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# The impact of soil compaction with different harvest technologies caused by agricultural machinery

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## Abstract

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The article presents the results of studies that characterized the percentage share of compacted area by the usage of agricultural machinery. Analysis was made for cultivation technology of corn for silage, sugar beet and meadow grasses. Research focused on statistical analysis of technological cards data. Technological cards are describing the different agricultural practices of harvest technologies. The analyzed data contained the information about corn for silage (K), sugar beet (BC) and meadow grasses (T) harvest technologies. Technological data covered 24 farms that were specified by area of below and above 5 hectares. The results showed that the area which was under the pressure of the agricultural machinery wheels for the most part exceeded the area of annual cultivation. The greatest pressure of the wheels was noted for technology covering the meadow grass cultivation on the area below 5 ha. For this technology, the percentage of the pressed field area was more than 500%. Technologies belonging to the least invasive cultivation was one-step sugar beet harvest on the field area over 5 hectares.

*Keywords:* harvest technologies; corn for silage; sugar beet; meadow grasses; field compaction
*JEL codes:* Q24, Q4

## Introduction

The main features of alternative fuel are possibilities that reduce the carbon dioxide and greenhouse gases emissions into the atmosphere. Despite the many positives in technologies of natural energy resources (Platt, 2007), exists a spectrum of environment degradation. Environmental hazards come from mechanization and automation of crop production. The use of agricultural operations involving the newer and morasses precision agriculture equipment can eliminate the soil disorders.

Producers of agricultural machines are trying to overcome the effects of their actions, applying the possibility of universal agricultural operations (Konieczna et al., 2021).

However, new equipment increases the weight of the tool, forcing machine to multiple drive on the agricultural area (Kuboń & Tabor, 2010; Marks et al., 2004). In a result causing chemical, physical and biological changes in the soil (Gupta & Allmaras, 1986; Horn et al., 1995), leading to over-compaction structure of the role, tightening pores and reduce the permeability (Hodara & Domżał, 1991; Alakukku, 1996).

Environmental degradation significantly reduces crop yield and is particularly high for the area of Europe, keeping the upward trend (Van Ouverkerk & Soane, 1994). Conducting a comprehensive cultivation involve usage of suitable tires, marking the riding lines or correct unit selection during the cultivation.

Gaining the greater knowledge of the plant needs or characteristics of the used tools can also be the way to reduce environmental degradation (Marks, 1996; Marks & Buczyński 2002). The following studies have purpose enrich and extend the knowledge of harvesting technology. Studies focus on selected species of plants allocated for energy purposes.

## Material and Methods

Research focused on statistical analysis of technological cards data. Technological cards are describing the different agricultural practices of harvest technologies. The analyzed data contained the information about corn for silage (K), sugar beet (BC) and meadow grasses (T) harvest technologies. Technological data covered 24 farms that were specified by area of below and above 5 ha.

During the calculations it was assumed that the mass of grass hay 160 kg, 1 $m^3$ of chopped corn 600 kg and the bulk sugar beet 650 kg. Assumed, that the machines that start work in the field haven't got any load, but at the end of the cycle was fully loaded. To correct the load characteristics were assumed that each cycle have half weight of loaded machine. Specific types of trailers covered harvests and transports of agricultural produce. Specifications of trailers were presented in Table 1.

Internal storage containers in agricultural machines may cover the load of crops during the harvest operations. Combines ROPA have possibilities to storage 40 $m^3$ of sugar beet roots for one cycle. In the combine Neptune Z-413 can be stored 180 kg of leaves and 2 500 kg of roots. Self-loading trailer T-150/1 during a single pass can store 14 bales of hay.

Tables described the characteristics of cultivation that was made. Technology of corn for silage harvesting where field area had less than 5 ha have 65 250 kg of maximum total weight equipment. In the technology of cultivation where area has more than 5 ha, the maximum total equipment weight was 59 400 kg. In the tables below was described the characteristics of corn for silage cultivation technology. Table 2 presents the description of technological procedures for harvesting corn for silage on less than 5 ha area, Table 3 – on more than 5 ha area.

The scope of research also included the characteristics of the sugar beet harvest technology. In the cultivation technology was used specialist harvesting equipment that was previously described. According to technology in the tables were described the harvest characteristics of sugar beet. Table 4 presents the description of technological procedures for harvesting sugar beet on less than 5 hectares area and on more than 5 ha area.

The scope of research also included the characteristics of the harvest technology grass meadow grasses for silage purpose. The technology of meadow grasses requires the multi-treatments cultivation that forces to cyclic travel of working machines during the harvest. Table 5 presents a description of harvest technology of meadow grass on less than 5 ha area, Table 6 – on more than 5 ha area.

The multistage character of cultivation technology is forcing to repeat the cyclic operations flattening the soil even six times.

