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SOIL COMPACTION WITH WHEELS OF AGGREGATES FOR FERTILIZATION WITH LIQUID MANURE

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ABSTRACT

Te objective of the research was determination of the impact of loading capacity of fertilization sets on soil compaction. Degree of soil compaction was determined based on four indexes. Three fertilization sets were selected for research: set A – tractor Renault 95.14 plus a waste removal vehicle of cubic capacity of 6 m^3, set B – tractor John Deere 6420 plus a waste removal vehicle 12 m^3, and set C Valtra N121 plus a waste removal vehicle 8 m^3. Four indexes were determined: field area compaction, loading a field with sets crossings, degree of compaction in the trace of wheels and cubic capacity of ruts. It was determined that the biggest surface of the compacted field was for the set A (27%) and the smallest for the set B (16%). Loading of a field with the sets crossings was the highest also for the set A (212 kN·km·ha^{-1}) and the lowest for the set B (167 kN·km·ha^{-1}). Degree of compaction in the trace of wheels was the highest for the set B (105 kN·m^{-1}) and the lowest for the set A (77 kN·m^{-1}). The highest cubic capacity of ruts was determined on the field fertilized with the set A (99 m^3) and the lowest for the set B (61 m^3). From among the technical parameters of fertilization machines the following affect the soil compaction degree: tractor mass and a waste removal vehicle mass and its cubic capacity and the working width, which depends on the application unit which was used. The set B may be recognized as the the best selected fertilization set (a tractor and a waste removal vehicle) on account of soil compaction and the least favourable – the set A.

Introduction

A waste removal vehicle is a basic machine in liquid manure fertilization technology, which transports and applies fertilizer (Dreszer et al., 2008; Romaniuk et al., 1995; Śiłovoj, 2013). Producers of waste removal vehicles are inter alia Polish companies Meprozet Kościan, Pomot Chojna and foreign: Holmer, Exmoor, Zunhammer Gulltechnik, Venhuis, Kyndestoft Maskinfabrik ApS, Freiberger, Oldenburger, Toric (Zbytek, et al., 2008). Waste removal vehicles are both agricultural machines as well as transport means. They move on various bases, both on public roads, hardened roads, and field roads as well as on fields, meadows and pastures. Thus, their equipment in appropriate driving systems, which meet the requirements regarding axis loads and unit loads are very important (Powałka, 2008). Tendencies concerning construction of even higher cubic capacities of waste removal vehicles and their equipment in additional devices, such as: spreading beams, cultivation tools cause that their mass in the recent years has increased a lot (it reaches several tonnes) (Rjazanov, 2009; Zbytek and Talarczyk, 2011; Zbytek, et al., 2013). Such big masses of machines cause high demand for power of cooperating tractors, which also are of big mass. The mass of an aggregate with fertilizers reaches up to 45 tonnes, which causes a threat of excessive soil compaction with tractor wheels and a waste removal vehicle wheels. This compaction, as numerous authors state (Buliński i Marczuk, 2007; Jakliński, 2006; Marczuk, 2006; Marczuk and Skwarcz, 2006; Koniuszy, 2010) may be minimized with the use of fertilization aggregates with properly selected mass, power of the tractor engine, number of wheels, size and pressure in tyres, wheel track (tractor wheels track compatible with the waste removal vehicle wheels track). Various indexes are used for assessment of the degree of soil compaction, including: the area of the compacted field, pressures on the axis of the driving system, unit pressures in a rut, depth of a rut, cubic capacity of the formed ruts (Marczuk and Kamiński, 2012). Each index describes only a part of soil compaction phenomenon. It is also significant, in what soil-climate conditions fertilization treatment is carried out (Pilarski, et al., 2008; Wesołowski, 2008; Iwaszkiewicz, 2013; Marczuk, 2013; Lorencowicz, 2013).

