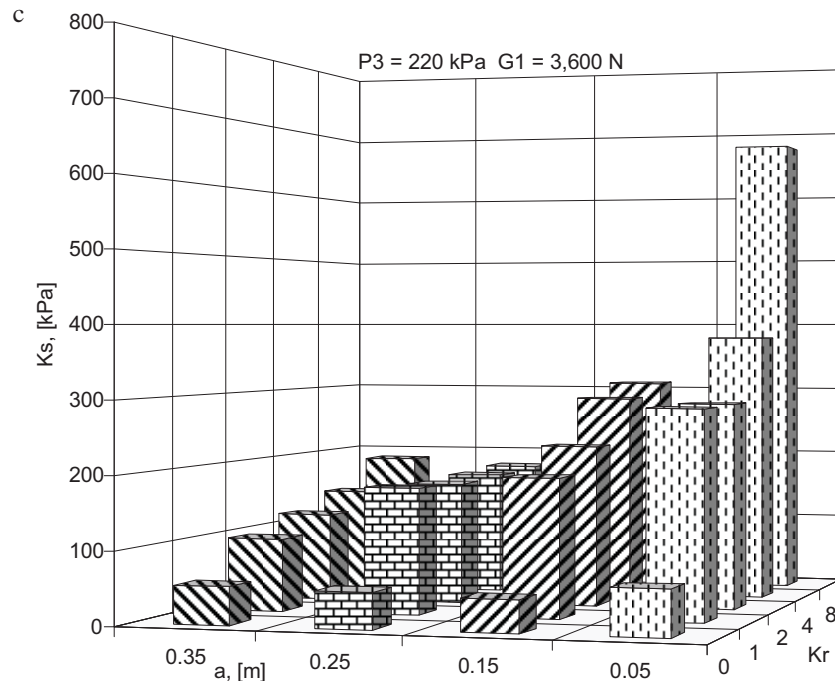


FIGURE 2. Changes in soil compaction at particular depths (a) and wheel loading 3,600 N

the surface layer of 0.05 m. Along with an increase in number of passages the soil compaction in this layer increased depending on tyre inflation pressure and the wheel loading. At pressure 140 kPa and wheel load 3,600 N, in the range of applied passage multiplicity (Kr 1–8) the soil compaction in surface layer varied from 131.16 to 335.06 kPa; it means an increase from 107 to 429% in relation to soil initial state (no passages). At pressure increased to 180 kPa, the soil compaction ranged from 250 kPa (at Kr = 1) to 507 kPa (at Kr = 8) and was increased by 3 to 7 times in relation to the initial state of soil. At the highest pressure (220 kPa) the soil compaction values ranged from 287 kPa (Kr = 1) to 672.7 kPa (Kr = 8) – it increased by 3.5 to 9.6 times, when compared to the soil without

passages. In deeper layer (a = 0.15 m) a systematic compaction increase was also found at the increased number of passages, although the compaction values were lower (from 29 to 32%), while in deeper layers (0.25 and 0.35 m) the compaction values were lower by 42 to 57% when compared to the surface layer. Considering all the measuring results one can find, that in relation to soil initial state a single passage of wheel loaded with force 3,600 N increased soil compaction on the average by 208%, two passages by 269%, four passages by 305%, and eight passages by 399%.

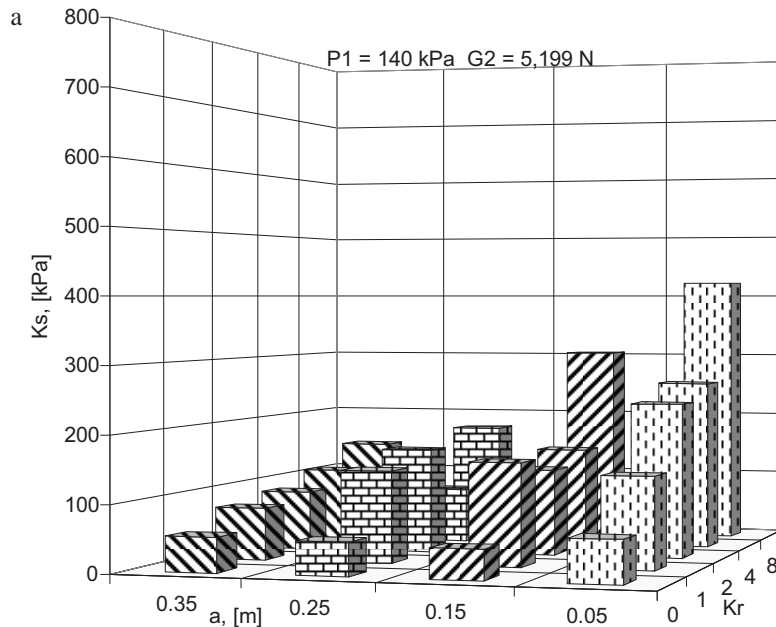
An increase in tyre inflation pressure resulted most often in the increased soil compaction in the wheel track: by 45 to 73%, when the pressure was raised from 140 to 180 kPa, and this effect was most