**Table 1. Technical data of used trailers**

| No. | Type | Load capacity, t | Dimension, m | Possibility of load |
|---|---|---|---|---|
| 1. | Chest trailer | 4.5 | 4.00 × 2.12 × 0.50 | 10 bales of grasses hay |
| 2. | Chest trailer with extensions | 4.5 | 4.00 × 2.12 × 0.50 + 0.50 m | 16 bales of hay |
| 4. | Volume trailer | 4.5 | 4.00 × 2 × 1.5 | 11 $m^3$ of hay |
| 5. | Chest trailer (IV) | 4.5 | 4.00 × 2.12 × 0.50 | 4.24 $m^3$ of corn for silage |
| 6. | Chest trailer (V) | 6 | 4.00 × 2.12 × 0.50 | 4.23 $m^3$ of raw material |
| 7. | Chest Trailer (VI) | 10 | 4.43 × 2.23 × 1.12 | 12 $m^3$ of raw material |
| 8. | Trailer „Autosan" D732 | 5 | 4.18 × 0.5 × 2.12 | 4.43$m^3$ of raw material |
| 9. | Trailer T076/1 i /2 | 10 | 4 × 2 × 1 | 8.00 $m^3$ of raw material |

*Source:* Own studies

**Table 2. Characteristics of corn for silage harvesting technologies on less than 5 ha field**

| Agricultural activity or technology operations | Characteristics of machine and equipment | Tractor mass, kg | Tire width of tractor | | Tool weight, kg | Tire width of tool, m | The distance between the driving row, m | The amount of work, ha | The mean weight of load, kg | Equipment weight, kg | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Back, m | Front, m | | | | | | | |
| Corn for silage I <5 ha (2.0) | | | | | | | | | | | |
| Harvesting | Chaff-cutter Claas 6rz | 11600 | 0.41 | 0.76 | | | 4 | 2 | | 11600 | |
| Transport and unloading (1) | Fendt + volume trailer | 6500 | 0.65 | 0.54 | 3000 | 0.46 | 4 | 2 | 3300 | 12800 | (11 $m^3$x600 kg $x^3$):2 |
| Transport and unloading (2) | Fendt + volume trailer | 6500 | 0.65 | 0.54 | 3000 | 0.46 | 4 | 2 | 3300 | 12800 | (11 $m^3$x600 kg $x^3$):2 |
| Transport and unloading (3) | Fendt + volume trailer | 6500 | 0.65 | 0.54 | 3000 | 0.46 | 4 | 2 | 3300 | 12800 | (11 $m^3$x600 kg $x^3$):2 |
| Piles compaction | Fadroma loader | | | | 9400 | 0.66 | 4 | 2 | | 9400 | |
| Corn for silage II < 5 ha (3.5) | | | | | | | | | | | |
| Harvesting | Zetor Proxima 8441+ Chaff-cutter Pottinger 2S | 3645 | 0.41 | 0.3 | 510 | – | 4 | 3.5 | | 4155 | Semi-trailed |
| Transport | MTZ 82 TS + trailer 6t | 3560 | 0.41 | 0.33 | 2110 | 0.28 | 4 | 3.5 | 1269 | 6939 | (4.23 $m^3$x600 kg):2 |
| Transport | Zetor Proxima 8441 + trailer 4.5t | 3645 | 0.41 | 0.3 | 1885 | 0.25 | 4 | 3.5 | 1269 | 6799 | (4.23 $m^3$x600 kg):2 |
| Pressing | MTZ 80 | 3820 | 0.38 | 0.18 | | | 4 | 3.5 | | 3820 | |
| Corn for silage III <5 ha (3.5) | | | | | | | | | | | |
| silage cutting | MF 255 + forage harvester Z364 | 2890 | 0.36 | 0.23 | 410 | - | 4 | 3.5 | | 3300 | Semi-trailed |
| Transport | Zetor 7011 + trailer autosan D732 | 3430 | 0.41 | 0.28 | 1500 | 0.25 | 4 | 3.5 | 1329 | 6259 | (4.43 $m^3$x600 kg):2 |
| Transport | III 330 M + trailer T076/1 | 2170 | 0.28 | 0.15 | 3160 | 0.38 | 4 | 3.5 | 2400 | 7730 | (8 $m^3$x600 kg):2 |
| Transport | III 360 + trailer T076/2 | 2170 | 0.36 | 0.15 | 3600 | 0.38 | 4 | 3.5 | 2400 | 8170 | (8 $m^3$x600 kg):2 |
| Piles compaction | MF 3070 | 4100 | 0.41 | 0.33 | | | 4 | 3.5 | | 4100 | |

