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MITIGATION OF SOIL COMPACTION IN SUGARBEET HARVESTING AND SLURRY APPLICATION BY INCREASING TIRE PRINT AND COVER CROPPING

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Abstract

The paper aimed to present results of two field experiments, where the effect of increased contact area between soil and tire (tire print) and the effect of cover crop on soil compaction was analysed in the Eastern part of Austria. One field experiment investigated the effect of chassis in a six-row sugarbeet harvester (two-axle, three-axle) and soil condition (wet, dry). The second experiment analysed the effect of tire inflation pressure in a slurry tanker (high: 300 kPa, low: 100 kPa) and field coverage (with and without covercrop) on track depth and soil penetration resistance. The results showed, that dry soil conditions in sugarbeet harvesting do not affect the soil penetration resistance and the bulk density negatively. The increase of the tire print area in a three-axle chassis reduced the risk of soil compaction. Lowering of the tire inflation pressure in the slurry tanker increased the tire print and reduced tire track depth in the field and soil penetration resistance. Cover crops created deeper track depths after traffic, which is explained by the loosening of cover crop roots.

***Key words**: sugarbeet tanker harvester, slurry tanker, tire inflation pressure, soil penetration resistance, track depth.*

INTRODUCTION

Agricultural soils can be affected in their ecological functions (biomass production; filter, buffer and transformation processes) through traffic of agricultural machinery. Soil compaction reduces the pore distribution, air permeability, hydraulic conductivity in the soil and root and plant growth. Resulted effects are yield depression, rut formation, soil erosion and increased draft force and fuel consumption in soil tillage. In agriculture, soil compaction as well as soil erosion by wind and water are classified as the most harmful processes which do not only end in a reduction of site-specific productivity but are also responsible for gas emission and a requirement for greater fuel energy in tillage processes (Horn et al., 2003). Subsoil compaction is a major concern in agricultural production, mainly due to its persistence. Effects of topsoil compaction are alleviated in a few years, when the soil is tilled, effects of subsoil compaction persist much longer and may even more or less permanent (Etana and Hakansson, 1994).
High field performance in the field operation can be reached with high working speed ("High speed farming") and/or increased working width. This driving factors are mostly coupled with higher machinery weight. Studies by Keller et al. (2019) stated that future agricultural operations must consider the inherent mechanical limit of soil, because the acceptable loads are exceeded due to upward trends in the average weight of farm machinery.
Shjonning et al. (2016) suggested as a consequence of their study - for highly inflated tires with tractor-trailer an upper threshold for springtime a wheel load of 3,000 kg for avoiding significant subsoil compaction.

In this context, the paper present two conducted field experiments in the eastern Part of Austria, with the aim to analyse technical adaption solutions (increasing the tire print through tire inflation pressure reduction and chassis adaption) and management measures (moisture content of the soil, covercrop integration) on selected physical soil parameters (track depth in the field, soil penetration resistance).

MATERIALS AND METHODS

One field experiment was carried out in 2015 at Hollabrunn (48°34'33.7"N 16°03'34.3"E), Lower Austria with good soil conditions for sugarbeet cropping (silty loam with average contents of 22.3% sand, 52.9% silt and 24.7% clay) to investigate the effect of two chassis (2-axle, 3-axle) of the six-row self-propelled sugarbeet tanker harvester on wet and dry soil conditions on soil physical properties (penetration resistance, dry bulk density, saturated hydraulic conductivity). A detailed description of the sugarbeet harvester and methodology is published in Moitzi et al. (2019). The second experiment was carried out on farm fields (loam soil with 34% clay, 49% silt and 17% sand with an soil organic carbon of 18.6 g/kg) in the northern part of the Austrian province of Burgenland in Krensdorf (47°80'N, 16°41'E, 194 m a.s.l.) in 2018. This study analysed the effect of slurry application in spring with different loads and tire inflation pressures in a field without cover crop and in a field with cover crop on track depth, soil penetration resistance and grain yield of the subsequently grown maize. The used methods for this experiment are detailled described in Moitzi et al., 2021.