Objective, scope and the methodology of research

The objective of the research was to determine the loading capacity of waste removal vehicles (6, 8 and 12 m^3) used in farms of a varied acreage, various livestock, on soil compaction, determined with four indexes which characterize the degree of soil compaction. The scope of research included three fertilization sets (a tractor and a waste removal vehicle) which differ with tractor power, cubic capacity of vehicles, number of wheels and the size of the set tyres.

Exploitation research of machines took place on the territory of Podlaskie voivodeship in farms with agricultural land acreage 28, 60 and 90 ha with cowsheds with respective livestock: farm I 25 dairy cows and 15 cattle, farm II 40 cows, 10 heifers and 10 cattle, 25 bulls, farm III 55 dairy cows, 25 heifers and 25 cattle. In farms there were tanks for natural liquid manure of cubic capacity 200, 850 and 250 m^3, which ensure collection of 6-month liquid manure production.

Fertilized cultivation fields were located in the following distance from farms (tanks for natural liquid manure): 400, 350 and 200 m. Liquid manure was spread on the surface of a field with sod podzod soil with stubble after winter wheat and skimming carried out with a disc harrow. Relative moisture of fertilized soils was 10-12%.

Three fertilization sets were accepted for research: set A – tractor Renault 95.14 and a waste removal vehicle of cubic capacity 6 m^3 Strautman&Sohne 580, set B – tractor John Deere 6420 and a waste removal vehicle of cubic capacity 12 m^3 Fliegl Fass 12000 and set C – tractor Valtra N121 and a waste removal vehicle of cubic capacity 8 m^3 Siegfried Marchner 8000 (fig. 1).

a) Set A b) Set B c) Set C

Figure 1. Fertilization aggregates during work on field; a setA, b. set B, c. set C

An abridged technical description of the used tractors and waste removal vehicles was presented in table 1 and 2.

Table 1
*Technical description of agricultural tractors**

Tractor type	Total mass (kg)	Engine power (kW/KM)	Tyre size (front/back)	Fuel consumption ($dm^3 \cdot h^{-1}$)	Tractor price (PLN)
Renault 95.14	4740	62.5/85	360/70R28 480/70R34	9.38	200.000
John Deere 6420	4.800	88/120	420/70R24 520/70R34	13.20	300.000
Valtra N121	4.950	101/137	480/65R28 600/65R38	15.15	389.610

* Acc. to producer's data and authors' own measurement

Table 2
Abridged technical description of waste removal vehicles (water carts)*

Type of water cart	Total mass (kg)	Tyre size	Cubic capacity of a tank (m^3)	Manner of filling	Manner of emptying	Performance W_{07} ($ha \cdot h^{-1}$)	Price of a water cart (PLN)
Strautman &Sochne 580	1000	550/60-22,5 (air)	5.8	compressor	compressor	0.88	61.500
Fiegl Fass 12.000	2000	600/55-22,5	12.0	compressor	compressor	2.06	123.000
Siegfried Marchner 8000	1300	550/60-22,5 (air)	8.0	compressor	compressor	2.86	55.000

* Acc. to producer's data and authors' own measurement

Methodology of research

For assessment of soil compaction degree, four following indexes were accepted citing Marczuk and Kamiński (2012): compacted field surface (k_s), field load (k_{ob}), degree of soil compaction in the trace of wheels (k_{ug}), cubic capacity of ruts (V_k).

Compacted field area. The field area compacted with tractor wheels and waste removal vehicles was determined with participation of trace area (ruts) of tractor wheels and waste removal carts in the total area. It is equal to the relation of the ruts width to the working width of a waste removal vehicle:

$$k_s = \frac{S_1}{S_2} \cdot 100 \quad (\%) \tag{1}$$

where:
k_s – participation of the compacted field area (%),
S_1 – width of left and right wheel tracks (m),
S_2 – working width of a machine (m).

