Effect of cereal cultivation technologies on soil compaction by the light tractor-machine outfits

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Abstract: Effect of cereal cultivation technologies on soil compaction by the light tractor-machine outfits. Soil compaction is usually associated with application of large and very heavy agricultural equipment. However, utilization of light tractors and machinery in small farms can lead to substantial soil compaction and unfavourable conditions of cultivated crops. The paper presents typical technologies for cereal cultivation in Polish small farms, different with respect to working width of the outfits applied, wheel loading values, and modes of tractor running over the field. The pressures of wheels on the field surface of tractor outfits used in particular technologies were analyzed together with distribution of the outfits’ tracks. It was found that tractor trailed machines caused an increased soil compaction (by 43–59%) in relation to tractor mounted machinery. The biggest field surface coverage with tracks (over 61%) was found for tractor trailed outfits of small working width, running over the field by traditional manner.

Key words: tractor-machine outfit, wheel pressures, cereal cultivation technologies.

INTRODUCTION

The basic aim of plant cultivation is to create the best conditions for the plant growth, development and yielding [Botta et al. 2002, Dzienia et al. 2000]. However, the soil structure is subjected to unfavourable compaction as a result of outfits’ running, even in the case of light tractors and machinery. As investigated, the changes in soil under wheels of agricultural vehicles are significantly influenced by improper selection of wheel system parameters in tractor outfits [Powałka 2005], improper selection of technical and exploitation parameters of the outfits in particular technologies [Buliński 1998], ground properties at outfit’s running over the field [Forssblad 1981] and others. This problem becomes more evident in the case of wide and heavy machines, which require the tractors of bigger weight and power [Carman 1994]. When the stress in soil exceeds its strength, the soil compaction hazard occurs [Guerif 1994, Van der Akker 1994], and the range of wheel effect increases along with the wheel loading. The wheel load of 50 kN is regarded as high by International Working Group for Soil Compaction by Vehicles of High Axle Loads (ISTRO). However, practical observations point out that this value can be exceeded several times in many cultivation technologies.

The investigations aimed at determination of changes in specific pressures of agricultural tractors and machines’ wheels on the field surface during operations performed in cereal cultivation technologies.
MATERIAL AND METHODS
The investigations were carried out in 149 farms in Podlaskie province by direct measurements of parameters (weight of outfits, load distribution on particular axles, surface of tire contact), and also by surveying. Basing on the measurements and questionnaire data, the cereal cultivation technologies were elaborated and parameters of field surface loadings were determined. In determination of wheel pressure distribution on the field surface in a given technology, a mathematical model for outfit’s running in the field [Buliński 2000] was used, with consideration to weight distribution between particular axles in the tractor outfit and the wheel parameters (diameter, inflation pressure, width of track, vertical load).

RESEARCH RESULTS AND DISCUSSION
The agricultural equipment in particular investigated farms (Figs 1 and 2) was different. It was found that many farms owned only the basic agricultural machinery for tillage, sowing, fertilizing and plant protection, while 38% of farmers owned 1 tractor only, and 43% – 2 tractors. The tractor power in majority of farms (about 63%) ranged from 20 to 40 kW.

Basing on technical parameters of the machines there were developed 7 variants of cereal cultivation technologies (T1 – T7) characteristic for the farms investigated, including 7 outfits and 7 operations performed after ploughing: secondary tillage – mineral fertilizing – pre-sowing tillage – sowing – after sowing tillage.

FIGURE 1. Specification of agricultural tractors and machines in investigated farms
– plant chemical protection – combine harvesting (Table 1).

The weight of outfits used in technologies T2, T4, T5, T6 and T7 and the connected total weight can be considered as similar, since the differences in relation to the heaviest set (T4) ranged from about 8% to about 12%. In technologies T1 and T3 the outfits of smallest weight were employed, while their total weight was lower than that used in technology T4 by 61% and 58%, respectively.

