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Effect of Axle Load Distribution in Tractor-machine Outfits on Soil Compaction in the Arable Layer

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Abstract: The investigations aimed at determination of the effect of soil compacting action of the wheels of agricultural vehicles of similar weights, but different number of axles, as well as the sequence of applied pressures on soil compaction. Investigations were carried out under field conditions on light soil, compacted with the use of vehicles of different weight distribution between particular axles and different number of axles. Soil compaction and density were measured within the track of passes in the layer 0 - 30 cm. Different weight and its distribution significantly increased soil density and compaction when compared to the initial state, while differences between particular vehicles were statistically insignificant. The highest soil compaction was found in layers to a depth 12.5 cm. The trailed outfit caused higher soil bulk density and soil compaction than mounted outfit of the same total weight.
Key words: tractor, agricultural outfit, axle load, soil compaction

Traktör-Alet Bağlantısında Aks Yükü Dağılımının Toprak İşleme Tabakasında Toprak Sıkışıklığına Etkileri

Özet: Araştırmanın amacı, birbirine yakın ağırlığa ancak farklı aks sayısına sahip tarım araçlarının tekerleklerinin oluşturduğu farklı uygulama basınçlarının toprak sıkışıklığına etkilerini incelemektir. Denemeler hafif toprağa sahip tarla koşullarında, farklı yük dağılımında ve farklı sayıdaki aksa sahip tarım araçlarıyla yapılmış ve sonuçta toprak sıkışıklığı incelenmiştir. Toprak sıkışıklığı ve yoğunluğu traktör tekerlek iz alanında toprağın 0-30 cm derinlik aralığında ölçülmüştür. Farklı yük ve dağılımı başlangıç koşullarıyla karşılaştırıldığında toprak yoğunluğu ve sıkışıklığı artarken, farklı araçların etkisi istatistiksel olarak önemsiz bulunmuştur. En yüksek toprak sıkışıklığı 12.5 cm toprak derinliğinde bulunmuştur. Çekilir tip bağlantı aynı ağırlıktaki traktörün üç nokta asma sistemi ile bağlantıya gore daha yüksek toprak hacim ağırlığına ve toprak sıkışıklığına neden olmaktadır.
Anahtar Kelimeler: traktör, traktör bağlantısı, aks yükü, toprak sıkışıklığı

INTRODUCTION

Soil compaction is inevitably connected with mechanization of field operations [Buliński and Majewski, 1994; Hadas, 1994, Ekwue and Stone, 1995]. Pressures of agricultural vehicle wheels exerted to the ground in the place of outfit's running lead to a change in series of soil parameters, resulting in alterations of physical, biological and chemical properties of the arable and subsoil layers. These changes are very often disadvantageous for agricultural production and can lead to: yield reduction and deterioration of its technological quality, increased inputs for restoring soil properties beneficial for the crop, degradation of environment, increased wear of soil engaging working elements, and the like.

Many investigations carried out under field and laboratory conditions describe the reasons for soil compaction (large loading on axles, improper soil moisture content, and multiple running of outfits on the field surface) as well as possible ways to avoid these compaction hazards. One of most important factors is necessity of reduction of field surface loading resulting from specific pressure of wheels.

It is well known that the stresses created under the rut of multiple running cumulate [Gameda *et al.*, 1987] and increase the soil compaction. Most of investigation results [Canillas and Salokhe, 2001; Taylor *et al.*, 1982] point out that highest soil compaction occurs during the first 3 - 4 runnings of wheels, when changes in soil compaction exceed 75% of maximal values. However, some researchers [Buliński, 1998] report the highest effect of the first 3 runnings of tractor, which gives twice higher value if the number of wheels moving over the same track is considered. There is lack of data determining the effect of pressure sequence on soil compaction, and determining different action of the outfits of the same weight but differing in number of axles.

The presented investigations aimed at explanation of scientific problem mentioned above.