Field load. Index of field load with working crossings of an aggregate were calculated according to the following formula:

$$k_{ob} = \frac{(G_c + G_w + 0.5G_l) \cdot L_B}{P_p} \quad (\text{kN·km·ha}^{-1}) \tag{2}$$

where:
k_{ob} – field load (kN·km·ha^{-1}),
G_c – tractor weight (kN),
G_w – waste removal weight (kN),
G_l – load weight in the waste removal vehicle (kN),
L_B – route of an aggregate of the working width B on the area P_p (km),
P_p – area of 1 ha.

Degree of soil compaction in the track of wheels. These are average axis pressures resulting from the tractor mass, waste removal vehicle mass with the content during the crossing of an aggregate on a field. Total pressure (k_{ug}), it is a sum of axis pressures of the set (tractor, waste removal vehicle with the tank half-filled):

$$k_{ug} = N_{opc} + N_{otc} + N_{opw} + N_{otw} \quad (\text{kN}) \tag{3}$$

where:
k_{ug} – total pressure of the fertilization set (kN),
N_{opc} – pressure of front axis of a tractor (kN),
N_{otc} – pressure of the back axis of a tractor (kN),
N_{opw} – pressure of the back axis of a waste removal vehicle (kN),
N_{otw} – pressure of the back axis of a waste removal vehicle (kN).

Unit pressure of the set on the unit of compacted area is a ratio of the total pressure and the rut width made by right and left wheels of the set.

$$Nj = \frac{k_{ug}}{S_{sl}} \tag{4}$$

where:
N_j – unit pressure ($kN \cdot m^{-1}$),
$S_{śl}$ – width of left and right wheels track (m).

Cubic capacity of ruts. It was determined as the cubic capacity of the tractor and waste removal vehicle wheels track made on the area of 1 ha, which was determined in the following manner:

$$V_k = S_k \cdot G_k \cdot D_a \quad (m^3) \tag{5}$$

where:
V_k – cubic capacity of ruts on the area of 1 ha (m^3),
S_k – the rut width of left and right wheels (m),
G_k – the rut depth at 1/2 content of a tank (m);
D_a – route of an aggregate on the area of 1 ha (km).

Measurements of width and depth of a rut was carried out with the use of a batten and measure with precision to 1 mm following crossing of front and back wheels of a tractor and front and back wheels of a waste removal vehicle.

Results of the research

Compacted field surface. Working width of a machine and the width of wheel tracks (right and left) of the machine set has a main impact on the compacted field surface. Working width of the waste removal vehicle depends on the type of and performance of a compressor used in the vehicle. In the researched waste removal vehicles the working width was respectively: 4,7.5 and 5 m. Te same wheel track of tractors and waste removal vehicles caused that ruts had a width equal to the size of the widest wheel. For sets A and B these were rut widths made by waste removal vehicles (tyres 550/60-22.5 and 600/55-22.5), in the set C it was the rut width made by tractor wheels (600/65 R38).

Width of tracks of left and right wheels, working width of machines and percentage participation of the compacted field area for three fertilization sets were presented in table 3.

Table 3
Percentage participation of the compacted field area during fertilization with liquid manure

Symbol of the fertilization set	Width of left and right wheels (m)	Working width of machines (m)	Compacted field area k_s (%)
A	1.10	4.0	27.50
B	1.20	7.5	16.00
C	1.20	5.0	24.00

The research and calculations show that the highest percentage participation of the compacted field area (27.5%) was reported for the fertilization set A (vehicle with cubic capacity of 6 m^3) the lowest for the set B, comprising a waste removal vehicle of cubic capacity of 12 m^3 – 16 %.

Loading a field with working crossings

Loading a field with working crossing was determined based on measurements and cal-cualtions including: the weight of the set comprising a tractor plus a waste removal vehicle with 0.5 loading capacity of a tank, widths of waste removal vehicle, travelled distance by the fertilization sets on 1 ha area. Table 4 presents values of the index of loading a field with working crossings for the testes three fertilization sets. It was determined that loading a field on the 1 ha area with fertilization sets crossings at the assumption that the half of total mass of the load is placed at the average in a tank, it was the highest for the set A (211.90 kN·km·ha^{-1}), average for the set C (201.11 kN·km·ha^{-1}) and the lowest for the set B (167.01 kN·km·ha^{-1}). Such values of the index mainly result from the fertilization sets masses and the working width of waste removal vehicles, which in case of lower values (load mass and working width of a vehicle) travelled a longer distance.

