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THE EVALUATION OF SURFACE DEFORMATION AND SOIL COMPACTION IN RUTS MADE BY TRACTOR WHEELS WITH AN ELEVATED PROTECTOR

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Abstract. This paper presents the results of investigations concerning geometry changes and soil compression caused by ruts left by the URSUS 1002 tractor. The tractor was equipped with a propulsive tyre with a high protector (h_5=85 mm). The investigations were carried out on a dry soil - light loamy sand. The ruts were made on soils of different humidity ranging from 4.1 % to 15 %. During the investigations attention was mainly focused on the ruts formed as a result of many repeated tractor passages on the same track. Ruts formed with the share of the tractor propulsive wheel slip were also analysed.

INTRODUCTION

The changes in technological-exploitation parameters of the traversing gear in tractors and agricultural machines influences the magnitude of deformation and the soil compression in ruts. Recently many authors have dealt with this problem. The effects of the action of tyred and stiff wheels on soil were analysed. Most of the studies concerned the influence of wheel progressive speed on the stress distribution in soil [3,4], the effect of the number of passes on soil compaction [1,6,11], and the wheel slip influence on the surface soil in the rut [5,8]. The effects of various unit tensions of tractor wheels on rut dimensions and bulk density of the soil [2,7,9] were also investigated. Little attention was paid to soil changes under the wheels with a high protector of the propulsive tyre. Some earlier papers concerned the traction parameters of the wheel [12] and effects of the degree of traditional tyre protector damages on physical properties of soil in the rut [5].

The results of the investigations presented in this paper relate to the ruts formed after passage of the tractor with the tyre wheels having an elevated protector of the propulsive tyre to a height of 85 mm. The paper discusses the rut's geometry and the changes in soil compactness under the tractor wheels.

METHODS

The investigations of ruts were carried out in an arable field, at the Plant Breeding Station Wierzonka near Poznań, on grey-brown podzolic soil. According to the Polish Soil Science Society criteria the soil plough layer was classified as a light loamy silty sand. Before the study the soil was cultivated by doing presowing cultivations. Then, the separated plots were wet with a sprinkling method to the following, different moisture contents of the soil: W_1=4.1-4.8 %; W_2=6.7-7.7 %; W_3=10.8-12.0 %; W_4=14.3-15.0 %. After stabilization of the soil humidity on the plots, the URSUS 1002 tractor of a weight of 4.2 t made several passes over the soil. The tractor was equipped with a propulsive tyre of the size 16.9-34 cm (Fig. 1), with the possibility of changing the protector overlying plates. This way there was the possibility of changing the protector height within the following range: h_0=35 mm, h_2=55 mm, h_3=65 mm, h_4=75 mm, h_5=85 mm. In this paper only the results of two different soil humidities (W_1,W_4) and for two heights of the protector (h_0,h_5) are discussed with special attention given to tendencies obtained due to changes in the slip of the tractor's driving wheel (S_2=6-9 %; S_6=18-21 %; S_9=27-30 %) and due to different number of tractor passages over the same wheel track (K_1- single passage, K_3- threefold passage; K_6- sixfold passage). Analyses of the soil surface deformation changes were based on the measurements of the ruts' geometry. This characteristic consisted of H_{av}- the average depth of the rut; B-the width; H_1- the depth of the soil layer loosened by the propulsive protector; P-the area of the rut's cross-section; $W_{m1/2}$- the index of the rut bottom longitudinal microinequality measured on the axis of symmetry; and $W_{m1/3}$ -the index of the longitudinal microinequality measured on the plain parallel to the axis of symmetry, at a distance from the bank of 1/3 of the rut's width. For measuring these magnitudes a profilometer was used with the stamen indices spaced 10 mm apart and the diameter of the index foot 5 mm.

The analysis of soil compaction in the ruts was carried out on the basis of soil bulk density. For this purpose, soil samples of undisturbed structure were collected into parted cylinders. This made it possible to estimate the density in the layers 20 cm thick. To check the local compactness a blanking chisel of 1 cm^3 capacity was used [10].