In technologies with traditional running system (T1 – T5), each outfit entered the field in the place resulting from its working width, thus entirely accidental. In technology T6 all the outfits had the selected working width (starting from

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**TABLE 1. Specification of investigated cereal cultivation technologies**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Outfits</th>
<th>Working width [m]</th>
<th>Mode of running</th>
<th>Total outfit weight [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Tractor mounted</td>
<td>10 10 2.1–2.7</td>
<td>traditional</td>
<td>161.5</td>
</tr>
<tr>
<td>T2</td>
<td>Tractor mounted</td>
<td>18 16 4.2–5.6</td>
<td>traditional</td>
<td>364.8</td>
</tr>
<tr>
<td>T3</td>
<td>Tractor trailed</td>
<td>10 12 2.7–2.8</td>
<td>traditional</td>
<td>175.6</td>
</tr>
<tr>
<td>T4</td>
<td>Tractor trailed</td>
<td>16 24 4.0–5.2</td>
<td>traditional</td>
<td>415.7</td>
</tr>
<tr>
<td>T5</td>
<td>Tractor mounted</td>
<td>18 16 4.5–5.2 till-sowing set</td>
<td>traditional</td>
<td>373.5</td>
</tr>
<tr>
<td>T6</td>
<td>Tractor mounted</td>
<td>12 12 4.0 till-sowing set</td>
<td>traffic path system (secondary. tillage)</td>
<td>370.4</td>
</tr>
<tr>
<td>T7</td>
<td>Tractor mounted</td>
<td>12 12 4.0–5.3 till-sowing set</td>
<td>traffic path system (sowing)</td>
<td>382.3</td>
</tr>
</tbody>
</table>

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**FIGURE 2. Power of tractors in investigated farms**
secondary tillage), equal to multiple width of seeder, thus, the traffic path system was set up at performing the secondary tillage.

In technology T7 the outfits used prior to sowing were running with traditional mode, while after sowing with the traffic path mode, i.e. in the determined places resulted from a multiple working width of the basic machine (seeder).

The structure of wheel pressure distribution for the outfits in particular technologies (Fig. 3) was determined basing on the outfits’ weights and the values of specific wheel ground pressures. The presented values are the percent shares of places compacted with particular specific pressures on the field surface.

Considering the obtained results one can find that in all technologies the largest area is taken by the places of total pressure ranged from 101 to 200 kPa. The areas of this pressure take from about 11% (T6) to 35.6% (T5), on the average 21.9%, which usually correspond to 2–3 runs of tractor wheels over the same track. The areas compacted with pressure 201–300 kPa took from about 8% (T2) to about 18% (T3), on the average 11.7% and corresponded to 3–4 runs of wheels over the same track. The share of areas compacted with higher pressures did not exceed 5% (with exception for T3 technology where the trailed outfits of small widths were used). It is evident that the biggest portion of compacted field had the areas of pressure equal to 400 kPa, resulted usually from the passage of trailed machinery for fertilizing and chemical plant protection. In technologies with traffic path system, where the outfits run over the same tracks, the total specific pressures can exceed even 1000 kPa, however, the share of these areas did not exceed 1% in traditional technologies and 3% in technologies with traffic path system. The traffic path mode of running applied from pre-sowing tillage leads to creation of narrow straps of highly compacted soil with large part of not compacted field. This is confirmed by wheel pressure distribution in technology T6, where the compacted areas of particular pressures ranged from about 0.3 to 7% of the field area (with the exception for group 1001–200 kPa).

Comparing the pressure values obtained in technologies T1 and T2 one can find that introduction of wider and heavier tractor mounted machines did not influence much the soil compaction. The share of pressures up to 100 kPa decreased, along with an increase in the area of pressure 101–200 kPa. The similar results were obtained in technologies T3 and T4. The effect of introduction of till-sowing set (T5), which decreased the number of runs over the field, was also inconsiderable. This technology still leaves a large area of the field (54%) compacted with pressure over 100 kPa. One can find that the most critical factor which determines changes in the compacted field areas is the mode of outfit running over the field.

