YIELD CROP DEPENDENCE ON SOIL PROPERTIES AND SOIL WATER AVAILABILITY

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Abstract. The research focused on soil trafficking by agricultural machinery and its impact on crop yields was established on the experimental plot where the soil was described as *Haplic Luvisol*. The experimental plot contained six variants of soil treatments and crossings: CTF (controlled traffic farming) and simulated random traffic, both named variants with and without deep loosening (DL) at the beginning of the experiment. For CTF variants the measurements were conducted on non-wheeled and wheeled areas. The measurements contained monitoring of soil water potential (SWP), undisturbed soil samples and crop yield samples. The results showed the lowest values of yield on the CTF variant measured on non-wheeled area while the highest values on the random traffic variant with DL. In the case of soil samples there were not statistically significant differences found among the variants. The SWP measurement showed very dry conditions during the vegetation period of winter wheat. The dry period during vegetation probably affected the growth and subsequent crop yield because the compacted soil held water longer than less compacted soil. This raises the question: to what extent is it appropriate to loosen the soil?

Keywords: controlled traffic farming, crop yield, soil physical properties, soil water potential

Introduction

Is the effect of soil compaction on crop yield significant? It is a question which was dealt by Voorhees in 1991 [1]. The answer is that indeed soil compaction affects crop yields in the negative sense and it was confirmed by numerous studies [2-4]. Ratford et al. [5] conducted a research on the influence of soil compaction on wheat in Australia. He found that in the first year of the experiment there were no differences in the yield of wheat between plots with minimal crossings and land crossed by machine with the load of 6 tons per axle. Significant differences occurred in the second and third year of the experiment, when there was a loss in the crop yield on compacted soil up to 23 % in comparison to non-compacted soil. Similar results were obtained during five year trial in Sweden where the yield losses (while crossing 350 $t\cdot km\cdot ha^{-1}$ and the cultivation of spring barley – *Hordeurnuulgare* L.) amounted to 12 % in comparison with non-compacted soil [3], this was confirmed in further experiments by Lipiec &Hatano [6]. The same experiment was performed with winter wheat (*Trificumaestivum* L.), where the results have not confirmed the effect of compaction on yields [3]. This result refutes the experimental test carried out in Pakistan, where various variants of soil compaction were performed with a self-propelled roller weighing 7 tons and with the width of 1.5 meters (non-compacted soil, two passes, four and six passes by roller). During the two-year monitoring it was found that two passes of 7 tons self-propelled roller was reducing the yield of winter wheat (*Trificumaestivum* L.) by 19 %, four passes by 25 % and six passes by 28 % compared to non-compacted soil [7; 8].

Long-termexperimentshoweda reduction incrop yieldsafter the introduction of the CTF technology. In the experiment the influence of compaction on yields of barley was monitored and it was demonstrated that introduction of minimum passes decreases the crop yields by an average of 6 % [9], it was also confirmed by other results [10; 11]. The yield crop increase occurred three years after the beginning of the experiment. In the fourth year of the experiment growth of the crop yield by 3.5 % was recorded compared to soils, where one and four passes by load of 16-19 tons were performed.

The aforementioned is linked with dependences of crop yields on the soil condition. Dependence of crop yields on soil bulk density is illustrated in Fig. 1 [12].The trend line of dependences of crop yields on soil bulk density has other interpretations, for example, the experiment where the crop yield of spring barley was evaluated in Poland (Fig. 2) [13]. Similar dependences were observed in the yields of maize on clayey soil [2].

However, the effect of soil compaction on one crop may not have a significant effect on another crop [1]. Compacted soil does not necessarily bring only negative effect on crop yields.Average soil compaction (approximate load of 4.5 t, 1 ton of load creates pressure of 100-500 $kg\cdot dm^2$, depending on the ability to compact the upper soil layers, wet/dry conditions) can provide higher crop yields, as mentioned by Arvidsson&Håkansson [3] and Bouwman et al. [14].