Table 4
Loading a field with working crossings of fertilization sets

Symbol of the fertilization set	Weight of the set: tractor+waste removal vehicle + 1/2 of load (kN)	Working width of waste removal vehicles (m)	Width of ruts (m)	Distance travelled by the sets (km)	Field load k_{ob} (kN·km·ha^{-1})
A	84.76	4.00	1.10	2.50	211.90
B	125.57	7.50	1.20	1.33	167.01
C	100.55	5.00	1.20	2.00	201.11

Unit pressure in the wheels track

Calculated average unit pressures of wheels on soil of the researched fertilization sets were presented in table 5. The highest values of this index characterize the B set, average values – the C set and the lowest – A set. They directly related to masses of tractors and waste removal vehicles with load rolled over on a field.

Table 5
Unit pressure in the wheels track of fertilization sets

Symbol of the fertilization set	Weight (kN)				Width of a rut (m)	Unit pressure N_j (kN·m^{-1})
	Tractor	Waste removal vehicle	1/2 of the load of a vehicle	Total		
A	46.50	9.81	28.45	84.76	1.10	77.05
B	47.09	19.62	58.86	125.57	1.20	104.64
C	48.56	12.75	39.24	100.55	1.20	83.79

Cubic capacity of ruts

Analysis of depth and width of ruts was carried out based on the measurements of cross section of wheels tracks of a tractor and a waste removal vehicle. At the same time, degree of fill-up in the tank – a full tank, 0.5 of cubic capacity of a tank and an empty tank were included. Depth and width of ruts made by front and back wheels of a tractor and waste removal vehicles were measured taking into account left and right side of an aggregate. Measurements were taken three times and then average values were calculated. Results of measurements and calculations were presented in table 6.

Table 6
Average values of measurements of wheel tracks of a tractor and a waste removal vehicle and cubic capacity of ruts V_k

<table>
<tr><th rowspan="3">Axes of wheels</th><th colspan="6">The state of fill-up of a waste removal vehicle tank</th><th rowspan="3">Index of cubic capacity of a rut V_k ($m^3 \cdot ha^{-1}$)</th></tr>
<tr><th colspan="2">Full tank</th><th colspan="2">1/2 of a tank</th><th colspan="2">Empty tank</th></tr>
<tr><th>Left side depth/width (mm)</th><th>Right side depth/width (mm)</th><th>Left side depth/width (mm)</th><th>Right side depth/width (mm)</th><th>Left side depth/width (mm)</th><th>Right side depth/width (mm)</th></tr>
<tr><td colspan="8">Fertilization set A</td></tr>
<tr><td>1 axis of a tractor</td><td>30.3/383</td><td>30.3/380</td><td>31.8/382</td><td>31.8/388</td><td>32.0/383</td><td>33.0/387</td><td rowspan="3">93.5</td></tr>
<tr><td>2 axis of a tractor</td><td>33.5/480</td><td>34.6/475</td><td>36.0/487</td><td>36.5/483</td><td>35.5/550</td><td>35.1/480</td></tr>
<tr><td>Axis of a waste removal vehicle</td><td>32.3/553</td><td>33.6/550</td><td>34.0/553</td><td>34.3/550</td><td>34.6/550</td><td>35.3/550</td></tr>
<tr><td colspan="8">Fertilization set B</td></tr>
<tr><td>1st axis of a tractor</td><td>34.0/430</td><td>34.6/425</td><td>32.0/420</td><td>32.3/420</td><td>30.3/420</td><td>31.0/420</td><td rowspan="4">62.2</td></tr>
<tr><td>2nd axis of a tractor</td><td>40.6/550</td><td>38.6/540</td><td>38.0/520</td><td>39.0/522</td><td>39.3/520</td><td>38.6/520</td></tr>
<tr><td>1st axis of a waste removal vehicle</td><td>40.3/600</td><td>39.6/600</td><td>38.3/600</td><td>38.0/600</td><td>38.0/600</td><td>38.3/600</td></tr>
<tr><td>2 axis of a waste removal vehicle</td><td>38.3/600</td><td>39.3/600</td><td>38.0/600</td><td>38.0/600</td><td>37.3/600</td><td>37.3/600</td></tr>
</table>

