INFLUENCE OF TRACTOR SLIPPAGE ON CROP YIELD

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Abstract. The tractor under draft causes slippage of the driving wheels, which negatively affects the soil structure and soil function, influences the plant growth and yield. Tires compress and compact the surface layer, erode the soil, and reduce liveliness of plant roots. Driving of tractors is unavoidable but may be more friendly to the environment. The aim of the research was to establish the dependence of the tire contact area and tractor slip on the plant yield, maintaining a constant draft. The investigative tractor "CASE MX135" was used in this research. The field test was performed by towing another tractor with implements for constant draft load. Several soil plots were compressed track to track separately, changing the tire contact area on each plot. Different tire contact area was achieved by changing the tire pressure and adding double wheels. The correlation of the adjustable contact area and wheel slip and crop yield was developed by comparing to the control plot without soil compression. The results show that enlargement of the tire contact area can reduce the slippage by 19,8% at constant draft and improve the crop yield, by reducing soil damage. It was noticed that the soil plots which were compressed with the lowest tire contact area gave the crop yield by 10% less; in the plots where the soil was compressed with the greatest tire contact area the crop yield increased by 9.5% compared to the control plot without compression of the soil.

Keywords: tire contact area, soil compaction, soil surface displacement.

Introduction

Increasing attention is paid to soil protection and reducing soil degradation in recent years, land use regulations have been issued on plant diversity, reducing the intensity of tillage to prevent soil erosion, etc. However, little attention is paid to heavy agricultural machinery with increases the soil compaction and reduces soil productivity. With increasing necessity for agriculture efficiency more powerful machinery in the future is required [1]. The harmful consequences of soil compaction are apparent in various ways: the structure is damaged, the water/air regime of the soil deteriorates, mineralization of organic matter slows down, mineral nutrition conditions of plants deteriorate, plant roots cannot penetrate into deeper layers, plant productivity decreases, soil erosion processes and crop weediness increases, plant diseases and pests spread more, fertilizer efficiency decreases, and the costs of cultivating compacted soil increase [2-4]. The tendency for soil compaction is higher in colder and moister climate zones [5; 6]. The problem of soil compaction is especially relevant in heavy clay soils, which are more compacted because they are often in a state that is not resistant to compression [7; 8]. The compaction effect depends on the dimensions of the tires, air pressure and the tractor load. The most used wheeled chassis of agricultural machinery have the greatest soil compaction impact for reduced yield [9]. Soil compression is caused not only by machinery mass but also by skidding of the driving wheels [10].

Slippage is inevitable when pulling the implement. Tractors at 30-40% slippage reach the maximum draft. For the net traction ratio, the soil moisture content between 15% and 20% is the optimum, for higher and lower moisture contents the maximum value is lower. From an energy point of view, slip at 8% is rational, if it is lower, more fuel is wasted due to the overweight of the tractor; if the slippage is higher, the soil is negatively affected [11]. There is evidence in the literature that slippage within 10 – 15% did not have a significant effect, but slippage at 30% had significant indications of soil compaction in the surface layers [12; 13]. Currently, researchers recommend use of ballast weight or reducing the tire air pressure to reduce slippage of tractors [14-17]. Then using this air pressure reduction method, depending on the size and type of tractor tires, the traction force can be increased by up to 8% [18]. Raper and Kirby [19] state that the contact length of the radial tire 18.4 R38 increases from 0.64 m at 124 kPa to 0.76 m at 41 kPa air pressure in them. A larger number of tire grips could then contact the soil by hooking it and participate in moving the soil layer. The tire contact area increases with the increasing wheel radius, width, and reduction of the tire pressure, consists of a larger contact area and always gives a higher net traction ratio [20]. Way and Kishimoto [21] state that the 18.4R38 tire's contact area with the ground depends on the air pressure and dynamic load. Their research shows that increasing the tire contact area results in 10% less slip in loose soils and 4% less slip in hard soils. It is difficult to