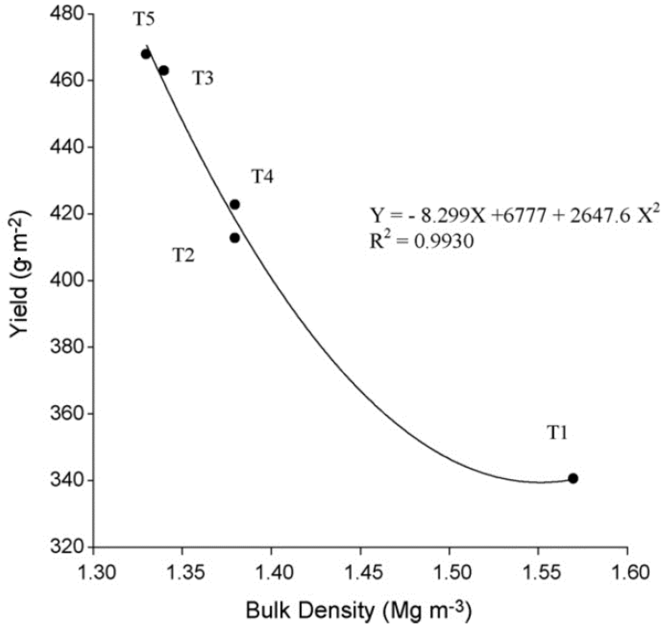

Fig. 1. **Relationship between soil bulk density and grain yield of wheat [12]**

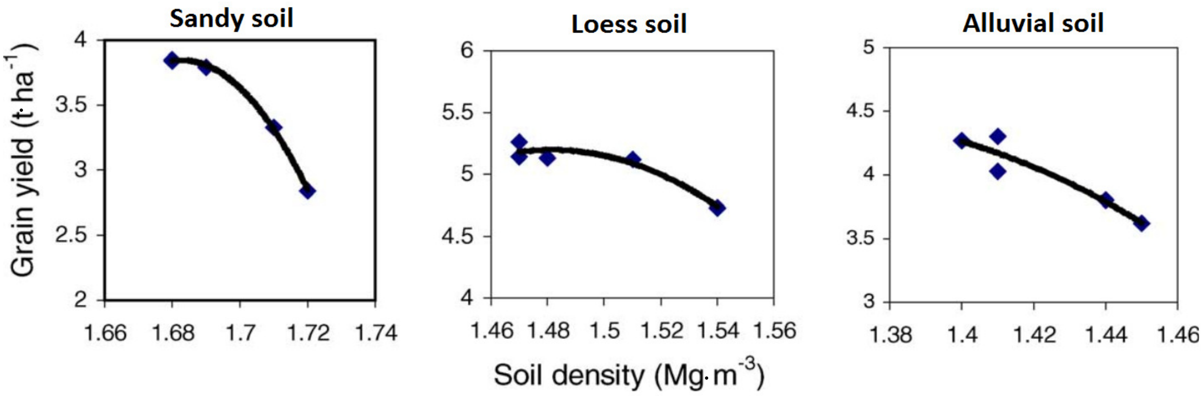

Fig. 2. **Effect of soil bulk density on grain yield of spring barley (*Hordeumvulgare*) [13]**

Materials and methods

The measurements were performed on the plot situated near to Červený Újezd town in the Czech Republic (Longitude: 14º10'11.3"E; Latitude: 50º04'08.6"N). The soil of this plot is described as *Haplic Luvisol* (clay 46.3 %, fine sand 49.3 %, sand 4.4 %). During the first year, after the harvest of oilseed rape, the experimental plot was established and deep loosened (DL) up to 0.45 m on its part like one of the future variants. On the whole experimental plot the following operations were made: loosening (0.15 m), power harrowing in combination with sowing. The experimental plot contains six variants of soil treatments and crossings: CTF (controlled traffic farming) and simulated random traffic (in areas with random traffic trajectories were shifted during stubble cultivation or soil preparation. This led to an increase in run-over areas at least once per season to 69.8 %.), both named variants with and without deep loosening at the beginning of the experiment. For CTF variants the measurements were conducted on non-wheeled and wheeled areas. The measurements were carried out during the second year of the experiment after the harvest of winter wheat (*Ludwig*).

The measurements of soil water potential (SWP) were carried out by Watermark 200SS-X (Irrometer, USA). The measurements were performed at three different depths (100-122; 200-222; 300-322 mm). The Watermark 200SS-X sensors were connected to the data logger Microlog SP (EMS

Brno, CZE). For rainfall measurements the meteorological station of the Czech University of Life Sciences Prague (Rain gauge SR 03 – 500 cm^2) was used.

For the measurement of physical properties of soil the undisturbed soil sample method was chosen [15]. Undisturbed soil samples were taken on steel rollers with a volume of 100 cm^3, and analysed for water and air ratios, including the determination of porosity and other parameters. Sampling was carried out in the field from the canter of individual horizons into Kopecky's steel cylinders. The samples were taken from five different depths of soil horizon (ranging from 0 to 0.25 m after 0.05 m).The values of soil bulk densityρ_d (g·cm^{-3}) can be obtained by simple calculation:

$$\rho_d = \frac{G_H}{V_S}, \tag{1}$$

where G_H(g) – weight of the soil sample after 24 hours of drying at 105º of Celsius
V_S(cm^3) – volume of steel roller.