Fertilization set C							
1st axis of a tractor	16.3/450	17.3/450	19.3/450	19.6/450	20.6/450	21.3/450	67.2
2nd axis of a tractor	25.0/593	26.6/593	29.0/593	30.0/573	30.3/593	32.0/593	
1st axis of a waste removal vehicle	27.3/600	28.0/600	28.0/600	30.0/600	30.3/600	31.3/600	
2nd axis of a waste removal vehicle	27.6/600	28.3/600	28.3/600	30.3/600	30.3/600	30.3/600	

Research and calculations prove that in caseof fertilization sets A and C, the ruts depth made by the front axis of a tractor increased along with emptying the waste removal vehicle tank. It means that a full tank of a vehicle considerably loads the back axis of a tractor which results in relieving the front axis. In case of the fertilization set B the ruts depth made by the front axis of a tractor decreases along with emptying the tank. It was calculated based on average values of depth and width of ruts which were formed during filling the tank of a waste removal vehicle to 0.5 maximum cubic capacity and were for the set A, B and C respectively 93.5 m^3, 62.2 m^3 and 67.2 m^3. High value of ruts cubic capacity in case of the A set at the lowest cubic capacity of the tank of a waste removal vehicle and at its lowest mass results from small working width (4.0 m).

Summary

Research proved that the used fertilization sets in farms cause considerable soil compaction in wheels tracks. The list of numerical values of soil compaction degree indexes for the analysed fertilization sets presented in fig. 2.

Cubic capacity of a rut, made on the area of 1 hectare of the fertilized field is a significant index which presents the soil compaction degree. Calculated cubic capacity of ruts based on average values of depth value and width of wheels track made at filling the tank of a waste removal vehicle which is 0.5 of maximum cubic capacity, was the maximum for the fertilization set of A – 93.5 m^3. For the remaining two sets it was on the similar level (B – 62.2 m^3, C – 67.2 m^3). From among four indexes of assessment of the soil compaction degree with wheels of fertilization aggregates for the A set the lowest unit pressures in wheels track were reported and for the b set the lowest field compaction, the lowest load of a field with working crossings and lowest cubic capacity of ruts. The C set featured average values of all four indexes.