find the tire contact area, soil contact pressure and the number of tyre grips interacting with the soil. The front and rear wheels of the tractor follow the same track, thus disturbance of the soil surface is impacting twice. Even if the tire contact area is only an inexact value, which does not consider any soil conditions, the correlations exist between the tire performance and the draft. The tire contact area adequately represents the influence on the tractive, but changes in soil conditions influence the traction performance much more than the changes in the tire dimensions [22]. However, the tire pressure and tire deformation influence the trend for the rolling resistance ratio on loose and hard soil surfaces. For loose soil a large contact area is advantageous because of less sinkage and soil deformation.

The second cause to reduce soil compaction is because tillage becomes less intensive at shallow harrowing depth, and the risk of soil damage increases [23]. Tractors can be more environmentally friendly by increasing the tire contact area and reducing slippage. Changeable tire air pressure and mounting of dual wheels are chosen for this test. The research investigates and establishes the dependence of the tire contact area and tractor slip on the plant biomass and grain yield, of a tractor maintaining a constant draft.

Materials and methods

The field experiments were conducted at the Joniškėlis Experimental Station of the Lithuanian Research Centre for Agriculture and Forestry in 2021 and 2022. According to FAO classification, the soil of the experimental site is Endocalcari Endohypogleyic Cambisol (CMg-n-w-can). Topsoil (0-25 cm) texture – clay loam. Weed control, diseases and pest management were carried out in accordance with the crop development as required, impact not assessed.

The studies were carried out on no-ploughed soil, where only shallow tillage with a spring tine cultivator was applied. The research was carried out on spring cereals to avoid the outside effect of autumn-winter conditions (frost, excess moisture, etc.).

Fig. 1. **Soil plots compressed by corresponding tire contact area variant (A)**

Spring wheat was grown in 2021 and peas in 2022. The results of the research are presented in the yield and biomass of plant ratios compared to control not wheeled plot yield. In 2021, after sowing it was a cold and dry period, only the end of May was followed by a warm spell. In May, there was some rainfall, but lack of warmth, later months followed by dry and excessively hot temperatures. 2022 was reasonably wet, warm in April and May, with especially hot and dry late July and early August. The investigative tractor "Case MX 135" was instrumented with a data acquisition system and used to measure the draft, velocity speed and slippage. Several soil plots were compressed track to track separately, changing the tire contact area on each plot, and repeated four times. The treatments were replicated four times in order to eliminate undesired experimental errors. Different tire contact area was achieved by changing the tire pressure and adding double wheels. The correlation of the adjustable contact area and wheel slip and crop yield was developed by comparing to the control plot without soil compression. The following soil compression by the tire contact area (A) variations: A1 – soil not rutted (control); A2 – nominal tire pressure, single wheels; A3 - reduced tire pressure, single wheels; A4 – nominal tire pressure, double wheels; A5 – reduced tire pressure, double wheels. According to the tire load data sheet chart, the nominal tire inflation pressure value was 160 kPa, reduced tire pressure was

83 kPa for working in loose soil prepared for sowing. The static weight distribution was 45% front and 55% rear axles, the total static weight from the tractor specification chart is 49.3 kN.

Fig. 2. **Tire contact area influenced slip and soil disturbance, tractor loaded with draft**

Table 1

Specification of tractor and tire

Property	Value
Mass of the tractor "CASE IH 135"	5030 kg
Front single and double tires	"Firestone" 420/70 R28
Rear single and double tires	"Firestone" 520/70 R38
Wheelbase	2.6 m

The tractor was loaded with constant draft force with another tractor (Fig.2). The draft data deviation of measurements did not overrun 1%. The draft induces slippage of the driving wheels. The slippage changes depend on the tire contact area. Deviation of data was based on the characteristics of the measurement devices. The slip of a tractor is described as speed loss, named as the ratio between the decreased actual speed v_W and the theoretical speed v_T, or the distance losses in the same number of revolutions of wheels, slippage is estimated by expression:

$$\delta = \frac{v_T - v_W}{v_T} = \frac{L_T - L_S}{L_T},$$ (1)

where L_T – distance length without load at the variant of contact area (rolling radius);
L_S – the actual distance with load and slip corresponding to the tire contact area variant (A).