RESULTS

During the investigations with the elevated protector tyre (h_5=85 mm), attention was paid to a partial process of forming the ruts after tractor passing. The ruts formed by the front wheel and by the rear wheel of the tractor were measured separately. It appeared that the front wheel made much deeper ruts compared to the rear wheel (H_{av}=10.5-15.9 cm, B=27-29 cm). The front-wheel rut had a cross section area of P_p=185-290 cm^2.

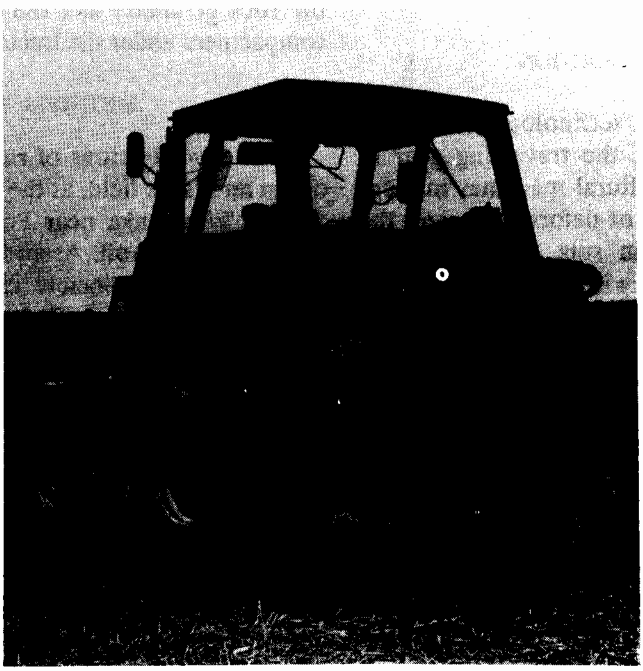

Fig. 1. The URSUS 1002 tractor equipped with the right propulsive wheel with a high protector (h_5=85 mm).

Smaller values were recorded in dry soil (W_1,W_2) but with increasing soil humidity the cross section of the ruts also increased. The tractor propulsive wheel with high protector (h_5) formed the final rut on this track with a cross section area of P_k=130-250 cm^2. Thus one can deduce that the rear wheel, in spite of being wider by about 40 % compared to the front wheel, eliminates a part of the rut formed by that front wheel. The cross section area of this rut decreased by about 11-17 %. However, it should be stressed that such an effect was observed in the wet soil (W_3,W_4) and mainly after the pass of a high protector wheel (h_5=85mm). With the traditional tyre (h_0) the tendency was different because soil in the inter-protector areas was compacted more (Figs 2 and 3) and the cross-section area of the final rut increased.

Analyzing the dimensions of ruts and the real values of the transversal cross-section areas, it can be seen that the real cross-section is much smaller than the theoretical one, which can be calculated from the rut's dimensions. This difference was the largest for the tyres with a high protector. In this case great deformations were formed at the bottom of the final rut and they changed the transversal profile of the rut which, in turn, made the cross-section area smaller.

The microdeformation indices ($W_{m1/2}$, $W_{m1/3}$) reached the greatest values on wet soil (W_3,W_4), when the high protector was moving without any slip. In these conditions the microdeformation indices were almost two times larger than those for ones near the ruts. It should be added that the repeating after-protector cavings in the rut lost