evident at the surface layer (0.05 m). Further increase of pressure from 180 to 220 kPa caused an increase in soil compaction on the average by 1.3 to 37%, but these value varied in some measuring variants.

At the wheel load increased from 3,600 to 5,199 N (Fig. 3) an increase in soil compaction was found mainly in the surface layer (0.05 m); depending on tyre inflation pressure, the soil compaction at wheel load 5,199 N was higher on the average by 4.7 to 20.7% than at the wheel load of 3,600 N. In deeper layers the compaction changes were not oriented: in some measuring variants one could find the values higher by over 30%, and lower by over 20%. This considerable scatter of values may result from bigger support area of wheel at lower inflation pressure and more stable movement of wheel over the ground; it leads to greater soil compaction. At higher pressure, the tyre of increased stiffness easily

penetrates the loosened soil and pushes it aside. Confirmation of these suppositions calls for additional investigations with consideration to side soil displacements in the zone of passage. Considering all the measuring results one can find that an increase in wheel axle load from 3,600 to 5,199 N at tyre inflation pressure 140 kPa caused an increase in soil compaction on the average by 21.2%, at pressure 180 kPa by 3.4%, while at the highest pressure the compaction increase was lower by 3.45%.

An increase in the number of wheel passages at load 5,199 N (similarly to the lower load) resulted in the increase soil compaction mainly in the surface layer. The effect of increased axle load was evident especially at higher pressures (180 and 220 kPa) and at bigger multiplicity of passages over the same track ($K_r = 4$ and $K_r = 8$), where average soil compaction values were higher by 13.9 to 50.3%.