*Source:* Own studies

**Table 3. Characteristics of corn for silage harvesting technologies on the over 5 ha field**

| Agricultural activity or technology operations | Characteristics of machine and equipment | Tractor mass, kg | Tire width of tractor | | Tool weight, kg | Tire width of tool, m | The distance between the driving row, m | The amount of work, ha | The mean weight of load, kg | Equipment weight, kg | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Back, m | Front, m | | | | | | | |
| Corn for silage IV > 5 ha (13.0) | | | | | | | | | | | |
| Harvesting | chaff-cutter Claas 6rz | 11600 | . | 0.76 | | | 5 | 13 | | 11600 | |
| transport and unloading (1) | Fendt + volume trailer | 6500 | 0.65 | 0.54 | 3000 | 0.46 | 5 | 13 | 3300 | 12800 | (11 $m^3$x600 kg):2 |
| transport and unloading (2) | Fendt + volume trailer | 6500 | 0.65 | 0.54 | 3000 | 0.46 | 5 | 13 | 3300 | 12800 | (11$m^3$x600 kg):2 |
| transport and unloading (3) | Fendt + volume trailer | 6500 | 0.65 | 0.54 | 3000 | 0.46 | 5 | 13 | 3300 | 12800 | (11 $m^3$x600 kg):2 |
| piles compaction | MF 675 | 3550 | 0.33 | 0.30 | | | 5 | 13 | | 3550 | |
| piles compaction | JD 5720 | 3700 | 0.41 | 0.33 | | | 5 | 13 | | 3700 | |
| piles compaction | JD 88 kW | 5100 | 0.52 | 0.41 | | | 5 | 13 | | 5100 | |
| pile covering | Jogger (wheel loader) | | | | 2900 | 0.28 | 5 | 13 | | 2900 | |
| Corn for silage V > 5 ha (5.07) | | | | | | | | | | | |
| Harvesting | III-360 + hanged Chaff-cutter Mengele | 2170 | 0.36 | 0.15 | 2050 | - | 5 | 5,07 | | 4220 | Semi-trailed |
| Transport | III-360 + trailer 4t (x2) | 2170 | 0.36 | 0.15 | 3900 | 0.28 | 5 | 5.07 | 5088 | 11158 | mass 1950x2, load 2544x2 |
| | | | | | | | | | | | 2544 = (4.24 $m^3$x600kgx2):2 |
| Transport | MTZ 1025 + trailer 6t (x2) | 4100 | 0.46 | 0.36 | 4220 | 0.28 | 5 | 5.07 | 5088 | 13408 | masa 2110 x2, załadunek 2544 x2 |
| | | | | | | | | | | | 2544 = (4.24 $m^3$x600 kgx$^2$):2 |
| Piles compaction | MTZ 1025 | 4100 | | 0.36 | | | 5 | 5.07 | | 4100 | |
| Corn for silage VI >5ha (13.0) | | | | | | | | | | | |
| Harvesting | Chaff-cutter Claas 6rz | 11600 | 0.41 | 0.76 | | | 5 | 13 | | 11600 | |
| Transport | JD 6620 + trailer 10t | 5300 | 0.65 | 0.54 | 3400 | 0.385 | 5 | 13 | 10674 | 19374 | (11.86 $m^3$x600 kgx$^3$):2 |
| Compacting In silos | JD 6620 | 5300 | 0.65 | 0.54 | | | 5 | 13 | | 5300 | |

*Source:* Own studies

**Table 4. Characteristics of sugar beet harvesting technologies on less than 5 ha field and on the over 5 ha field**

| Agricultural activity or technology operations | | Sugar beet I | Sugar beet II | Sugar beet III | Sugar beet IV | Sugar beet V | Sugar beet VI |
|---|---|---|---|---|---|---|---|
| | | < 5 ha | | | > 5 ha | | |
| | | Roots harvesting | Roots harvesting | Sugar beet harvesting | Harvesting and stacking in prism | Harvesting | Sugar beet harvesting |
| Characteristics of machine and equipment | | Zetor Proxima 8441 + Combine Neptun Z413 | Ursus C360-3P + One-row combine for sugar beet Neptun Z-413 | Combine ROPA | Combine ROPA | Zetor 7211 + One-row combine for sugar beet Neptun Z-413 | U 3512 + One-row combine for sugar beet Neptun Z-413 |
| Tractor mass, kg | | 3645 | 2170 | | | 3450 | 2500 |
| Tire width of tractor | Back, m | 0.41 | 0.36 | | 0.41 | 0.36 | |
| | Front, m | 0.3 | 0.15 | | 0.23 | 0.23 | |
| Tool weight, kg | | 2750 | 2750 | 8540 | 8540 | 2750 | 2750 |
| Tire width of tool, m | | 0.38 | 0.38 | 0.54 | 0.54 | 0.38 | 0.38 |
| The distance between the driving row, m | | 2 | 2 | 2 | 3 | 2 | 2 |
| The amount of work, ha | | 2 | 3 | 3.04 | 6 | 6 | 5.7 |
| The mean weight of load, kg | | 1340 | 1340 | 13000 | 13000 | 1340 | 1340 |
| Equipment weight, kg | | 7735 | 6260 | 21540 | 21540 | 7540 | 6590 |
| Note | | (180 liscie+2500 harvesting):2 | (180 liscie+2500 harvesting):2 | (40m3 * 650):2 | (40m3 * 650):2 | (180 liscie+2500 harvesting):2 | (180 liscie+2500 harvesting):2 |