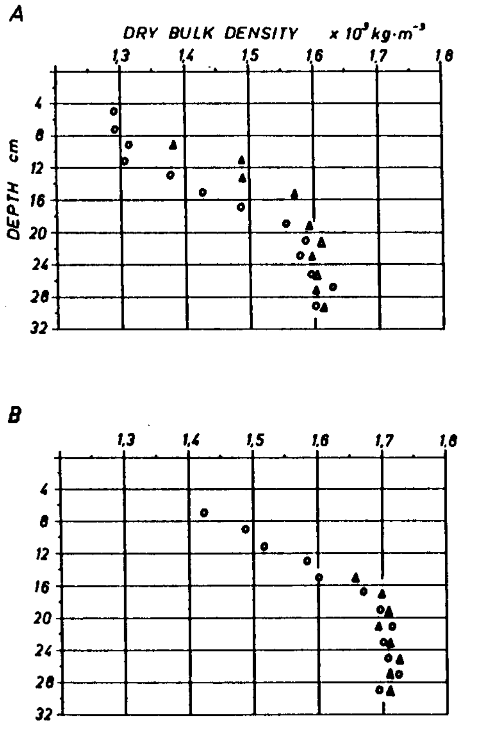

Fig. 2. Changes in soil density in ruts made with: A - high protector h_5= 85 mm on dry soil W_1= 4.1 - 4.8 %; B - high protector h_5=85 mm on wet soil W_4=14.3-15 %. O - soil density in zones under the protector; Δ- soil density in inter-protector zones.

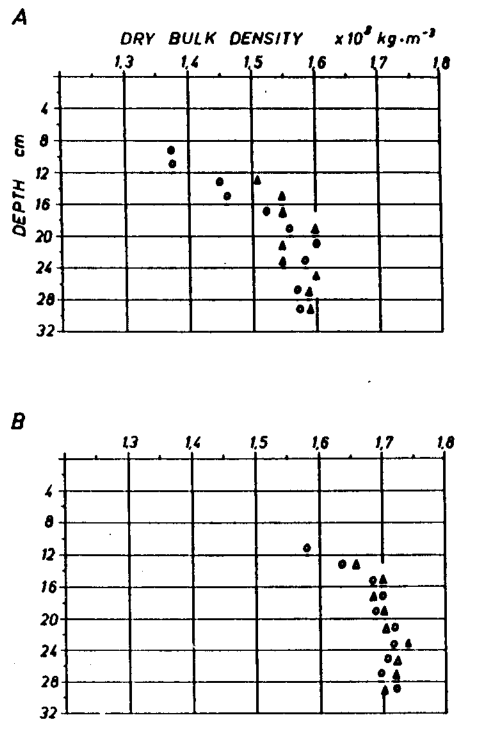

Fig. 3. Changes in soil density in ruts made with: A - standard protector h_0=35 mm on dry soil W_1= 4.1 - 4.8 %; B - standard protector h_0=35 mm on wet soil W_4=14.3-15 %. Explanations as in Fig. 1.

their regular forms as the slip of the tractor's wheel and the number of tractor passes increased. As a result the value of the W_4 indices decreased (Tables 1 and 2).

Agricultural usefulness of a deep after-protector pits in ruts is debatable. It seems, however, that in ruts left on slopes they may appear to be very useful. During heavy rainstorms they will protect soil against water erosion which first of all will appear in ruts. Leaving big after-protector cavings also preserves a thicker surface layer of the soil with smaller density (Figs 2, 3). This layer, as is well known, is mainly composed of the inter-protector areas, which occupy around 65 % of the rut's bottom surface. During rolling of the wheel with a high protector, they undergo much less compaction compared with the traditional rut.

The increase in slip of the propulsive wheel with the high protector increases the range and dynamics of the protector's influence on the soil. First of all, the inter-protector areas are loosened and moved back, and then the deeper soil layers are cut. In this way, a layer of loose soil thicker than the total height of a given propulsive wheel protector is formed in ruts (Figs 4, 5). In ruts formed in wet soil (W_4), one can see single pieces of an excessively compacted soil in a loose soil layer. They can reach density values of from 1.72 to 1.75 x 10^3 kg m^{-3}. In dry soil (W_1), however, the opposite phenomenon occurs, i.e., excessive pulverization of the soil takes place. In the ruts after the high protector wheel passes, this process is less intensive but when the protector height decreases, the soil pulverizing increases (Table 1). This tendency is supported by earlier investigations

