The Impact of Various Soil Tillage Methods on Soil Physical Properties in Grain Maize Stands

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Summary

The technology of differentiated soil tillage contributes significantly reduction of costs and energy along with ecological requirements. Different soil tillage technologies have a different effect on the physical state of soil. Different soil tillage technologies – ploughing, deep loosening (0.30 m by deep cultivator), no-till, loosening (0.25 m by chisel cultivator), strip-till were compared. The results showed a positive influence of strip tillage. It is a compromise between the traditional technology and intensive loosening and sowing into untilled soil. The strip being loosened affects positively the physical properties of the soil and facilitates maize stand establishment and its development. The untilled strip supports more efficient water management and soil protection. As the row spacing increases, of course, the percentage of soil surface covered with mulch is increasing. The soil protection effect can be also achieved by soil tillage done in non-freezing or freezing catch crops in the agriculture practice. Strip tillage therefore can be a suitable alternative for the establishment of wide-row crops.

Key words

grain maize, differentiated soil tillage, soil properties, soil compaction

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Introduction

Maize (*Zea mays L.*) is a very important crop for the farmers in Central Europe. Maize plays a very important role in human and animal nutrition (Lošák et al. 2010). Growing grain maize in the Czech Republic has occupied higher and higher areas of crop rotation in the last decades. This requires looking for new innovative process of growing maize.

The technologies of differentiated soil tillage and fertilization have been intensively tested in Europe recently. The differentiated soil tillage technologies represent modern trends of approach to the growing of maize (*Zea mays L.*) and are fully consistent with the objectives of sustainable soil management. Primarily, these technologies aim to increase the energy and economic effectiveness of cultivation technologies and to reduce the soil degradation processes.

The technology of differentiated soil tillage contributes significantly to reducing costs and energy along with ecological requirements. Different soil tillage technologies have different effect on the physical state of soil, in particular on density, porosity and structure which is subsequently reflected on soil infiltration capability (Hůla and Procházková et al., 2008).

Material and methods

There was established a semi-operational experiment with different soil tillage variants in the maize production region in the field of University Farm in Žabčice near Brno (48°58'39.826"N, 16°38'10.247"E) in a very hot, dry region in order to verify the working tools and prototypes being developed for differentiated soil tillage.

According to the long-term temperature and rainfall values (1961 – 1990), the average annual temperature at the experimental site is 9.2 °C, the warmest month in the year is July with an average daily air temperature of 19.3 °C. The coldest month with an average of – 2.0 °C is January. It is a dry area where the average annual rainfall amounts to 480 mm. There is also a rain shadow in the area. A considerably uneven distribution of rainfall is typical for the vegetation period. The month of June with s 68.6 mm is the richest in rainfall. The month of March with an average rainfall of 23.9 mm is one of the poorest. The sunshine duration varies from 1800 to 2000 hours per year.

Long-term temperature and precipitation average values are listed in Table 1.

The experimental plot was located on a medium weight soil. According to the Taxonomic Classification System of soils in the Czech Republic, the soil type is modal, carbonate fluvisol.

Five variants of differentiated soil tillage were prepared in the autumn agricultural soil tillage term (the number in brackets shows the depth set for soil tillage):

1. Ploughing (0.25 m)
2. Deep cultivator (0.30 m),
3. No-till – control variant (0 m),
4. Chisel cultivator (0.25 m),
5. Strip-till (0.25 m).

The variant 5. was divided into 5a. – the loosened strip and 5b. – the non-loosened strip.

Individual variants of the experiment were sown with precise seeding machine in spring 2015. Hybrid P9241 (FAO 310) by Pionner was used.

To determine the influence of differentiated soil tillage on the changes of soil properties, the penetrometer resistance of soil was measured at the experimental site after the experiment had been established (22.12.2014) in order to determine soil compaction. Soil compaction was measured using a hand-held cone penetrometer with digital recorder Penetrologger from Eijkelkamp, a tip with an area of 1 cm^2 and an angle of 60° was chosen for the measurement. The speed of penetration of the tip into soil was set to 3 $cm.s^{-1}$. Soil moisture was recorded using a Penetrologger probe during the measurement (Figure 6). The evaluation of measured data is in accordance with the ASAE EP 542 standard (2004). PenetroViewer software, ver. 5.08 was used for the evaluation.