For the detection of crop yields the sampling method of the sectors within the selected area (0.5625 m^2) has been selected. The method consists in the multiple sampling of these sectors in one variant and subsequent conversion of the anticipated yield per hectare. The sampling was carried out for each variant within and outside the tracks of agricultural machinery.

The data were evaluated by MS Excelspreadsheet for trendline creation. For statistical calculation analysis ANOVA Tukey's test in Statistica 12 software was used.

Results and discussion

The rainfall measurements are shown in Fig. 3. These measurements showed dry term ranging from 20.6. to 4.7. in the same year when the winter wheat (*Ludwig*) was in the stage of GS 70-89 (grain filling) while the average rainfall of 8 mm occurred not before 5.7.(Fig. 4). This rainfall affected SWP and increased values were registered in the track even after six days, while outside the track only one or two days. This means that in non-compacted soils rapid drainage of water into the lower layers of soil or water evaporation from the soil occurred. In contrast, the compacted variants have better capabilities to hold water in the upper soil layers. We can say that tillage without unnecessary passes helps the infiltration characteristics of the soil. On the other hand, the question remains to what extent it is appropriate to loosen the soil?

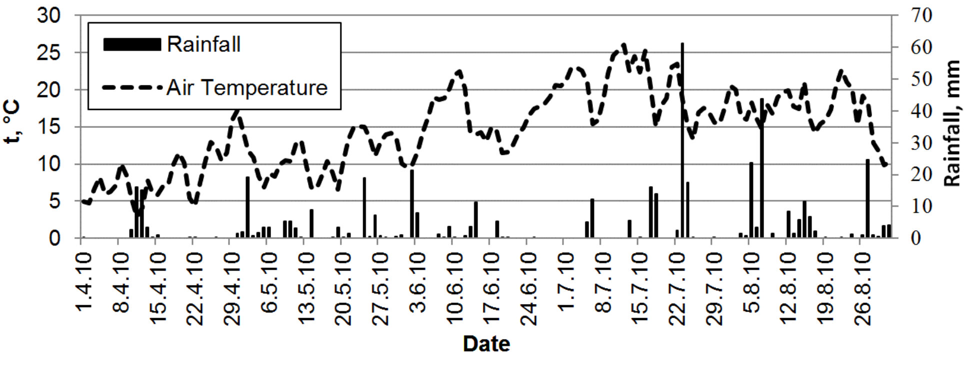

Fig. 3. **Rainfall and temperature measurements**

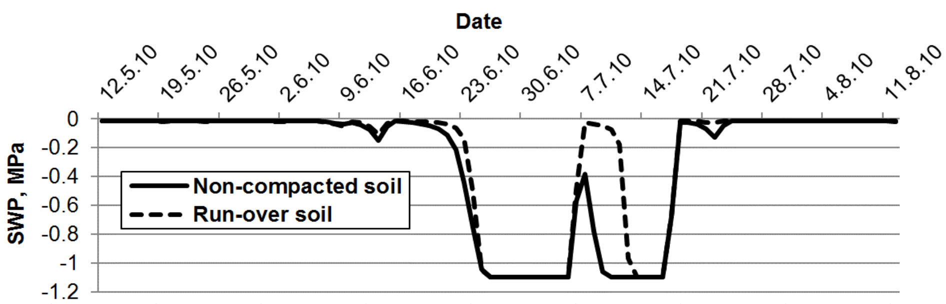

Fig. 4. **Soil water potential from depth of 100-122 mm**

The average values of the estimated yield crops with test of homogenous groups are shown in Table 1. From the table it is obvious that the lowest values of yields were observed in the variant CTF measured outside the traffic lines (non-compacted soil) than for the same variant with deep loosening. There were no significant statistical difference between the rest of the measured variants (see homogenous groups in Table 1), but the highest average values of yields were observed in the random traffic variant with deep loosening.

Table 1

Average values of yield with Tukey's HSD test

Variant	Yield, t·ha^{-1}	1	2	3
CTF O	6.11	****		
CTF O+DL	6.78		****	
CTF I	7.05		****	****
CTF I+DL	7.18		****	****
RAN	7.06		****	****
RAN +DL	7.50			****

CTF – controlled traffic farming; RAN – random traffic; O – outside of traffic lines; I – inside of traffic lines; DL – deep loosening; 1, 2, 3 – homogenous groups

The values of soil bulk density are shown in Table 2. The table shows no statistical significant difference between the variants up to the depth of 0.20 m. However, the changes in average values can be monitored.