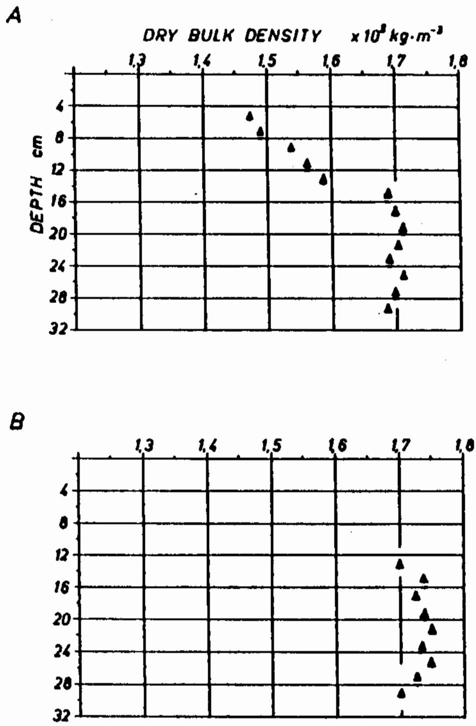

Fig. 4. Changes in soil density in ruts made with: A-high protector (h_5) with the wheel slip S_9 = 27-30 % on wet soil (W_4); B-high protector (h_5), six times kneaded by the tractor (K_6) on wet soil (W_4); Δ- mean soil density.

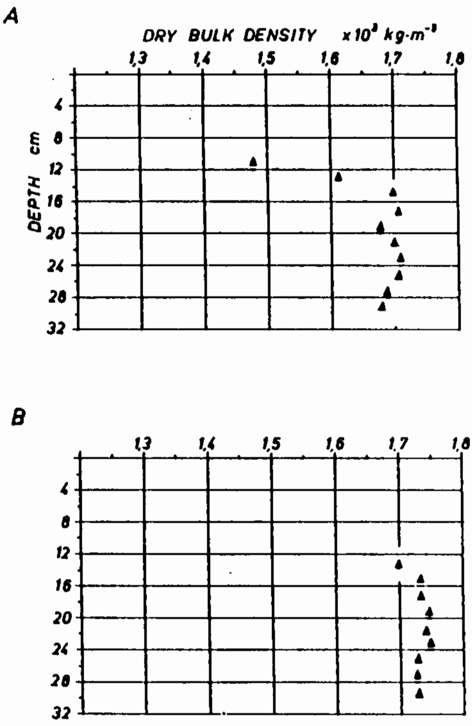

Fig. 5. Changes in soil density in ruts made with: A-standard protector (h_0) with the wheel's slip (S_9) on wet soil (W_4); B- standard protector (h_0), six times kneaded by the tractor (K_6) on wet soil (W_4). Denotations as in Fig.5.

Table 1. Index of soil pulverization and ruts geometry on dry soil W_1=4.1-4.8 %

Measured feature	Unit	Types of ruts											
		h_0 = 35 mm			h_5=85 mm			h_0=35 mm			h_5=85 mm		
		Number of tractor passes						Slip of propulsive wheel					
		K_1	K_3	K_6	K_1	K_3	K_6	S_2	S_6	S_9	S_2	S_6	S_9
Wr	%	2.92	1.88	1.35	3.10	1.83	1.67	3.04	2.38	2.23	3.16	2.92	2.85
H_{av}	cm	7.5	12.7	13.2	9.5	10.1	13.3	8.2	8.0	6.2	8.8	7.3	6.9
B	cm	44	46	49	45	49	49	44	45	47	45	46	46
H_1	cm	1.8	2.7	2.7	3.0	3.2	4.6	2.2	2.9	4.5	6.3	6.7	9.1
P	cm^2	211	412	430	143	295	361	236	201	158	160	99	114
$W_{m1/2}$	mm	12.8	11.2	5.5	21.3	17.0	10.2	14.0	7.1	7.9	28.5	19.4	14.2
$W_{m1/3}$	mm	18.6	13.9	12.1	25.0	18.9	8.4	19.5	11.3	9.1	19.0	10.1	11.7