The determination of the soil physical properties was based on sampling intact soil samples (in natural storage) and their subsequent laboratory analysis. Kopecky's physical cylinders (23.3., 29.5., 26.8. 2015) were sampled from three depths (0-0.10 m, 0.10-0.20 m and 0.20-0.30 m) in five repetitions. The modified Kopecký-Novák method used at the Department of Agrosystems and Bioclimatology MENDELU in Brno (Kostelanský, 1982) was used for the analyses. Dry bulk density was determined. The change of density reflects the changes in total porosity. Air capacity and volumetric moisture content were chosen as other characteristics reflecting the changes in the three-phase soil composition. Statistical evaluation of the observed values of soil physical properties was made using the STATISTIKA v. 12. Programme.

Results and discussion

The long-term average of the mean annual temperature was 9.2 °C, while precipitation in the region was 480 mm (Table 1). Figure 1. indicate average air temperatures and total quantity of precipitation for Žabčice area in 2015. Higher values of the average monthly air temperatures were observed in the studied period in comparison to the outlined long-term average. Higher temperatures were on average recorded in all months of the studied period, except in April 2015. Deviations of monthly precipitation from the long-term average are even more interesting. Precipitation in 2015 was below the long-term average with only 75.9% of normal long-term precipitation. Great disturbance in distribution was noticeable, when the recorded precipitation in summer months (March – July) was 112 mm lower and make only 45% of long-term average

Table 1. Long-term temperature and precipitation average values (1961 – 1990)

Month	Average temperature (°C)	Precipitation (mm)
January	-2.0	24.8
February	0.2	24.9
March	4.3	23.9
April	9.6	33.2
May	14.6	62.8
June	17.7	68.6
July	19.3	57.1
August	18.6	54.3
September	14.7	35.5
October	9.5	31.8
November	4.1	36.8
December	0.0	26.3
Year	9.2	480

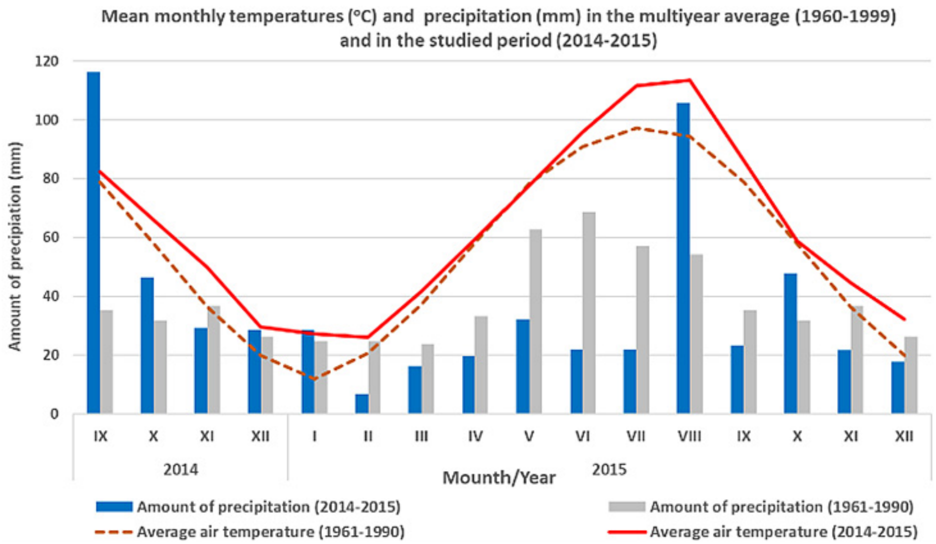

Figure 1.
Weather conditions (Žabčice, 2015)

Table 2. Average values of physical soil properties (Average value for all season)