Table 2

Average values of soil bulk density with Tukey's HSD test

Soil bulk density ρ_d, g·cm^{-3}												
Depth, m	**CTF O**		**CTF O+DL**		**CTF I**		**CTF I+DL**		**RAN**		**RAN +DL**	
0-0.05	1.38	a / 1	1.31	a / 1	1.44	a / 1	1.41	a / 1	1.39	a / 1	1.36	a / 1
0.05-0.10	1.40	a / 1	1.37	a / 1.2	1.48	a / 1.2	1.47	a / 1,2,3	1.40	a / 1	1.40	a / 1.2
0.10-0.15	1.43	a / 1	1.45	a / 2	1.52	a / 1.2	1.43	a / 1.2	1.46	a / 1	1.43	a / 1,2,3
0.15-0.20	1.43	a / 1	1.45	a / 2	1.53	a / 1.2	1.53	a / 3	1.47	a / 1	1.44	a / 2.3
0.20-0.25	1.53	a,b / 1	1.46	a / 2	1.56	b / 2	1.52	a,b / 2.3	1.51	a,b / 1	1.49	a / 3

a,b.. – homogenous groups in a row, 1,2.. – homogenous groups in column;
CTF – controlled traffic farming, RAN – random traffic, O – outside of traffic lines,;
I – inside of traffic lines, DL – deep loosening

In the case of the trend line dependence of yield crop on the soil bulk density the values showed a similar trend line as were measured by Czyz [13] and McKyes [2]. The trend of dependence is downwardpolynomial as shown in Fig. 5. For the trend analysis the linear (as the most used basic control trend) polynomial trend of the second order was chosen. As already stated, both used trends are downward and the polynomial trend was used to determinate the similarities with other authors. The polynomial trend in the figure also points to the possibility of declining revenue trend toward the left. This means that there is a possibility to lower yields in soils which are more loosened and thus have lower soil bulk density. The coefficient of determination (R^2)[16] refers to the relationship between two values (crop yield and bulk density) and their interdependence. In the case of using the linear trend, the determination coefficient is 0.3349, it means that the interdependence is medium. The medium interdependence was observed also for the values which were fitted by the polynomial trend (R^2 = 0.3753).

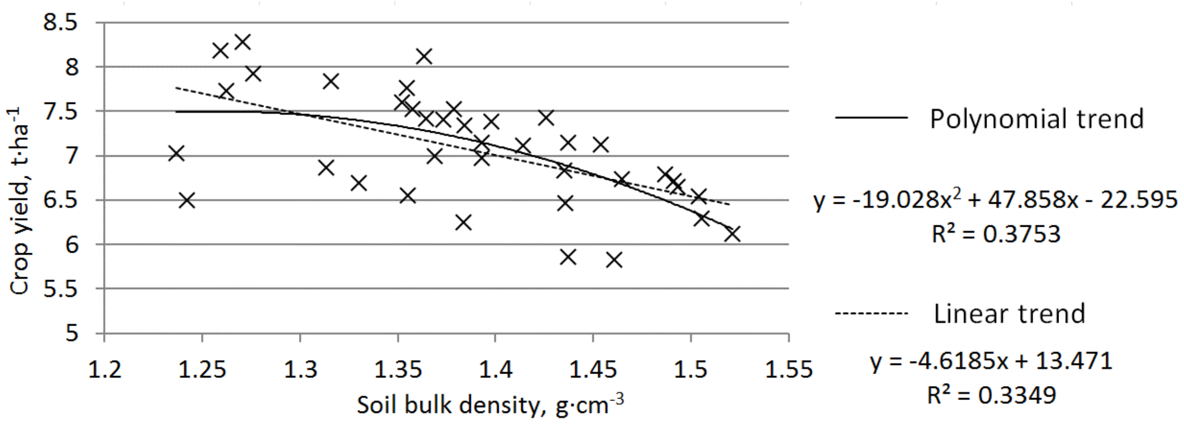

Fig. 5. **Dependence of yield crop on soil bulk density**

Conclusions

1. In general, the soil bulk density to some extent is affecting the crop yields. However, the main finding lies in the values of SWP, which pointed on the connection of the soil bulk density, rainfall, consequently weather during the annual season, tillage technologies and, the most important, the crop yields. From the achieved results it is clear that the soil with greater densities can keep water from rainfall over much longer periods than less compacted soil. It can cause increased crop yields on the compacted parts of the field, especially during the drier season as it was also in the case in this measurement.
2. The yield crop of winter wheat showed the highest yield in the random traffic variants and also for the CTF wheeled variants, while the lowest values were measured for the CTF non-wheeled areas. This may be caused by already mentioned very dry season.
3. The result of the trend lines in dependence of the crop yield on the soil bulk density is interesting. The measured trend was pointed as a concave trend line, as stated by McKyes[2] and Czyz[13], rather than a convex trend line. Nevertheless, it is necessary to take into account the variability of these trend lines from the aspects of different crops and the aspects of different soil types.

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