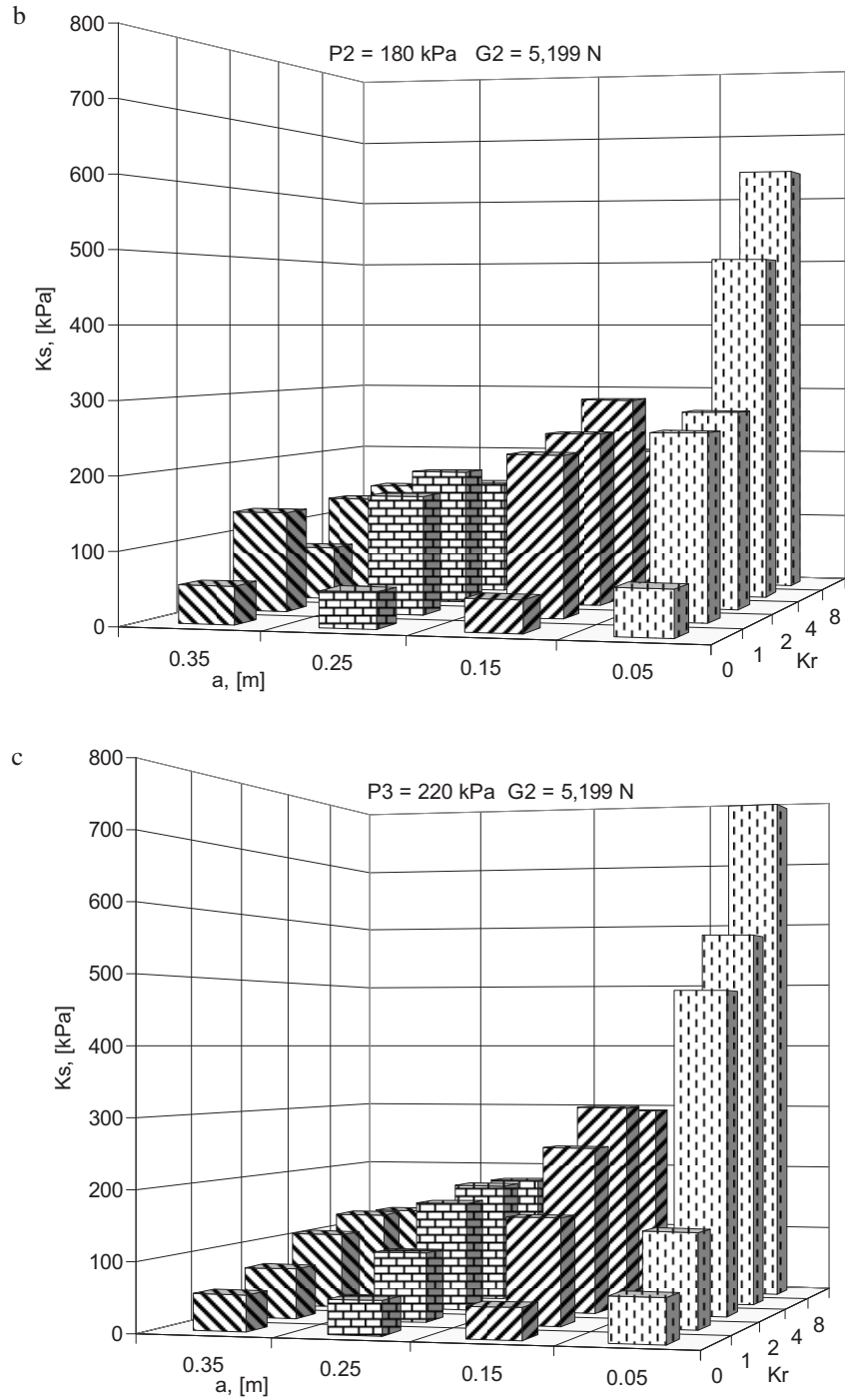


FIGURE 3. Changes in soil compaction at particular depths (a) and wheel loading 5,199 N

In order to determine the effect of particular factors on soil compaction in the wheel track, the entire research material was analyzed statistically by multivariate analysis of variance – type III, sum of squares (Table 1).

of regression equation. Using the multiple regression method there was determined an equation that connected soil compaction with wheel passages multiplicity, tyre inflation pressure and depth of measurements:

TABLE 1. Analysis of variance for soil compaction

Source of variability	Sum of squares	Degrees of freedom	Mean square	F _{emp.}	Significance level
Multiplicity of passages (Kr)	709,538.00	4	177,384.00	26.73	0.0000
Load (G)	1,952.89	1	1,952.89	0.29	0.5886
Depth (a)	730,040.00	3	243,347.00	36.67	0.0000
Tyre inflation pressure (P)	113,419.00	2	56,709.50	8.55	0.0000
Residue	723,255.00	109	6,635.37	×	×
Total	2.2782·10 ⁻⁶	119	×	×	×

The obtained values of statistics pointed out that, with the exception of wheel load, the remaining factors (multiplicity of passages, tyre inflation pressure, depth of layer) affected significantly the soil compaction in the wheel track, within the range of executed measurements' depth. The results of statistical analysis were taken as a basis for determination

$$K_s = 85.5 + 24.216 Kr + 0.872 P - 666.33 a$$

for which $R^2 = 58.22\%$, $SEE = 90.58$.

Comparison between soil compaction values obtained on the basis of measurements and the values calculated with the above equation is presented in Figure 4.

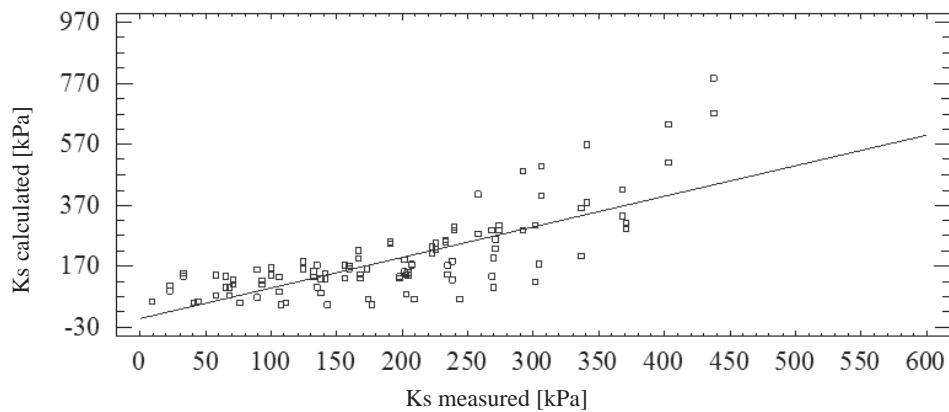


FIGURE 4. Comparison between the measured and calculated values of soil compaction

Scatter of points that characterize fitting of the equation to measuring value confirms the results of statistical analysis and points out at some imperfection of the model, especially in the range of higher soil compaction that correspond to higher wheel passage multiplicity.