Variants	Bulk density ($t.m^{-3}$)	Total porosity (%)	Volume soil moisture (%)	Minimum air capacity (%)
1. Ploughing	1.32 a	49.6 2a	18.79 a	19.00 a
2. Deep cultivator	1.40 b,c	45.73 b,c	21.95 c	15.75 b,c
3. No-till – control variant	1.54 d	41.34 d	22.89 c	10.34 e
4. Chisel cultivator	1.3 8b	47.38 b,c	22.23 c	14.6 1c
5a. Strip-till - the loosened strip	1.33 a	49.15 a	20.27 b	16.78 b
5b. Strip-till - the non-loosened strip	1.42 c	45.73 c	22.17 c	12.45 d

The different letters (a, b, c) indicate a statistically significant difference (P = 0.95)

precipitation. Precipitation rates in 2015 during first three months do not differ from long-term average. Intense precipitation was in August. Precipitation rates this month were 106 mm. This was 51.7 mm higher than the long-term average (195% long-term average). These precipitations were only 3 days, when the one day was 83 mm (18.8.2015). Overall can be said, that the growing season 2015 was thermally supernormal (11.1 °C) and precipitated undernormal (355 mm). This was reflected in the quantity and quality of maize production.

The observed soil physical properties reflect very well each mechanical intervention into the three-phase soil system (solid soil matter, water and air).

Kwong (2002) includes the soil bulk density to a group of minimum data for monitoring the soil quality, as an indicator of both soil structure and soil strength. The change in bulk density reflects changes in total porosity. Hůla and Procházková et al. (2008) describes as an optimum bulk density in the range of 1.2-1.5 $t.m^{-3}$, which are values that we have found also in our experiment. The obtained results are shown in Table 2.

Kisić et al. (2002) addressed the issue of optimizing the ploughing depth on the pseudogley soils (luvisoils) in central Croatia. He points out to the positive influence of deep ploughing on the yields of maize. Our experimental variant with ploughing to 0.25 m showed more favourable values in dry bulk density. Similar results were published by Farkas et al. (2008) when comparing the physical properties of the soil in three variants of soil tillage while verifying a study of the possible impact of climate changes. The variant with ploughing (variant 1) showed also more favourable values in total porosity and the minimum air capacity in comparison with the reduce tillage technologies (var. 2-4). Strip loosening of a row in the strip-till variant (Var. 5a) had a very similar effect on the soil physical properties. On the contrary, a non-loosened catch row (var. 5b) behaved similarly as the no-till variant (var. 3). These findings were compared also by the ANOVA statistical analysis (Table 2).

The measurements capturing the amount of water in soil showed a higher representation of water in the minimum tillage technologies. The higher values of volumetric moisture content are most likely to be related to a lower loosening of the lower part of soil profile and the higher proportion of capillary pores. Similar results are stated by many authors (Procházková 1986, Lacko-Bartošová 1992, Aura 1999). Their analyses showed better preservation of soil water balance in conservation tillage than in conventional tillage. On the contrary Kováč et al. (2005) notes that during the three-year experiment, the soil tended to spare considerably more humidity by conventional tillage (15.75%), a considerably lower moisture (14.74%) was achieved when mulching. Also, Matula (2003) came to the conclusion that reduced soil tillage and no-till show a significant decrease in infiltration rate for Orthic luvisol.

In all compared variants, the increasing depth of sampling resulted in deterioration of the soil physical properties parameters (Figure 2; 3; 5). It did not apply to moisture which increased with the depth of sampling (Figure 4). Similar conclusions were made by Smutný et al. (2013) who states that the density values increased with a lower intensity of soil tillage and the soil depth. Minimum