*Source:* Own studies

**Table 5. Characteristics of meadow grasses harvesting technologies on less than 5 ha field**

| Agricultural activity or technology operations | Characteristics of machine and equipment | Tractor mass, kg | Tire width of tractor | | Tool weight, kg | Tire width of tool, m | The distance between the driving row, m | The amount of work, ha | The mean weight of load, kg | Equipment weight, kg | Overall weight times the number of repetitions | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Back, m | Front, m | | | | | | | | |
| Meadow grasses I <5 ha | | | | | | | | | | | | |
| Harvesting 3x | JD 5720 + disc mower 2.6 m (Samasz KDT) | 4600 | 0.43 | 0.35 | 550 | | 2.6 | 4 | | 5150 | 15450 | |
| Tedding 6x | III-360-3p + Mesko-Rol Z 548 | 2170 | 0.36 | 0.15 | 304 | 0.31 | 2.6 | 4 | | 2474 | 14844 | |
| Raking 3x | JD 5720+Mesko-Rol Z 548 | 4600 | 0.43 | 0.35 | 304 | 0.31 | 3 | 4 | | 4904 | 14712 | |
| Harvesting-pressing 3x | JD 5720+Vicon RV186 | 4600 | 0.43 | 0.35 | 2200 | 0.38 | 3 | 4 | 80 | 6880 | 20640 | |
| Bales loading 3x | Loader Jogger | | | | 2900 | 0.28 | 3 | 4 | 80 | 2980 | 8940 | |
| Bales transport 3x | III-360- + 2 trailers | 2170 | 0.36 | 0.15 | 2100 | 0.28 | 3 | 4 | 800 | 5070 | 15210 | 10 bales |
| Bales wrapping 3x | Cgn 66 (Ursus 6614) + Wrapping machine (MASCAR – 3100) | 3600 | 0.48 | 0.38 | 900 | 0.56 | 3 | 4 | 80 | 4580 | 13740 | |
| Meadow grasses II <5 ha | | | | | | | | | | | | |
| Harvesting 2x | III-360+ Rotary mower SAMASZ | 2170 | 0.36 | 0.15 | 360 | | 1.65 | 3.25 | | 2530 | 5060 | |
| Hay tedding 3 razy | III-355+ Agroma Z-211/2 | 2000 | 0.38 | 0.15 | 430 | 0.31 | 3 | 3.25 | | 2430 | 7290 | |
| Raking 2x | III-355+ Agroma Z-211/2 | 2000 | 0.38 | 0.15 | 430 | 0.31 | 3 | 3.25 | | 2430 | 4860 | |
| Compacting 2x | JD 5720 + Round baler Sipma Z-279 | 4600 | 0.43 | 0.35 | 1900 | 0.28 | 3 | 3.25 | 80 | 6580 | 13160 | |
| Bale wrapping 2x | Zetor 8145 + Round baler Sipma Z-279 | 4300 | 0.43 | 0.31 | 1900 | 0.28 | 3 | 3.25 | 80 | 6280 | 12560 | |
| Bale loading 2x | JD 5720 + loader | 4600 | 0.43 | 0.35 | 575 | | 3 | 3.25 | 80 | 5255 | 10510 | |
| Bales transport 2x | U-912+2 trailers 4.5 t | 3970 | 0.47 | 0.28 | 2100 | 0.28 | 3 | 3.25 | 800 | 6870 | 13740 | 10 bales |
| Bale unloading 2x | JD 5720 + Loader | 4600 | 0.43 | 0.35 | 575 | | 3 | 3.25 | 80 | 5255 | 10510 | |
| Meadow grasses III <5 ha | | | | | | | | | | | | |
| Harvesting 3x | U4011+ Rotary mower SAMASZ | 2100 | 0.36 | 0.15 | 360 | | 1.65 | 4 | | 2460 | 7380 | |
| Tedding 3x | U4011+ Raking machine Mesko-Rol Z 548 | 2100 | 0.36 | 0.15 | 304 | 0.31 | 3 | 4 | | 2404 | 7212 | |
| Raking 3x | U4011+ Raking machine Mesko-Rol Z 548 | 2100 | 0.36 | 0.15 | 304 | 0.31 | 3 | 4 | | 2404 | 7212 | |
| Compacting 3x | Ciągnik 360 + Round baler Sipma Z-279 | 2170 | 0.36 | 0.15 | 1900 | 0.28 | 3 | 4 | 80 | 4150 | 12450 | |
| wrapping 3x | Ciągnik 360 + Wrapping machine (MASCAR – 3100) | 2170 | 0.36 | 0.15 | 900 | 0.27 | 3 | 4 | 80 | 3150 | 9450 | |
| Bale loader 3x | Ciągnik 360 + bale clamps | 2170 | 0.36 | 0.15 | 575 | | 3 | 4 | 80 | 2825 | 8475 | |
| Transport 3x | U912+2 trailer 4.5 t | 3970 | 0.47 | 0.28 | 2100 | 0.28 | 3 | 4 | 800 | 6870 | 20610 | 10 bales |
| transport 3x | U4011+2 trailer 3 t | 2100 | 0.36 | 0.15 | 2100 | 0.28 | 3 | 4 | 640 | 4840 | 14520 | 8 bales |