Material and methods

Investigations were carried out under field conditions on loamy sand of fluming content 19% (< 0.02 mm) at soil moisture content ranged from 10.1 to 12%. Prior to measurements, the field was ploughed to a depth of 0.35 m and the measuring lengths were staked out for particular research variants.

To determine the effect of outfit's mass distribution on soil compaction, running of the outfits of various loads were executed (A1, A2 and A3).

In order to determine different action of the outfits of the same weight but differing in number of axles, there were carried out comparative investigations on the two-axle (A2) and three-axle (A3) outfits. Each of them passed three times over the same track on the measuring length. The applied values of outfit loads are presented in Table 1 together with per cent distribution of their total weight between particular axles.

The outfit A1 was tractor Ursus 4512 itself, while the outfits A2, A3 and A4 consisted of the same tractor coupled to various machines: mounted plough (A2), mounted sprayer (A3), and trailed sprayer (A4), respectively. The tractor was equipped with front tires 7.5-20 and rear tires 13.6/12-36 inflated to typical operational pressures amounted to 210 and 110 kPa, respectively.

The trailed sprayer was equipped with wheel tires 7.5-20 inflated to pressure 250 kPa. The outfits A1 and A2 differed in total weights by 12%, while the outfits A2 and A3 by 10%. The outfits A3 and A4 had the same total weights, however, weight transfer on the third axle in the trailed sprayer caused a twofold increase in front axle load with simultaneous decrease in the load on tractor rear axle.

The soil compaction and soil bulk density were measured after each measuring run within the track in the layer of 0 – 30 cm, and also within the control measuring length, which was denoted on diagrams as "A0".

The soil bulk density was determined with the use of Eijkelkamp probe 04.17 with containers of capacity

100 cm^3 and height 5 cm; the relative error amounted to 0,24%. The measured values were related to the centre of considered layer, i.e. to 2.5 – 7.5 – 12.5 – 17.5 – 22.5 – 27.5 cm.

Soil compaction was measured with a cone penetrometer equipped with cone tip of cone angle 30° and base diameter 20.27 mm according to ASAE Standard 313.2 [1993]. The maximal relative terror for soil compaction, with consideration to measuring equipment applied (force and displacement converters), amounted to 2.3%. The measurements were executed in 7 repetitions according to Sample-Size Determination of STATGRAPHICS® package.

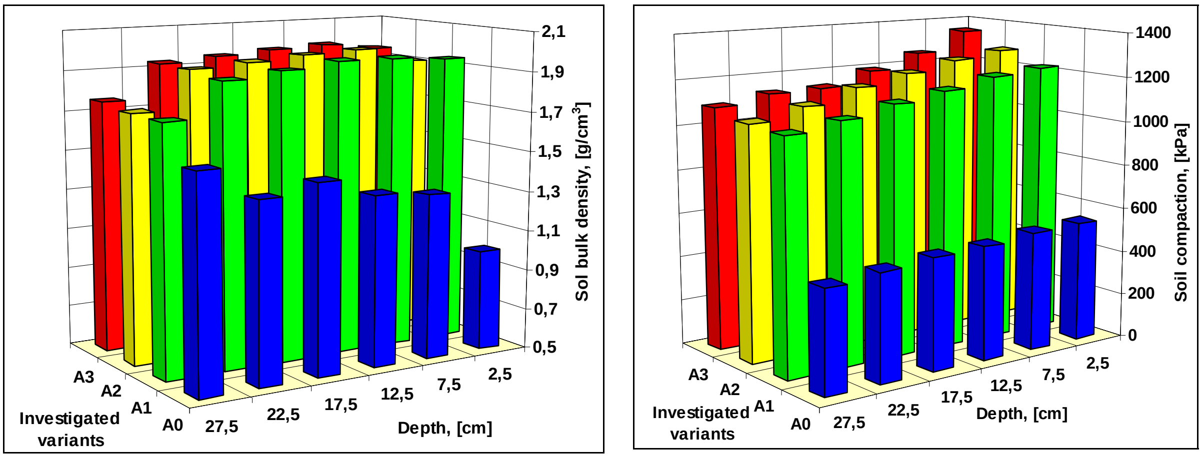
Results of investigations

Results of investigations on the effect of outfit weight and its distribution on soil bulk density and soil compaction are presented in Fig.1.