Assuming that the pressure of 100 kPa is a limit value for advantageous development of the root system, one can compare particular technologies with respect to total field area compacted with higher pressures and not compacted areas (Fig. 3h). Considering the presented results one can find that the least harmful effects on plants had the outfits in technology T6 (tractor mounted outfits of large widths, running on traffic paths made in secondary tillage). The area of compaction...
FIGURE 3. Structure of field compaction with particular wheel pressure values (a–g) and comparison between not compacted area (Pk = 0) and compacted area of pressure (Pk > 100) in particular technologies.
over 100 kPa took in this technology about 36% of field area and was from 1.4 to 1.7 times smaller than that in the remaining technologies. The application of this technology enabled also to obtain over 63% of area totally free from wheel compacting. The largest area compacted with so large pressure was found in technology T3 (tractor trailed outfits of small working widths) and in T5 (tractor mounted outfits of large working widths, including the till-sowing set, running in traditional mode). These two technologies left the least area without the wheel tracks.

Technology T7 with the outfits running on traffic paths made during sowing was slightly more advantageous than traditional technologies with respect to field compaction, but was worse than technology with traffic paths (T6) made during secondary tillage.

Since the remaining technologies (apart from T6) left considerably bigger field areas compacted with high pressures, there was introduced the compaction index to evaluate selection of the outfits for a given technology. The index relates the field area free of compaction to the area compacted with pressures above 100 kPa (the assumed limit value from the viewpoint of plant development) (Fig. 4).

As it is evident from the diagram, technology T6 is characterized by most advantageous ratio of not compacted field area to the area compacted excessively (index value of 1.77) which means, that almost 1.8 units of the area free of compaction falls to every unit of field excessively compacted. The values of this index in the remaining technologies were lower than 1 (the excessively compacted area was bigger than the area without the wheel tracks). However, introduction of technology T6, where the traffic paths are made at the beginning of secondary tillage, calls for proper selection of outfits’ widths and for application of the system of outfits’ traffic over the field with the use of DGPS system.

CONCLUSIONS
1. In solving problems of soil compaction by the wheels of tractor outfits one should
consider the optimal selection of their technical and exploitation parameters. This is particularly important in small farms of limited financial resources, where tractor-machine combinations for particular technologies are often selected without consideration to working width, weight and other selection criteria.

2. It was found that tractor trailed machines caused an increased soil compaction (by 43–59%) in relation to tractor mounted machinery. The biggest field surface coverage with tracks (over 61%) was found for tractor trailed outfits of small working width, running over the field by traditional manner.

3. The most advantageous distribution of wheel tracks and the pressure structure were found in technology variant based on application of traffic paths made during secondary tillage prior to sowing. However, it calls for application of satellite traffic system (DGPS) in all technological operations.

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**Streszczenie:** Wpływ technologii uprawy zbóż na ugniatanie gleby przez lekkie agregaty ciągnikowo-maszynowe. W rozwiązywaniu zagadnień ugniatania gleby kółmi agregatów ciągnikowych należy uwzględnić problematykę optymalizacji zestawienia parametrów techniczno-eksploatacyjnych agregatu ciągnikowego. Problem ten jest szczególnie ważny w małych gospodarstwach rolniczych, w których ze względu na ograniczone możliwości finansowe zestawianie narzędzi, maszyn z ciągnikiem do technologii najczęściej odbywa się bez uwzględniania kryteriów doboru, takich jak: szerokości robocze, masa itp. W pracy zestawiono typowe technologie uprawy zbóż stosowane w małych gospodarstwach rolniczych województwa podlaskiego. Technologie zróżnicowane ze względu na szerokości robocze agregatów i wartości obciążeń kół, sposobu wykonywania przejazdów po polu. Wykonano analizę rozkładu i wartości nacisków kół na powierzchni pola agregatów ciągnikowych stosowanych w rozpatrywanych technologiach. Badania i analizy wykazały, że największą powierzchnię pola pokrytą śladami (> 61%) pozostawiały po sobie agregaty o małej szerokości roboczej, przyczepiane do ciągnika i poruszające się po polu systemem tradycyjnym. Najkorzystniejszy rozkład śladów i struktur nacisków otrzymano dla wariantu technologii opartego na ścieżkach przejazdowych, zakładanych od zabiegów uprawy wykonywanej przed siewem. Stosowanie takich technologii wymaga użycia satelitarnego systemu prowadzenia agregatu po polu (DGPS) we wszystkich zabiegach technologii.

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