*Source:* Own studies

**Table 6. Characteristics of meadow grasses harvesting technologies on the over 5 ha field**

| Agricultural activity or technology operations | Characteristics of machine and equipment | Tractor mass, kg | Tire width of tractor | | Tool weight, kg | Tire width of tool, m | The distance between the driving row, m | The amount of work, ha | The mean weight of load, kg | Equipment weight [kg] | Overall weight times the number of repetitions | Note |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Back, m | Front, m | | | | | | | | |
| Meadow grasses IV >5 ha | | | | | | | | | | | | |
| Harvesting 3x | JD 5720 + disc mower 2,6m (Samasz KDT) | 4600 | 0.43 | 0.35 | 550 | | 2.6 | 14.4 | | 5150 | 15450 | |
| tedding 6x | III-360-3p + Mesko-Rol Z 548 | 2170 | 0.36 | 0.15 | 304 | 0.31 | 3.6 | 14.4 | | 2474 | 14844 | |
| Raking 3x | JD 5720 + Mesko-Rol Z 548 | 4600 | 0.43 | 0.35 | 304 | 0.31 | 3.6 | 14.4 | | 4904 | 14712 | |
| Harvesting- pressing 3x | JD 5720 + Vicon RV186 | 4600 | 0.43 | 0.35 | 2200 | 0.38 | 3 | 14.4 | 80 | 6880 | 41280 | |
| Bales loader 3x | Loader Jogger | | | | 2900 | 0.28 | 3 | 14.4 | 80 | 2980 | 17880 | |
| Bales transport 3x | III-360+2 trailers | 2170 | 0.36 | 0.15 | 6000 | 0.46 | 3 | 14.4 | 800 | 8970 | 53820 | (10x160 kg):2 |
| Bales wrapping machine 3x | Cgn 66 (Ursus 6614) + wrapping machine (MASCAR – 3100) | 3600 | 0.48 | 0.38 | 900 | 0.27 | 3 | 14.4 | 80 | 4580 | 27480 | |
| Meadow grasses V >5 ha | | | | | | | | | | | | |
| Harvesting 2x | U-1014 + disc mower 2.6 m | 4570 | 0.47 | 0.38 | 550 | | 5 | 22 | | 5120 | 10240 | |
| tedding 2x | III-360 3p + Mesko-Rol Z 548 | 2170 | 0.36 | 0.15 | 304 | 0.31 | 5 | 22 | | 2474 | 4948 | |
| Raking into windrows 2x | III-360 3p + Mesko-Rol Z 548 | 2170 | 0.36 | 0.15 | 304 | 0.31 | 5 | 22 | | 2474 | 4948 | |
| Harvesting 2x | Zetor 8145 + Round baler Sipma Z-279 | 4300 | 0.43 | 0.31 | 1900 | 0.28 | 5 | 22 | 80 | 6280 | 12560 | |
| Bales wrapping 2x | III-360 3p + wrapping machine (MASCAR – 3100) | 2170 | 0.36 | 0.15 | 900 | 0.27 | 5 | 22 | 80 | 3150 | 6300 | |
| Loading and transport | III-360 3p + Loader TUR-6 | 2170 | 0.36 | 0.15 | 575 | | 5 | 22 | 80 | 2825 | 2825 | |
| Loading and transport | Zetor 8145 + trailer 2 os. 4.5 t with extensions | 4300 | 0.43 | 0.31 | 2100 | 0.28 | 5 | 22 | 1280 | 7680 | 7680 | (16*160)/2 |
| Stacking | III-360 3p + Loader TUR-6 | 2170 | 0.36 | 0.15 | 575 | | 5 | 22 | 80 | 2825 | 2825 | |
| Meadow grasses VI >5 ha | | | | | | | | | | | | |
| Harvesting 2x | U-4514 + side disc mower | 3200 | 0.41 | 0.28 | 550 | | 5 | 20.9 | | 3750 | 7500 | |
| tedding 2x | MF-375DT + Rotary tedder | 3090 | 0.41 | 0.30 | 304 | 0.31 | 5 | 20.9 | | 3394 | 6788 | |
| Raking into windrows 2x | MF-375DT + Rotary tedder | 3090 | 0.41 | 0.30 | 304 | 0.31 | 5 | 20.9 | | 3394 | 6788 | |
| Haylage Harvesting 2x | KUBOTA M 9540 + Round baler 1,8m | 3865 | 0.48 | 0.28 | 1850 | 0.28 | 5 | 20.9 | 80 | 5795 | 11590 | |
| Haylage bales wrapping | MF-255 + Bales wrapper | 2500 | 0.36 | 0.15 | 900 | 0.27 | 5 | 20.9 | 80 | 3480 | 3480 | |
| Loading, transport and stacking | U-4514 + self loader trailer T-150/1 | 3200 | 0.41 | 0.28 | 3560 | 0.50 | 5 | 20.9 | 1120 | 7880 | 7880 | (14*160)/2 |
| Stacking | MF-255+ front loader TUR-5 | 2500 | 0.36 | 0.15 | 2100 | - | 5 | 20.9 | 80 | 4680 | 4680 | |

*Source:* Own studies

## Results and Discussion

Exerted pressure is the result of machine wheels impact during the travel operations. The pressure exerted on the soil by the wheels of the tractor and agricultural machinery was calculated according to surface area. Calculation results of all technologies were presented in Tables 7, 8 and 9.