Considering the presented values one can find that the passes of particular outfits A1, A2 and A3 (differing in total weight and its distribution on tractor front and rear axles) caused close changes in soil bulk density in the investigated soil profile (Fig.1a). All investigated outfits caused the highest soil compaction in shallow layers, i.e. to a depth of 12.5 cm, amounted to 1.96 – 1.97 g/cm3 and depended on the outfit used. The soil density increased with an increase in outfit's weight, however, differences in soil compaction values at particular levels between the outfits did not exceed 2%, on the average for the entire profile amounted to 1%. When compared to the control non-compacted plot (A0), the outfit passes caused an average increase in soil density in the range of 0.56 – 0.58 g/cm3, which corresponded to soil compaction increment of 94 – 95%.

Table 1. Specification of outfits with the loads on their axles

Outfit	Weight [kN]	Axle load [kN]		
		1st axle	2nd axle	3rd axle
A1	31.9	11.95 (37.5%)	19.95 (62.5%)	-
A2	35.8	9.7 (27.1%)	26.1 (72.9%)	-
A3	39.5	5.3 (13.4 %)	34.2 (86.6%)	-
A4	39.5	10.85 (27.5%)	21.5 (54.4%)	7.15 (18.1%)



a b

Fig. 1. Effect of outfit weight distribution and sequence of loadings on: a/- soil bulk density, b/- soil compaction

Changes in soil compaction after outfit passes (Fig. 1b) were more differentiated, however, the highest values of this parameter were found for outfit A1, which caused almost double increase (by 631 kPa) in soil compaction when compared to the initial state (A0). An increase in outfit's weight by 4.9 kN (A1 – A2) resulted in increased soil compaction by 3.6%, while further increase in outfit's weight by 7.6 kN increased compaction by 4.9% only. Changes in soil compaction related to initial state (A0) ranged from 631 kPa to 638 kPa (from 125% to 136%), which can be explained by a decrease in load on the front narrow wheels of the outfits, usually causing high specific pressures with simultaneous transfer of the increased load on rear axle wheels, equipped with wide low-pressure tires.

Statistical analysis executed with the use of Multiple Range Test of STATGRAPHICS® package (Table 1) proved that passes of outfits A! – A2 – A3 significantly increased the soil density and its compaction in relation to initial state, while the differences between particular outfits were statistically insignificant.

This means that first pass of the outfits on pulverized field caused a substantial and statistically significant increase in soil density (by 94%) and soil compaction (by 125%), while within investigated range of loads and weight distribution between the axles the effects of their increase were less significant.

Table 2. Results of Multiple Range Test (method: 95.0% of LSD)

Tractor outfit	Mean	Contrast	Difference	+/- Limits
	soil bulk density			
A0	1,34167	A0 - A1	*-0,5617	0,143622
		A0 - A2	*-0,5685	
		A0 - A3	*-0,5617	
A1	1,90333	A1 - A2	-0,0068	
		A1 - A3	0,02	
A2	1,91017	A2 - A3	-0,0132	
A3	1,92333	-	-	
	soil compaction			
A0	504,507	A0 - A1	*-631,707	90,1855
		A0 - A2	*-672,169	
		A0 - A3	*-688,225	
A1	1136,21	A1 - A2	-40,4627	
		A1 - A3	-56,5183	
A2	1176,68	A2 - A3	-16,0556	
A3	1192,73	-	-	

* denotes a statistically significant difference

Comparison between the effects of multiple passes of 2-axle and 3-axle outfits of similar total weights on changes in soil bulk density and soil compaction is presented in Fig. 2a and 2b.