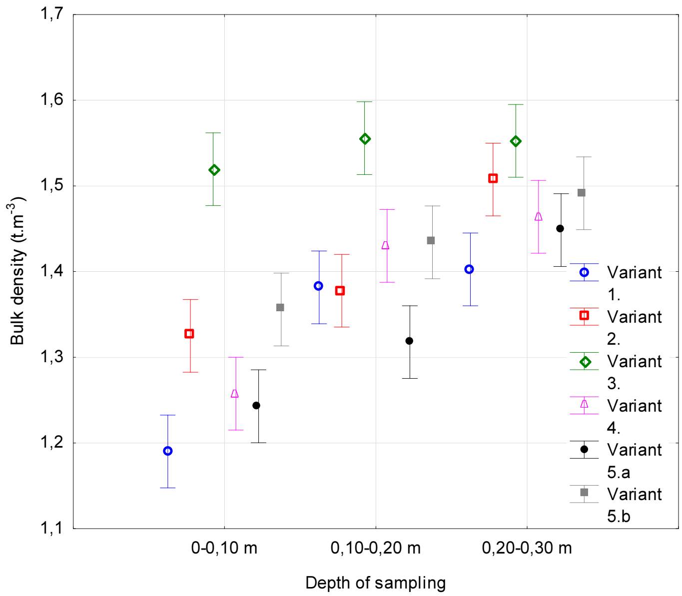

Figure 2. Bulk density of soil at different depths of sampling (Average value for all season)

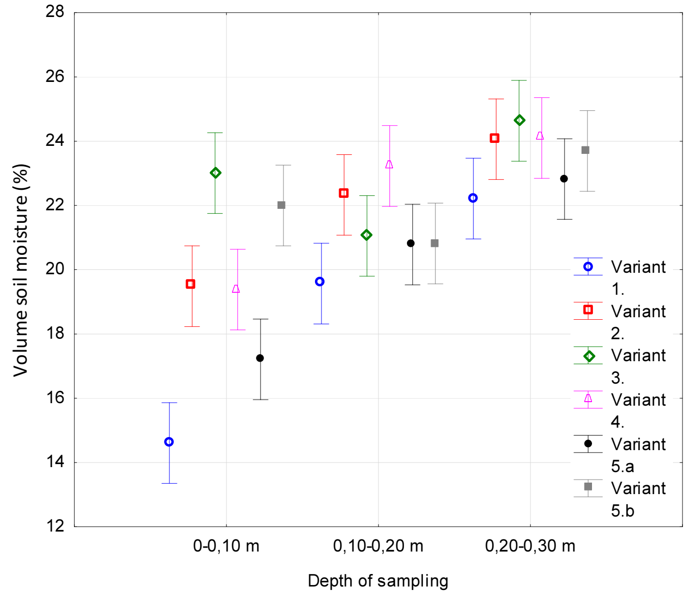

Figure 4. Volume soil moisture at different depths of sampling (Average value for all season)

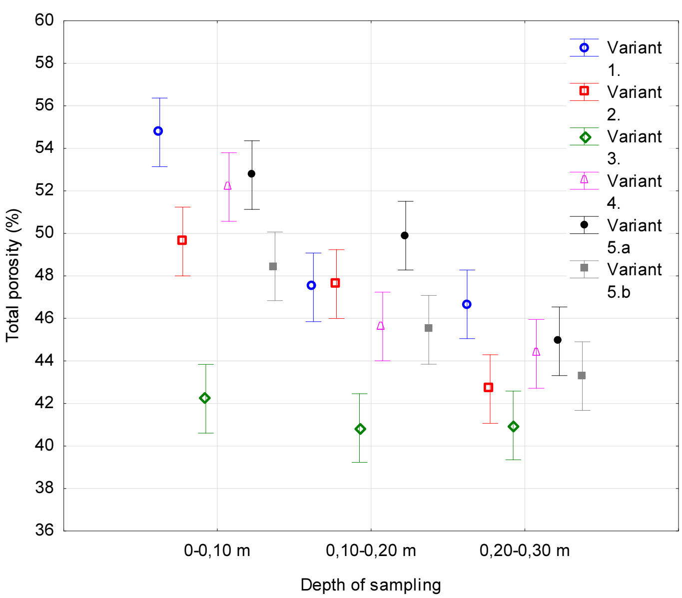

Figure 3. Total porosity of soil at different depths of sampling (Average value for all season)