The results of studies deliver the percentage share of compacted area. On the field was used tractors and agricultural machinery during all cultivation process, for every technology. The percentage share of compacted area due to traveling sets of agricultural machines was presented in Figure 1.

**Table 7. The area of compacted soil and the pressure exerted by the wheels of the tractor and agricultural machinery in particular technologies of corn for silage harvesting**

| Agricultural activity or technology operations | The area of tractor tires compaction | | The area of agricultural machinery tires compaction, $m^2$ | The area of compaction, $m^2$ | Pressure exerted by tractor | | Pressure exerted by agricultural machinery with load, Pa | Exerted pressure, Pa |
|---|---|---|---|---|---|---|---|---|
| | Back, m | Front, m | | | Back, Pa | Front, Pa | | |
| Corn for silage I < 5ha (2.0) | | | | | | | | |
| Harvesting | 4 100 | 7 600 | | 11 700 | 14.15 | 7.63 | | 21.78 |
| Transport and unloading (1) | 6 500 | 5 400 | 9 200 | 21 100 | 5.00 | 6.02 | 6.85 | 17.87 |
| Transport and unloading (2) | 6 500 | 5 400 | 9 200 | 21 100 | 5.00 | 6.02 | 6.85 | 17.87 |
| Transport and unloading (3) | 6 500 | 5 400 | 9 200 | 21 100 | 5.00 | 6.02 | 6.85 | 17.87 |
| Piles compaction | | | 13 200 | 13 200 | | | 7.12 | 7.12 |
| Corn for silage II <5 ha (3.5) | | | | | | | | |
| Harvesting | 7 175 | 5 250 | | 12 425 | 2.54 | 3.47 | | 6.01 |
| Transport | 7 175 | 5 775 | 9 800 | 22 750 | 2.48 | 3.08 | 3.45 | 9.01 |
| Transport | 7 175 | 5 250 | 8 750 | 21 175 | 2.54 | 3.47 | 3.60 | 9.62 |
| Pressing | 6 650 | 3 150 | | 9 800 | 2.87 | 6.06 | | 8.94 |
| Corn for silage III < 5 ha (3.5) | | | | | | | | |
| Silage cutting | 6 300 | 4 025 | | 10 325 | 2.29 | 3.59 | | 5.88 |
| Transport | 7 175 | 4 900 | 8 750 | 20 825 | 2.39 | 3.50 | 3.23 | 9.12 |
| Transport | 4 900 | 2 625 | 13 300 | 20 825 | 2.21 | 4.13 | 4.18 | 10.53 |
| Transport | 6 300 | 2 625 | 13 300 | 22 225 | 1.72 | 4.13 | 4.51 | 10.37 |
| Piles compaction | 7 175 | 5 775 | | 12 950 | 2.86 | 3.55 | | 6.41 |
| Corn for silage IV >5 ha (13.0) | | | | | | | | |
| Harvesting | 21 320 | 39 520 | | 60 840 | 2.72 | 1.47 | | 4.19 |
| Transport and unloading (1) | 33 800 | 28 080 | 47 840 | 109 720 | 0.96 | 1.16 | 1.32 | 3.44 |
| Transport and unloading (2) | 33 800 | 28 080 | 47 840 | 109 720 | 0.96 | 1.16 | 1.32 | 3.44 |
| Transport and unloading (3) | 33 800 | 28 080 | 47 840 | 109 720 | 0.96 | 1.16 | 1.32 | 3.44 |

**Table 7. Continued**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Piles compaction | 17 160 | 15 600 | | 32 760 | 1.03 | 1.14 | | 2.17 |
| Piles compaction | 21 320 | 17 160 | | 38 480 | 0.87 | 1.08 | | 1.95 |
| Piles compaction | 27 040 | 21 320 | | 48 360 | 0.94 | 1.20 | | 2.14 |
| Pile covering | | | 29 120 | 29 120 | | | 1.00 | 1.00 |
| Corn for silage V >5 ha (5.07) | | | | | | | | |
| Harvesting | 7 301 | 3 042 | | 10 343 | 1.49 | 3.57 | | 5.05 |
| Transport | 7 301 | 3 042 | 22 714 | 33 056 | 1.49 | 3.57 | 3.96 | 9.01 |
| Transport | 9 329 | 7 301 | 22 714 | 39 343 | 2.20 | 2.81 | 4.10 | 9.10 |
| Piles compaction | 9 329 | 7 301 | | 16 630 | 2.20 | 2.81 | | 5.01 |
| Corn for silage VI >5 ha (13.0) | | | | | | | | |
| Harvesting | 21 320 | 39 520 | | 60 840 | 2.72 | 1.47 | | 4.19 |
| Transport | 33 800 | 28 080 | 40 040 | 101 920 | 0.78 | 0.94 | 3.51 | 5.24 |
| Compacting in silos | 33 800 | 28 080 | | 61 880 | 0.78 | 0.94 | | 1.73 |