Considering the presented values one can find that application of trailed sprayer A4 caused an increase in soil bulk density and soil compaction under the track, when compared with mounted outfit A3 of the same weight. When compared to control measuring length, the passes 1 -2 -3 of A3 outfit over the same track caused an increase in soil density by 25 – 30%, while these values for 3-axle outfit A4 by 29 – 33%. Bigger changes were found in soil compaction; after 1 – 2 – 3 passes of 2-axle outfit average values of this parameter ranged from 74% to 124% in relation to non-compacted soil, while for 3-axle outfit they ranged from 78% to 134%.

Slightly bigger soil compaction caused by 3-axle outfit can be explained by higher pressures of narrow front wheels of the tractor (not unloaded as in outfit A3) and by the pressure of narrow sprayer wheels. Running of bigger number of wheels over the same track, exerting higher total specific pressures caused the accumulated stress in the soil layers under the rut and an increase in soil density.

Although average values of soil density and soil compaction obtained for particular outfits after subsequent passes did not differed significantly, however, these observations can be important from the viewpoint of plant requirements. Variety of cultivated crops and their requirements related to their growth and development, as well as natural variability of soil conditions are important factors, which call for consideration of many relations in predicting the stresses exerted by the wheels on the ground. It should be underlined that in typical agricultural operations the number of outfits moving over the fields is considerably higher than that used in these investigations. One can expect the higher soil compaction as a result of stress accumulation. The presented results point out at direction of further research to obtain more detailed answers to the questions asked previously.

Conclusions

1. Passes of outfits A1 – A2 – A3 different in their weight and its distribution between particular axles caused a significant increase in soil density and soil compaction in relation to an initial soil state, while differences between particular outfits were statistically insignificant.

2. The outfits A1 – A2 – A3 caused the highest soil density in superficial layers, i.e. to a depth of 12.5 cm, ranged to 1.96-1.97 g/cm^3 depending on the outfit used.

3. Considering the presented diagrams one can find that application of trailed sprayer A4 led to the increased in soil bulk density and soil compaction under the track, when compared to mounted outfit A3.

4. The passes of 3-axle outfit caused bigger soil bulk density by about 3-4% and soil compaction by about 4-10%, when compared to 2-axle outfit

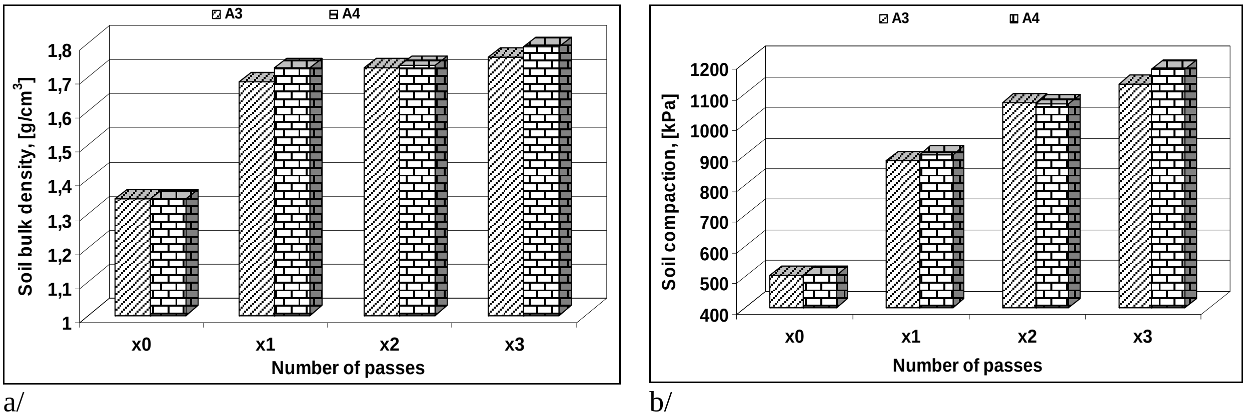


Fig. 2. Effect of outfit type on changes In: a/- soil bulk density, b/- soil compaction during multiple outfit running

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