In order to investigate whether the mean values of dependent variable obtained at particular levels of independent variable action differ from each other, the significance of differences was compared using the Fisher multiple range test, based on the least significant differences (LSD) at confidence level 95% (Table 2).

The results of analysis pointed out that especially number of wheel passages (Kr) strongly affected the soil compaction. The significant differences in the compaction mean values between all levels of passage multiplicity were found for that variable.

Change in tyre inflation pressure resulted in significant differences in the mean value obtained for levels 140 and 180 kPa as well as 140 and 220 kPa, whereas mean values of soil compaction for levels 180 and 220 kPa did not differ significantly.

Considering soil compaction at particular depths there were found big differences between the surface layer of

TABLE 2. Test of difference significance for particular groups of soil compaction

Factor	Mean	Contrast	Calculated difference	Boundary value	
Kr	0	52.172	0-1	*-101.2610	46.6100
			0-2	*-144.8410	
			0-4	*-173.9780	
			0-8	*-228.4090	
	1	153.430	1-2	-43.5802	
			1-4	*-72.7168	
			1-8	*-127.1480	
	2	197.014	2-4	-29.1367	
			2-8	*-83.5675	
	4	226.150	4-8	*-54.4308	
8	280.581				
P	140	138.805	140-180	*-59.4206	36.1006
	180	198.226	140-220	*-69.7741	
	220	208.58	180-220	-10.3535	
a	0.05	306.028	0.05-0.15	*117.6180	41.6854
			0.05-0.25	*176.5410	
			0.05-0.35	*202.4700	
	0.15	188.409	0.15-0.25	*58.9224	
			0.15-0.35	*84.8513	
	0.25	129.487	0.25-0.35	25.9289	
0.35	103.558				

*Differences statistically significant.

soil and the remaining layer; the calculated difference values greatly exceeded the boundary value. Significant differences between layer $a = 0.15$ m and the remaining layer, while depths $a = 0.25$ and $a = 0.35$ m turned out to be the homogeneous groups from the viewpoint of investigated feature.

These group mean values did not differ significantly; it was proved by the values presented in Figures 2 and 3 – it may result from small sinking of wheel action within the range of assumed independent variables.

CONCLUSIONS

1. The investigations carried out in a soil bin proved the highly significant effect of number of wheel passages, tyre inflation pressure and depth of measurement on soil compaction in the wheel track profile.
2. Within the range of applied wheel loads and tyre inflation pressures the highest changes in soil compaction occurred in the surface layer – down to 0.05 m.
3. Particularly strong effect on soil compaction in the wheel track was found for number of wheel passages (Kr). The significant differences in compaction mean values were found for all action levels of this factor.
4. An increase in tyre inflation pressure resulted in the increased soil compaction in majority of measuring variants. The change in pressure from 140 to 180 kPa caused an increase in soil compaction on the average by 45 to 73%, while this effect was most visible in the surface layer (0.05 m).

Further increase in tyre inflation pressure from 180 to 220 kPa resulted in an increase in soil compaction on the average by 1.3 to 37%.

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Streszczenie: *Wpływ liczby przejazdów koła i ciśnienia w oponie na zwięzłość gleby w koleinie.* W pracy przedstawiono wyniki badań, których celem było określenie, w jakim zakresie liczba przejazdów koła, ciśnienie w oponie oraz obciążenie koła wpływa na zagęszczenie gleby wyrażone jej zwięzłością. Badania przeprowadzono w kanale glebowym o wymiarach $10 \times 2 \times 1$ m (długość \times szerokość \times wysokość warstwy gleby) na glinie drobnopiaszczystej o wilgotności 12%. W badaniach zastosowano koło ciągnika z oponą 7,50 – 16. Podczas badań, koło obciążone siłą osiową o wartościach 3600 i 5199 N przetaczano po odcinku pomiarowym 1–2–4–8-krotnie z prędkością 0,82 m/s. Badania wykazały wysoce istotny wpływ liczby przejazdów koła, ciśnienia w oponie oraz głębokości pomiaru na zwięzłość gleby w profilu pod koleiną przejazdów. W zakresie stosowanych obciążeń koła i ciśnień w oponie największe zmiany zwięzłości gleby następowały w warstwie powierzchniowej – do 0,05 m.

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