The two-year data of crop biomass (M) and grain yield (Y) of spring wheat and peas were collected from each variant plot compressed by the corresponding tire contact area (A); there were five soil compression variant plots. The measurements of the yield were done by taking manually crop yield samples from 1 m^2 expressed at 14% moisture content and calculated by formula (2). The crop yields were different from year to year for differ crops, they are not discussed separately as an indicator. The impact of the soil compression assessment indicator was the plant mass ratio of the samples taken at a certain stage of plant growth. The aboveground biomass of crop was collected three times during vegetation and compared to the crop biomass from the control plot A1. The aboveground biomass was determined from three crop rows of 50 cm length from each variant plot with three replications for measurement accuracy. The biomass was different each sampling time and is not provided here separately, biomass data deviation of one variant did not overrun 2%. The aboveground biomass and grain yield divergence between plants was calculated as a ratio of biomass and yield in each soil plot to the control plot. The ratios of grain yield were marked as Y2/Y1, Y3/Y1 Y4/Y1, Y5/Y1. The ratios of biomass were marked as M2/M1, M3/M1 M4/M1, M5/M1. The grain yield (t·h^{-1}), approximated according to:

$$Y = \frac{N_e * N_g * G}{10^5},$$ (2)

where N_e – number of ears;

N_g – grain number in each ear;

G – mass of thousand grains.

Results and discussion

When the tractor pulls the implement by constant speed, relating to constant traction force it causes slippage of the tractor. With increasing contact area, the slippage (δ) reduces and as the working speed (v_W) is increasing, the road distance L_S towards the theoretical distance L_T positions in accordance with wheel revolutions. Increasing the tire contact area from A1 to A5, the grip with the soil was improved, slippage was reduced from 28.0% to 8.2%. It was determined that the slipping drive wheels carry the soil layer. Greater slippage causes the biggest road losses, displacement of the soil instead of the actual traveled road becomes smaller in accordance with the slip percentage unit. It was determined that with increasing the tire contact area, the displacement of the soil layer has decreased from 30.6 cm to 14.8 cm, the depth of track has decreased from 11.4 to 7.3 cm. Battiato et. al [24] found that 27% slip move the soil layer 35 cm. In the process of slippage, the soil is compacted more than just passing through the soil [25]. Later Battiato et. al [26] found that with increasing the slip from 1% to 27%, the normal soil pressure increases from 90.6 to 104.4 kPa, and the maximum shear pressure of the front wheels increases from 19.7 to 42.6 kPa and the rear wheels - from 6.0 to 61.6 kPa at the tire pressure 160 kPa selected.

Blocking of dry crust is more noticeable in the clay loam soil, there is no contact with seeds. Such rough soil aggregate structure characteristic brings a low level of seed germination, poor soil contact with plant roots. After rutting the soil aggregates were pulverized and showed significant structure differences between the treatments of compactness by the tire contact area combinations. It was determined that at the conditions of the dry sowing period, the seeds began to germinate faster after rutting the soil with a chassis with a smaller tire contact area; in the control plots, the germinating of seeds was weak - there were less plants. Rutting and compacting of the soil, keeping the soil moist but driving with the smallest tire contact area created deeper ruts. Biomass of the plants was higher in less damaged soils rutted with double wheels. The plants grew more biomass, compared to the plants in not wheeled soil, regardless of the plant growth period, the plant biomass ratios were similar at each measurement. The crop highest productivity reliance is due to favourable moisture conditions after sowing, good start of sprouts accompanies later during the whole growing period as a result of the soil compaction level. The results of the research showed that the plant biomass and grain yield correspond to the certain tire contact area. The biomass of spring wheat and peas per square meter was lower in the A2 and A3 plots than in the A4 and A5. The aboveground biomass sample M2 and M3 was 13% and 8% lower than control, and the sample M4 and M5 was 7% and 12% higher than biomass at the control plot M1. The grain yield sample Y2 and Y3 was 10% and 7% lower than control, and the sample Y4 and Y5 was 8% and 9.5% higher than the yield in the control plot Y1 (Table 2).