RESULTS AND DISCUSSIONS

Sugarbeet harvester experiment

The three-axle harvester reached a total weight of 60.9 mg and was 11.8 mg heavier than the two-axle harvester with total weight of 49.1 mg. The total weight of the three-axle harvester was distributed equally with about 20 Mg each axle. Two-axle harvester distributed the total weight of 49.1 mg to the rear axle with 27.3 mg and to the front axle with 21.8 mg. With the three-axle undercarriage the maximum wheel-load (10.5 mg) was 23.3% (= 3.2 mg) lower than the maximum wheel-load (13.7 mg) of the two-axle harvester.
The bulk densities and the volumetric soil water contents of the two- and three axle harvester wheeled area (Table 1) were associated with total harvester weights of 60 mg and 47 mg, respectively.

The differences in bulk density between treatments were small. Statistically significant differences were found only in the dry treatment in a soil depth of 25-30 cm and 50-50 cm. The two-axle harvester reduced the bulk density in comparison to un-wheeled and three-axle treatment plots under dry conditions. This effect can be explained by the higher wheel-load of the axle in connection with the lower soil water content with higher tendency of deformation. Under wet soil conditions, more pores were filled with water and became rather incompressible (Smith et al., 1997). This could be the possible reason why the high wheel-load of the two-axle harvester did not alter the bulk density statistically significant under wet soil condition. In tendency, the bulk density was smaller after wheeling with the two-axle harvester than three-axle harvester and un-wheeled (Table 1). The effect of higher wheel-loads on bulk density was also found in Arvidsson (2001), where the traffic with the six-row harvester caused greater subsoil compaction than that with the three-row harvester. In our practical experiment, it was difficult to set the moisture content exactly with irrigation especially in the subsoil.

The course of soil penetration resistance differed between dry and wet treatments (Figure 1).
Soil penetration resistance increased with depth in the dry top soil (0-15 cm) and it was in the range of 5 and 7 MPa at the depth of 15-35 cm. Soil penetration resistance was smaller in the wet treatments. The undercarriage effect on the penetration resistance was small in the dry plots. In each treatment, an increased penetration resistance down to 15 cm soil depth was found, which could be explained by the dry hard soil (Figure 1). Some soil penetration measurements had to be rejected in the dry

plots because it was impossible to penetrate into the hard soil (reduced n in Figure 1).

The wheeling with two-axle and three-axle harvester on the wet soil resulted in significantly higher soil penetration resistances in comparison to the un-wheeled control treatment, especially in depths of 0-10 cm and 11-20 cm (Table 2). The water content here was the same before and after harvest.

The soil penetration resistance was strongly influenced by the soil water content (Table 2). For wet soil conditions, the cumulated penetration resistance was reduced by 59% (un-wheeled), 44% (two-axle harvester) and 51% (three-axle harvester), respectively.

The multiple wheeling of the soil is caused by the offset track driving using diagonal steer (crab steering). Due to crab steering, the area was differented wheeled. For the 2-axle harvester, un-wheeled area was 6.7%, single-wheeled area was 66.7% and double-wheeled are 26.7%. For the 3-axle harvester, there was no un-wheeled area. 23.3% of the area was single-wheeled, 68.3% was double-wheeled and 8.3% was triple-wheeled. was 6.7%, single-wheeled area was 66.7% and double-wheeled are 26.7%. The wheeling effect on penetration resistance was higher in the wet plot. Single and multiple wheeling showed higher penetration resistance than un-wheeled in the depth 0-10 cm and 11-20 cm. No significant differences were observed in the soil depth 20-30 cm (Moitzi et al. 2019).

Long-term differences in soil penetration of high-axle traffic were found in many studies: Arvidsson (2001) found in his study significant differences in penetration resistance between treatments 2-4 years after traffic.

Slurry tanker experiment

The experiment with three slurry tanker filling levels and two tire inflation pressure of the tanker wheels (Table 3) was carried out on two adjacent fields (à 3 ha).