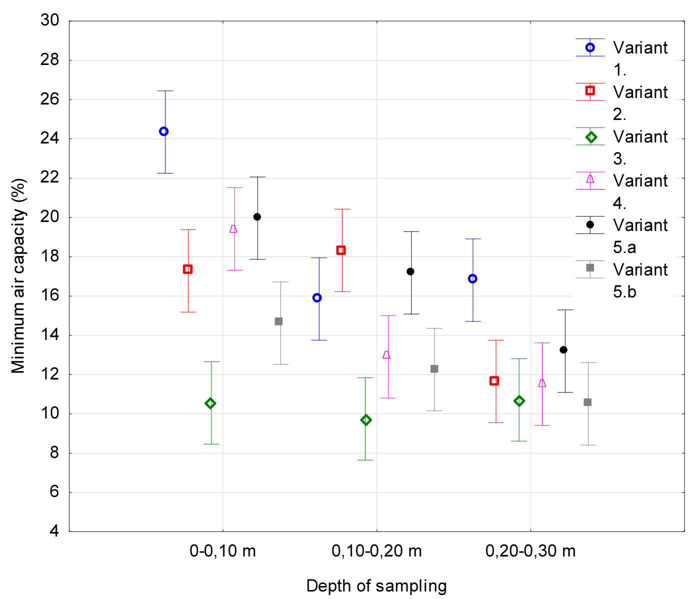

Figure 5. Minimum air capacity of soil at different depths of sampling (Average value for all season)

air capacity has decreased with the intensity of soil tillage in minimum soil tillage (MT) and conventional soil tillage (CT). The layers in deeper layers were lower than 10%. The highest soil moisture was in no-till (NT), where the surface and deepest layers had the highest values. The CT and MT variants had the driest layer near the surface.

Optimal values of bulk density, porosity and minimum air capacity were achieved in the first date of sampling. The soil physical properties have changed gradually during the vegetation. Whereas in the case of bulk density it was the opposite, the highest values of soil moisture were in the last sampling for all the zero-tillage variants (the variants 2-5). In terms of ploughing, the highest moisture was recorded in the 2nd date of sampling. The date of sampling affected soil moisture considerably more than the chosen soil tillage technology. The same results were recorded also by Pabin et al. (1998) in field experiences lasting several years. They observed that soil moisture was more influenced by weather conditions than the soil tillage technology.

Soil compaction increases bulk density and penetrometer resistance while reducing the penetration of roots into the soil (Unger and Kaspar, 1994; Taser and Kara, 2005). Soil compaction can considerably deteriorate soil productivity by decreasing aerating, storage of soil water and crop utilization efficiency (Radford et al., 2001). Birkás et al (2002) states in her contribution that the