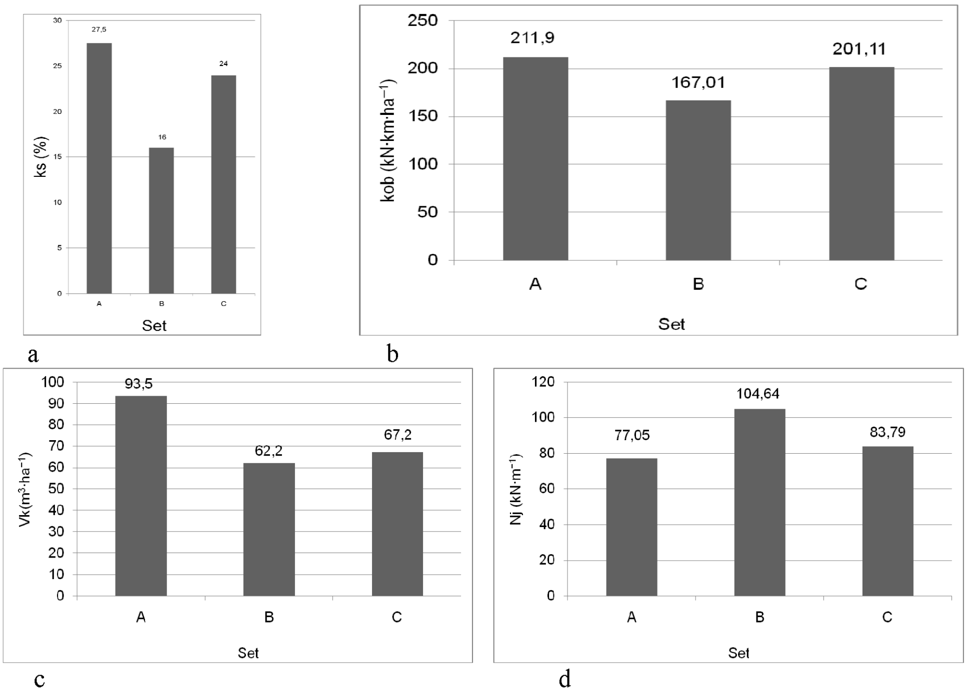

Figure 2. Numerical values of soil compaction degree indexes: (a) compacted field surface k_s, (b) field load k_{ob}, (c) rut cubic capacityV_k, (d) rut load N_j

Conclusions

1. Technology of fertilization with liquid manure should include besides agricultural requirements also ecological requirements related to soil compaction and pollution of natural environment. Numerous factors affect the degree of coil compaction, inter alia: technical parameters of a machine, exploitation parameters and weather conditions (soil moisture).
2. The smallest area of the compacted field (16%) was reported in the B set. It is related to the working width of a set which translates into the distance travelled on the area of 1 ha.
3. Along with increase of the cubic capacity of waste removal vehicles also cubic capacity of ruts made on the field surface decreased from 93 m^3 to 62 m^3.
4. Tests on the fertilization sets proved that the B set (with a vehicle 12 m^3) obtained most favourable indexes and the least favourable the A set (with a vehicle 6 m^3).

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UGNIATANIE GLEBY KOŁAMI AGREGATÓW DO NAWOŻENIA GNOJOWICĄ

Streszczenie. Celem badań było określenie wpływu ładowności zestawów nawozowych na ugniecenie gleby. Stopień ugniecenia gleby określono na podstawie czterech wskaźników. Do badań wytypowano trzy zestawy nawozowe: zestaw A – ciągnik Renault 95.14 plus wóz asenizacyjny o pojemności 6 m^3, zestaw B – ciągnik John Deere 6420 plus wóz asenizacyjny 12 m^3, i zestaw C – ciągnik Valtra N 121 plus wóz asenizacyjny 8 m^3. Określono cztery wskaźniki: ugniecenie powierzchni pola, obciążenie pola przejazdami zestawów, stopień ugniecenia w śladzie kół jezdnych i objętość kolein. Stwierdzono, że największa powierzchnia ugniecionego pola wystąpiła dla zestawu A (27%) a najmniejsza dla zestawu B (16%). Obciążenie pola przejazdami zestawów było największe również dla zestawu A (212 $kN \cdot km \cdot ha^{-1}$) a najmniejsze dla zestawu B (167 $kN \cdot km \cdot ha^{-1}$). Stopień ugniecenia w śladzie kół jezdnych był natomiast największy dla zestawu B (105 $kN \cdot m^{-1}$), a najmniejszy dla zestawu A (77 $kN \cdot m^{-1}$). Największą objętość kolein stwierdzono na polu nawożonym zestawem A (99 m^3) a najmniejszą dla zestawu B (61 m^3). Z parametrów technicznych maszyn nawozowych na stopień ugniecenia gleby wpływ mają: masa ciągnika oraz wozu asenizacyjnego a także jego pojemność i szerokość robocza, która zależy od zastosowanego zespołu aplikacyjnego. Za najlepiej dobrany zestaw nawozowy (ciągnik i wóz asenizacyjny), z punktu widzenia ugniatania gleby, należy uznać zestaw B, a za najmniej korzystny zestaw A.

Słowa kluczowe: gleba, ugniatanie gleby, zestaw nawozowy, ciągnik rolniczy