Regarding all treatments, the tire track depth tended to be deeper in the filled and half-filled slurry tanker setting than in the empty one (Table 4). In the field with cover crop, the average tire track depth was deeper in the field with cover crop than in the field without cover crop (6.88 cm vs. 5.83 cm, p = 0.014). Additionally, high tire inflation pressure of the slurry tanker showed significantly deeper tire tracks in the field than with low inflation pressure (6.68 cm vs 6.03 cm, p = 0.000).

Soil penetration resistance was not significantly affected by the filling level of the the slurry tanker (Table 4), rather. It was only by tendency that the filled tanker tended to resulted in higher top soil penetration resistance than the half-filled and empty tanker. The averaged soil penetration resistance (0-20 cm) was significantly differentiated by the treatment: un-wheeled plot at 0.76 MPa, low inflation pressure at 1.17 MPa, high inflation pressure at 1.31 MPa (p = 0.000). At the soil depth of 21-40 cm, the averaged soil penetration resistance was significantly lower (p = 0.007) in the un-wheeled plot (2.06 MPa) than in the low inflation pressure (2.24 MPa) and high in-flation pressure plots (2.26 MPa).

The effect of ground cover was significant in at athe soil depth of 0-20 cm (+cover crop: 1.01 MPa vs. -cover crop: 1.14 MPa, p=0.008), but not at soil depth of 21-40 cm (+cover crop: 2.15 MPa vs. -cover crop: 2.20 MPa, n.s.).

Compared to un-wheeled, the increase of soil penetration resistance (0-20 cm) was lower with low tire inflation pressure than with high tire inflation pressure: 72% vs 108% (total filled), 54% vs 64% (half-filled) and 50% vs 62% (empty). In the sub-soil (21-40 cm) the effect of tire inflation pressure was much lower: 7% vs 12% (total filled), 15% vs 15% (half-filled) and 7% vs 6%).

Table 1. Mean soil bulk density and mean volumetric water content after passing with the filled sugarbeet harvester

		Bulk density (g cm^{-3})			Volumetric water content (cm^3 cm^{-3})		
Soil conditions	Depth (cm)	Un-wheeled	Two-axle	Three-axle	Un-wheeled	Two-axle	Three-axle
Dry[1)]							
	10-15	1.63 (n[3)]=13)	1.57 (n=7)	1.54 (n=7)	0.33	0.31	0.30
	25-30	1.55[b4)] (n=3)	1.48[a] (n=3)	1.59[b] (n=3)	0.30	0.27	0.29
	50-55	1.35[ab] (=3)	1.27[a] (n=3)	1.44[b] (n=3)	0.22	0.22	0.24
Wet[2)]							
	10-15	1.60 (n=13)	1.59 (n=7)	1.61 (n=7)	0.48	0.49	0.47
	25-30	1.52 (n=3)	1.42 (n=3)	1.46 (n=3)	0.41[b]	0.39[b]	0.31[a]
	50-55	1.32 (n=3)	1.29 (n=3)	1.31 (n=3)	0.18[a]	0.26[b]	0.27[b]

[1)] gravimetric soil water content 20%, [2)] gravimetric soil water content 30%, [3)] number of score samples is the same for the volumetric water content, [4)] statistically significant differences are shown for the wheeling effect with small letters; Student-Newmann-Keuls ($p<0.05$).