Explanations: W_r - index of soil pulverization in the rut; H_{av} - average depth of the rut; B - width of the rut;

Table 2. Geometry of the ruts made on wet soil W_4=14.3-15%

Measured features	Units	Types of ruts											
		h_0 = 35 mm			h_5=85 mm			h_0=35 mm			h_5=85 mm		
		Number of tractor passes						Slip of propulsive wheel					
		K_1	K_3	K_6	K_1	K_3	K_6	S_2	S_6	S_9	S_2	S_6	S_9
H_{av}	cm	12.6	14.2	14.9	12.9	14.0	14.4	11.0	10.2	8.6	12.0	7.7	5.8
B	cm	47	48	48	48	49	49	47	48	48	48	49	49
H_1	cm	-	-	-	-	-	-	-	3.0	4.6	6.9	6.6	10.3
P	cm^2	418	421	463	248	327	350	391	304	211	219	180	153
$W_{m1/2}$	mm	14.3	15.4	10.9	40.7	25.9	11.7	19.8	21.5	11.4	36.0	26.8	21.5
$W_{m1/3}$	mm	16.0	15.4	8.2	32.1	29.0	13.5	19.0	18.1	13.5	37.4	29.3	20.7

For explanation see Table 1.

carried out in ruts formed with traditional tyres of different degrees of protector's wear [5]. Repeated passages on the same track contributed to the higher degree of soil pulverization in ruts compared with the action of wheel slip. We should explain here that in Table 1 higher values of the W_r index indicate less pulverization of the soil and opposite. On the basis of soil density changes in separate ruts one can describe the thickness of the soil layer of smaller density as well as its depth in ruts in relation to the field surface. In the ruts formed by a high protector this layer reached its maximum thickness in wet soil (W_4) H_1=10.3 cm, to a depth of 16 cm, as measured from the field surface. The layer of the most dense soil was found at a deeper layer than in the traditional ruts after the low protector.

CONCLUSIONS

The investigations carried out so far allow us to draw the following conclusions:

1. The admissible height of the protector has been determined (h_5=85mm) for tyres 16.9-34.0 cm. The use of such tyres is mainly recommended for field operations during cultivation.

2. An elevation of the protector and an increase in soil humidity increases the microdeformation of the rut's bottom and decreases its transversal cross-section area.

3. The tyre with the elevated protector, working with slip, loosens the soil in the rut deeper than the traditional tyre.

4. A high protector, when used on dry soil, causes its partial pulverization. This process is, however, much weaker than that under the traditional protector.

5. In the ruts after a high protector the layer of the most compacted soil was found deeper than in traditional ruts.

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OCENA ODKSZTAŁCENIA POWIERZCHNIOWEGO I ZAGĘSZCZENIA GLEBY W KOLEINACH WYTWORZONYCH KOŁAMI CIĄGNIKA Z PODWYŻSZONYM PROTEKTOREM

W pracy przedstawiono wyniki badań dotyczące zmian geometrii kolein i zagęszczenia gleby w koleinach pozostawionych przez ciągnik URSUS 1002. Ciągnik był wyposażony w oponę napędową z wysokim protektorem h_5=85 mm. Badania prowadzono w terenie na glebie lekkiej - piasek gliniasty lekki pylasty. Koleiny wytwarzano na glebie o różnej wilgotności w zakresie od 4,1 do 15,0 %. W ramach wykonanych badań zwrócono szczególnie uwagę na koleiny formowane na skutek wielokrotnych przejazdów ciągnikiem po tym samym śladzie, jak również analizowano koleiny formowane z udziałem poślizgu kół napędowych ciągnika.