*Source:* Own studies

**Table 8. The area of compacted soil and the pressure exerted by the wheels of the tractor and agricultural machinery in particular technologies of sugar beet harvesting**

| Agricultural activity or technology operations | The area of tractor tires compaction | | The area of agricultural machinery tires compaction, $m^2$ | The area of compaction, $m^2$ | Pressure exerted by tractor | | Pressure exerted by agricultural machinery with load, Pa | Exerted pressure, Pa |
|---|---|---|---|---|---|---|---|---|
| | Back, m | Front, m | | | Back, Pa | Front, Pa | | |
| Sugar beet I < 5 ha (2.0) | | | | | | | | |
| Roots harvesting | 8 200 | 6 000 | 7 600 | 21 800 | 2.22 | 3.04 | 5.38 | 10.64 |
| SUGAR BEET II < 5 ha (3.0) | | | | | | | | |
| Roots harvesting | 10 800 | 4 500 | 11 400 | 26 700 | 1.00 | 2.41 | 3.59 | 7.00 |
| Sugar beet III < 5 ha (3.04) | | | | | | | | |
| Sugar beet harvesting | | | 49 248 | 49 248 | | | 4.37 | 4.37 |
| Sugar beet IV > 5 ha (6.0) | | | | | | | | |
| Harvesting and stacking in prism | | | 64 800 | 64 800 | | | 3.32 | 3.32 |
| Sugar beet V >5 ha (6.0) | | | | | | | | |
| Harvesting | 24 600 | 13 800 | 22 800 | 61 200 | 0.70 | 1.25 | 1.79 | 3.75 |
| SUGAR BEET > 5 ha (5.7) | | | | | | | | |
| Sugar beet harvesting | 20 520 | 13 110 | 21 660 | 55 290 | 0.61 | 0.95 | 1.89 | 3.45 |

*Source:* Own studies

**Table 9. The area of compacted soil and the pressure exerted by the wheels of the tractor and agricultural machinery in particular technologies of meadow grasses harvesting**

| Agricultural activity or technology operations | The area of tractor tires compaction | | The area of agricultural machinery tires compaction, $m^2$ | The area of compaction, $m^2$ | Pressure exerted by tractor | | Pressure exerted by agricultural machinery with load, Pa | Exerted pressure, Pa |
|---|---|---|---|---|---|---|---|---|
| | Back, m | Front, m | | | Back, Pa | Front, Pa | | |
| Meadow grasses I < 5 ha (4.0) | | | | | | | | |
| Harvesting 3x | 13 231 | 10 769 | | 24 000 | 1.74 | 2.14 | | 3.87 |
| Tedding 6x | 11 077 | 4 615 | 19 077 | 34 769 | 0.98 | 2.35 | 0.16 | 3.49 |
| Raking 3x | 11 467 | 9 333 | 16 533 | 37 333 | 2.01 | 2.46 | 0.18 | 4.65 |
| Harvesting-pressing 3x | 11 467 | 9 333 | 10 133 | 30 933 | 2.01 | 2.46 | 2.25 | 6.72 |
| Bales loading 3x | | | 14 933 | 14 933 | | | 2.00 | 2.00 |
| Bales transport 3x | 9 600 | 4 000 | 29 867 | 43 467 | 1.13 | 2.71 | 0.97 | 4.81 |
| Bales wrapping 3x | 12 800 | 10 133 | 14 901 | 37 835 | 1.41 | 1.78 | 0.66 | 3.84 |
| Meadow grasses II < 5 ha (3.25) | | | | | | | | |
| Harvesting 2x | 14 182 | 5 909 | | 20 091 | 0.77 | 1.84 | | 2.60 |
| Hay tedding 3 razy | 8 233 | 3 250 | 13 433 | 24 917 | 1.21 | 3.08 | 0.32 | 4.61 |
| Raking 2x | 8 233 | 3 250 | 13 433 | 24 917 | 1.21 | 3.08 | 0.32 | 4.61 |
| Compacting 2x | 9 317 | 7 583 | 6 067 | 22 967 | 2.47 | 3.03 | 3.26 | 8.77 |
| Bale wrapping 2x | 9 317 | 6 717 | 6 067 | 22 100 | 2.31 | 3.20 | 3.26 | 8.77 |
| Bale loader 2x | 9 317 | 7 583 | | 16 900 | 2.47 | 3.14 | | 5.61 |
| Bales transport 2x | 10 183 | 6 067 | 12 133 | 28 383 | 1.95 | 3.27 | 2.39 | 7.61 |
| Bale unloading 2x | 9 317 | 7 583 | | 16 900 | 2.47 | 3.14 | | 5.61 |
| Meadow grasses III < 5ha | | | | | | | | |
| Harvesting 3x | 17 455 | 7 273 | | 24 727 | 0.60 | 1.44 | | 2.05 |
| Tedding 3x | 9 600 | 4 000 | 16 533 | 30 133 | 1.09 | 2.63 | 0.18 | 3.90 |
| Raking 3x | 9 600 | 4 000 | 16 533 | 30 133 | 1.09 | 2.63 | 0.18 | 3.90 |
| Compacting 3x | 9 600 | 4 000 | 7 467 | 21 067 | 1.13 | 2.71 | 2.65 | 6.49 |
| Wrapping 3x | 9 600 | 4 000 | 7 200 | 20 800 | 1.13 | 2.71 | 1.36 | 5.20 |
| Bale loading 3x | 9 600 | 4 000 | | 13 600 | 1.13 | 2.91 | | 4.04 |
| Transport 3x | 12 533 | 7 467 | 29 867 | 49 867 | 1.58 | 2.66 | 0.97 | 5.21 |
| Transport 3x | 9 600 | 4 000 | 29 867 | 43 467 | 1.09 | 2.63 | 0.92 | 4.64 |
| | | | | 233 793.94 | | | | 35.44 |
| Meadow grasses IV > 5 ha (14.4) | | | | | | | | |
| Harvesting 3x | 47 631 | 38 769 | | 86 400 | 0.48 | 0.59 | | 1.08 |
| Tedding 6x | 28 800 | 12 000 | 49 600 | 90 400 | 0.38 | 0.90 | 0.06 | 1.34 |
| Raking 3x | 34 400 | 28 000 | 49 600 | 112 000 | 0.67 | 0.82 | 0.06 | 1.55 |
| Harvesting- pressing 3x | 41 280 | 33 600 | 36 480 | 111 360 | 0.56 | 0.68 | 0.63 | 1.87 |
| Bales loader 3x | | | 53 760 | 53 760 | | | 0.55 | 0.55 |
| Bales transport 3x | 34 560 | 14 400 | 176 640 | 225 600 | 0.31 | 0.75 | 0.38 | 1.45 |