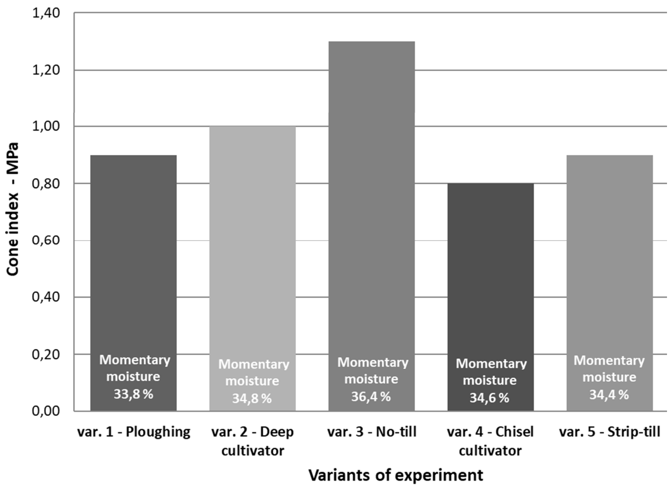

Figure 6. Penetrometer resistance – Cone index

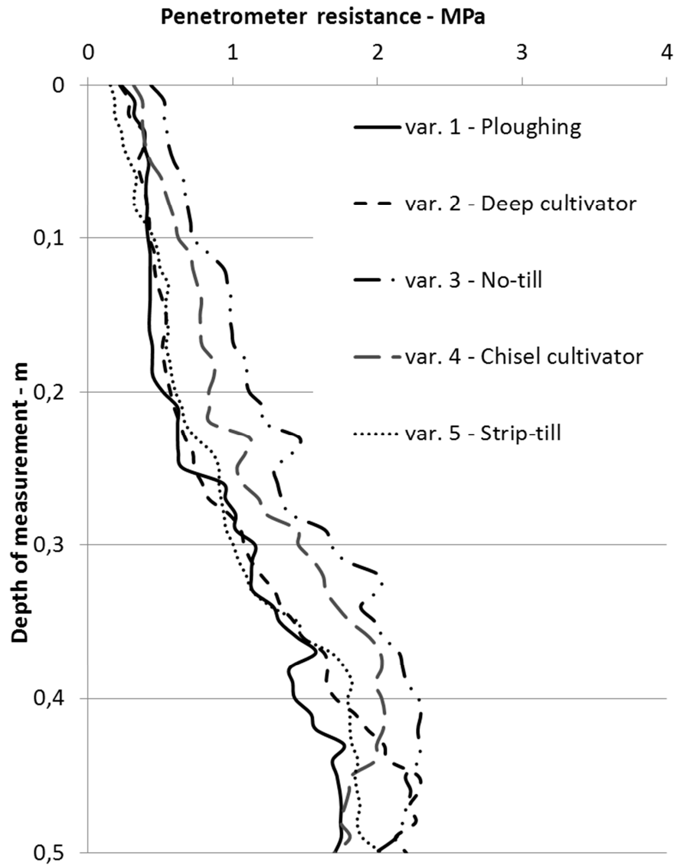

Figure 7. Penetrometer resistance

soil state deteriorated by compaction has conclusively reduced the yield of maize by 20 and 42%. Penetration resistance over 1 MPa usually reduces the yields (Khalilian et al., 1991). The value of penetrometer soil resistance, limiting root growth, is set at the limit of 2 MPa according to ASAE (2004). Lhotský (2000) has set as a limit value compaction for heavy soil in the interval of 3.3 – 3.7 MPa. The soil, where the penetrometer pressure values rise sharply and then decline again, is usually considered to be the compacted layer.

Our recorded measurements of penetrometer resistance using hand-held penetrometer have shown in individual variants that there are no big differences in the Cone index (Figure 6). A little bit higher values were measured in variant 3 – without any soil tillage which is logical because in this variant, the soil remained in the original state after the harvest. This fact is evidenced by the data of the course of penetrometer resistance in the soil profile of the individual variants (Figure 7). The curves of the values recorded during the measurement have an approximately same shape in all variants and therefore we can say that there is no significant difference among then variants in the establishment of the field experiment. At a depth of approximately 0.25 m, there is only a slight increase of penetrometer resistance, pointing out to a more compacted plough pan as a remain of soil tillage (ploughing) in the previous years. In the variant with depth cultivator, this compacted plough pan layer was eliminated by the loosening effect to the depth of 0.30 m. Javůrek and Vach (2006) state that the soil-protection technologies reduce in the long run the excessive soil compaction, especially in subsoil horizons.

Any change in the method of soil tillage necessarily leads to changes of the soil environment. The scope of these changes depends on the degree of reducing the depth and intensity of soil tillage, on the amount of plant residues left on the surface or on the upper layer of soil. The content, availability and movement of soil water are changing. Water is an important factor not only for the production of biomass of cultivated plants but also for the preservation of soil fertility both from a physical and chemical point of view. Both excess and lack of soil water are harmful. The highest loss of water occurs in the topsoil horizon and therefore we need to consider what soil tillage technology we choose.

If we use a deeper depth setting of the machine working body which reaches up to the subsoil, differentiated soil usage across the plot is used to increase the permeability of soil and to eliminate compaction. Hermann et al. (2012) see the advantages of strip soil tillage in improving the soil physical properties for development of crops in rows. Also Brant et al. (2016) came to similar conclusions and results.

Conclusion

Different soil tillage technologies have different effect on the physical state of soil. Each mechanical intervention into soil is manifested in the three-stage soil system (solid soil matter, water and air). Soil compaction can significantly deteriorate soil productivity. The results showed a positive influence of strip soil tillage. It is a compromise between the traditional technology and intensive loosening and sowing into untilled soil. The strip being loosened affects positively the physical properties of the soil and facilitates maize stand establishment and its development. The untilled strip supports more efficient water management and anti-erosion soil protection. As the row spacing increases, of course, the percentage of soil surface covered with mulch is increasing. The soil protection effect can be also achieved by soil tillage done in non-freezing or freezing catch crops in the agricultural practice. Strip tillage therefore can be a suitable alternative for the establishment of wide-row crops.

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