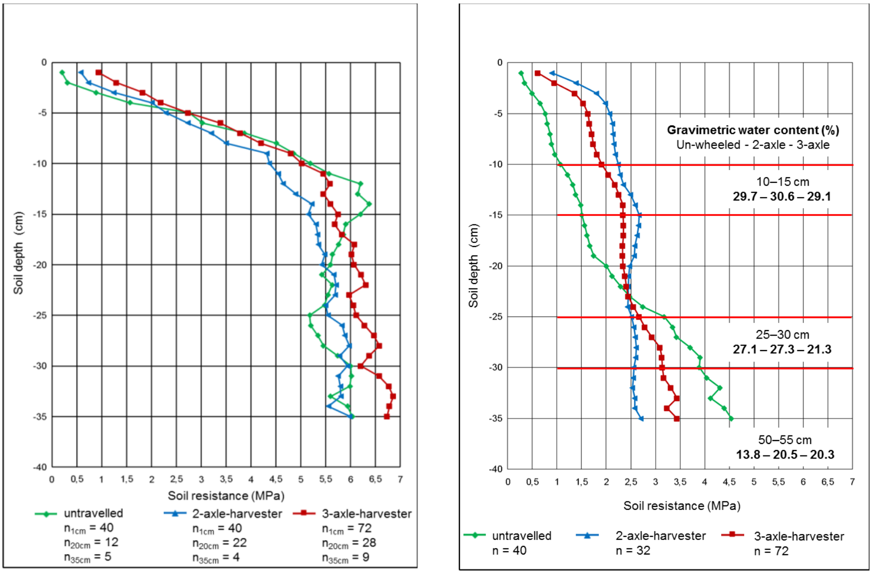

Figure 1. Course of penetration resistance in the dry treatment (left) and wet treatment (right)

Table 2. Mean cumulated penetration resistance (MPa) in different soil depths of dry and wet soil conditions

Soil condition	Depth (cm)	Un-wheeled	Two-axle-harvester	Three-axle-harvester
Dry[1)]				
	0-10	24.8 (n[3)]=40)	24.2 (n=40)	28.3 (n=72)
	11-20	55.3 (n=12)	50.2 (n=22)	52.6 (n=28)
	21-30	53.2 (n=5)	55.0 (n=4)	58.6 (n=9)
	0-30	125.9	124.4	133.5
Wet[2)]		n=40	n=32	n=72
	0-10	7.1[a2)]	19.0[c]	15.1[b]
	11-20	15.5[a]	25.3[c]	22.8[b]
	21-30	29.2[a]	25.2[a]	27.1[a]
	0-30	51.8[a]	69.5[b]	64,9[b]

[1)] gravimetric soil water content 20%, [2)] gravimetric soil water content 30%, [3)] number of score samples, [4)] statistically significant differences are shown for the wheeling effect with small letters; Student-Newmann-Keuls ($p<0.05$).

Table 3. Characteristics of the experimental design with technical parameters for the tractor slurry tanker combination

Tanker filling level	Wheel	Wheel load [4] (kN)	Tire-soil contact area [5] (cm^2): Low inflation pressure [6]	Tire-soil contact area [5] (cm^2): High inflation pressure [7]	Mean ground pressure (kPa): Low inflation pressure [6]	Mean ground pressure (kPa): High inflation pressure [7]
Filled	Tractor front [1]	11	1,904		57	
	Tractor rear [2]	46	4,840		96	
	Tanker 1st axle [3]	57	7,445	4,152	76	136
	Tanker 2nd axle [3]	56	7,727	4,526	72	123
Half-filled	Tractor front	10	1,926		54	
	Tractor rear	41	4,335		95	
	Tanker 1st axle	39	5,112	3,713	76	105
	Tanker 2nd axle	37	5,584	4,029	66	91
Empty	Tractor front	13	2,348		57	
	Tractor back	31	3,691		83	
	Tanker 1st axle	18	4,060	3,652	45	50
	Tanker 2nd axle	18	4,335	3,607	43	51

[1] 540/65 R30, [2] 650/65 R42, [3] 750/60 R30.5, [4] measured on farm's electronic weighbridge, [5] tire print was chalked and photometrically evaluated, [6] 100 kPa, [7] 300 kPa.

Table 4. Tire track depth (cm) affected by tire inflation pressure, filling level of slurry tanker (filled, half-filled and empty), and ground covering (+cover crop, −cover crop).