**Table 9. Continued**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bales wrapping machine 3x | 46 080 | 36 480 | 25 920 | 108 480 | 0.39 | 0.49 | 0.38 | 1.26 |
| Meadow grasses V > 5 ha | | | | | | | | |
| Harvesting 2x | 41 360 | 33 440 | | 74 800 | 0.55 | 0.68 | | 1.24 |
| Tedding 2x | 31 680 | 13 200 | 54 560 | 99 440 | 0.34 | 0.82 | 0.06 | 1.22 |
| Raking into windrows 2x | 31 680 | 13 200 | 54 560 | 99 440 | 0.34 | 0.82 | 0.06 | 1.22 |
| Harvesting 2x | 37 840 | 27 280 | 24 640 | 89 760 | 0.57 | 0.79 | 0.80 | 2.16 |
| Bales wrapping 2x | 31 680 | 13 200 | 23 760 | 68 640 | 0.34 | 0.82 | 0.41 | 1.58 |
| Loading and transport | 31 680 | 13 200 | | 44 880 | 0.34 | 0.88 | | 1.23 |
| Loading and transport | 37 840 | 27 280 | 49 280 | 114 400 | 0.57 | 0.79 | 0.69 | 2.04 |
| Stacking | 31 680 | 13 200 | | 44 880 | 0.34 | 0.88 | | 1.23 |
| Meadow grasses VI > 5 ha | | | | | | | | |
| Harvesting 2x | 34 276 | 23 408 | | 57 684 | 0.47 | 0.68 | | 1.15 |
| Tedding 2x | 34 276 | 25 080 | 25 916 | 85 272 | 0.45 | 0.62 | 0.12 | 1.18 |
| Raking into windrows 2x | 34 276 | 25 080 | 25 916 | 85 272 | 0.45 | 0.62 | 0.12 | 1.18 |
| Haylage Harvesting 2x | 40 128 | 23 408 | 23 408 | 86 944 | 0.48 | 0.83 | 0.82 | 2.13 |
| Haylage bales wrapping | 30 096 | 12 540 | 22 572 | 65 208 | 0.42 | 1.00 | 0.43 | 1.85 |
| Loading, transport and stacking | 34 276 | 23 408 | 83 600 | 141 284 | 0.47 | 0.68 | 0.56 | 1.71 |
| Stacking | 30 096 | 12 540 | | 42 636 | 0.42 | 1.06 | | 1.48 |

*Source:* Own studies

## Conclusions

The results showed that the field area in the greater part of cultivated area has over-pressured. That means if the plane of the pressed soil would be spread onto the field will give the area that could cover all cultivation area few times.

The greatest wheels pressure during the harvesting was noted in meadow grasses technologies. The exerted pressure was covered over 500% of cultivated area on field below 5 hectares. Cause of the over-pressured operations was the multistage of subsequent treatments. For example in the case of straw IV harvest technology mean pressure was 69.36 Pa.

The technologies that belong to the least invasive were noted as the one-step sugar beet harvest operations on the field area that have less than 5 hectares. According to above, only two types of technologies showed a slight excess in the course of the sowing machinery travel.

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