Table 2

Crop biomass ratio and grain yield ratio at various tire contact area

A1 – not wheeled plot	δ – slippage, %	Displacing of soil, m L_T - L_S	Biomass ratio	Yield ratio
A2	28.0[a]	L_T - $L_{S\ A2}$ = 4.48[a]	M2/M1 = 0.87[a]	Y2/Y1 = 0.90[a]
A3	22.5[b]	L_T - $L_{S\ A3}$ = 3.60[a]	M3/M1 = 0.92[a]	Y3/Y1 = 0.93[a]
A4	10.5[c]	L_T - $L_{S\ A4}$ = 1.68[c]	M4/M1 = 1.07[c]	Y4/Y1 = 1.08[c]
A5	8.2[d]	L_T - $L_{S\ A5}$ = 1.31[c]	M5/M1 = 1.12[c]	Y5/Y1 = 1.095[c]

Ahmada et al. [27] determined that the grain yield was significantly reduced by soil compaction. In the first harvest year, the maximum wheat grain yield (395.7 g·m^{-2}) was obtained from T1 (no compaction), which progressively decreased to the minimum (278.9 g·m^{-2}) from T4 (six passes). A similar trend of the grain yield was observed in the second harvest year when the maximum grain yield (432.6 g·m^{-2}) was recorded for T1 (control) and the minimum (323.0 g·m^{-2}) from T4 (six passes). It was established that from compacted soil the wheat grain yield was lower than control for both years [27]. The results of our research showed that the yield of spring wheat and peas negatively responds to the soil compaction by tractor slippage, approximately like stated by Ahmada et al. It was determined that there are no significant grain yield mass differences between the options when the soil was rutted by

single wheels, it differed significantly between the options when the soil was rutted by single and double wheels.

Conclusions

The results of adjusting this specific practice study provide helpful indications and appropriate choices of tractor chassis configurations for optimizing the soil structure requirement on clay soils, thereby reducing soil compaction. The research determined that soft rutting kept the soil moisture and could improve the spring crop yield at dry conditions.

1. It was determined that by increasing the tire contact area the grip with the soil was improved, slippage was reduced from 28.0% to 8.2%, displacement of the soil surface layer has decreased from 4.48 m to 1.31 m.
2. It was determined that on loam clay treatments the soil aggregates were pulverized and showed a significantly better structure in the compactness plots than in control. In the dry conditions, the seeds began to germinate faster after rutting the soil with a smaller tire contact area; in the control plots, the seeds germinated weakly - there were smaller number of plants. Compacting of the soil kept the soil moist, but rutting with the smallest tire contact area created deeper ruts and dried thick soil layers.
3. Based on the results of the plant biomass, increasing of the tire contact area gives a higher biomass ratio on compacted soil with double wheels compared to control, the lowest ratio was on compacted soil with the smallest tire contact area.
4. It was established that the soil plots compressed with the lowest tire contact area gave the crop yield by 10.0% less; in the plots where the soil was compressed with the greatest tire contact area the crop yield increased by 9.5% compared to the control plot without any compression of the soil.

Acknowledgement

Author contributions

Conceptualization, V.D.; methodology, V.D. and A.J.; investigation, V.D.; writing – review and editing, A.J. and V.D. All authors have read and agreed to the published version of the manuscript.

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