Tire Inflation Pressure	Filled Tanker			Half-Filled Tanker			Empty Tanker		
	+Cover Crop	−Cover Crop	Mean	+Cover Crop	−Cover Crop	Mean	+Cover Crop	−Cover Crop	Mean
Low	6.20	5.80	6.00 ^{a}	6.86	5.83	6.35 ^{a}	6.61	4.89	5.75 ^{a}
High	7.49	7.11	7.30 ^{b}	7.23	5.93	6.58 ^{b}	6.88	5.41	6.15 ^{b}
Mean	6.85 ^{B}	6.46 ^{A}	6.65	7.05 ^{B}	5.88 ^{A}	6.47	6.75 ^{B}	5.15 ^{A}	5.95

Statistically significant differences ($p < 0.05$) are shown for the cover crop effect with capital letters and for the tire inflation pressure effect with small letters.

Table 5. Soil penetration resistance (MPa), averaged for the depths (0-20 cm and 21-41 cm) affected by the treatment (un-wheeled, low and high inflation pressure), filling level of slurry tanker (filled, half-filled, empty), and ground covering (+cover crop, −cover crop)

Soil Depth (cm)	Treatment	Filled Tanker			Half-Filled Tanker			Empty Tanker		
		+Cover Crop	−Cover Crop	Mean	+Cover Crop	−Cover Crop	Mean	+Cover Crop	−Cover Crop	Mean
0–20	Un-wheeled	0.74	0.67	0.71 ^{a}	0.70	0.82	0.76 ^{a}	0.72	0.81	0.76 ^{a}
	Low	1.17	1.27	1.22 ^{b}	1.11	1.23	1.17 ^{b}	1.06	1.21	1.14 ^{b}
	High	1.30	1.66	1.48 ^{c}	1.18	1.32	1.25 ^{c}	1.16	1.24	1.23 ^{c}
Mean		1.07 ^{A}	1.20 ^{B}	1.14	1.00 ^{A}	1.12 ^{B}	1.06	0.98 ^{A}	1.09 ^{B}	1.03
21–40	Un-wheeled	2.09	2.06	2.08 ^{a}	1.88	1.99	1.94 ^{a}	1.95	2.24	2.10 ^{a}
	Low	2.25	2.21	2.23 ^{b}	2.21	2.24	2.23 ^{b}	2.15	2.34	2.25 ^{b}
	High	2.33	2.32	2.33 ^{b}	2.20	2.25	2.23 ^{b}	2.30	2.15	2.23 ^{b}
Mean		2.22	2.20	2.21	2.10	2.16	2.13	2.14	2.24	2.19

Statistically significant differences ($p < 0.05$) are shown for the cover crop effect with capital letters and for the inflation pressure effect with small letters.

CONCLUSIONS

The study showed that under rather dry soil conditions, **sugarbeet harvesting** with self-propelled six-row sugarbeet tanker harvesters did not impair the soil physical properties (bulk density, soil penetration resistance).

For wet soil conditions, there were significant differences between the two-axle harvester and three-axle harvester on soil penetration resistance. Single and multiple wheeling in wet soil showed higher soil penetration resistance in the top soil.

Findings under moist soil conditions indicated a higher risk of potential soil compaction. Therefore, soil protecting sugar beet harvesting requires a good load carry capacity of the soil.
The results obtained in this field experiment on passage of a **tractor-slurry tanker** combination with different wheel loads and tire inflation pressure show a soil pro-tecting effect of reduced tire inflation pressure.
Regarding this fact, a slurry tanker should be equipped with an automatic tire pressure controller. This would enable a lower tire inflation pressure in the field and higher tire inflation pressure on the street.
The soil penetration resistance in the subsoil was higher in the wheeled treatments than in the un-wheeled control, but there were no significant effects detected caused by tire inflation pressure (high: 300 kPa, low: 100 kPa) and wheel load (filled, half-filled, empty slurry tanker).
Cover crops created deeper track depths after traffic, which is explained by the loosening of cover crop roots. Cover crops with their positive ecological effects can reduce the risk of potential soil compaction and have ameliorative effects on restoring the soil structure.

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