EFFECT OF PLOWING AND DEEP LOOSENING ON CONE INDEX AND WATER FLOW

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Abstract. Deep cultivators are often used in agricultural practice. These machines provide deeper soil preparation and are often perceived as an alternative to plowing. For these reasons, a comparison of a plough (Vidium) and a deep cultivator (Diger 3) was made. Compared tillage took place at stubble cultivated field after spring barley. Tillage depth of both machines was set to 0.3 m. Measured values were the cone index and preferential flow of water. For the cone index measurement the penetrometer PN-10 was used with the cone angle 30º and cone area 100 mm2. Cone index was measured to a depth of 0.4 m after 0.04 m and width of 1.5 m after 0.05 m. For monitoring water preferential flow a 0.3 % solution of E133 brilliant blue CFC colorant in water was used. First, the solution was poured on the surface of the soil. Then, after a period of 24 hours the hole was excavated so that it was possible to take photos of vertical slices of the evaluated soil profile. The results of the cone index measurement pointed to the function of wings of the deep cultivator. The wings ensured intense lifting of soil layers and their subsequent decline led to breaking and crumbling of soil. This effect is likely the reason of higher homogeneity of soil in the lower layers of the soil profile. This uniformity was reflected by lower values of the cone index variation coefficient. When comparing the values of deep loosening and ploughing, there were found lower average values of cone indexes to a depth of 0.16 m in the case of deep loosening. Conversely, in the depths of 0.32-0.36 m lower average values for ploughing were measured. Monitoring of the water flow showed, in the case of deep cultivator, that the tines of the machine formed the primary path for water infiltration. Also the impact of the wings of the machine was significant that ensured water supply to the sides and lower parts of the soil profile. Between the tines of the machine, in the upper layer of the soil profile, locations were found that have not been disturbed (locations with lower infiltration effect). This may contribute to a better distribution of rainwater and nutrients mainly in dry seasons. When evaluating the ploughed profile the infiltration was detected as more homogeneous, but significant effect of lateral movement of water was not recorded.

Keywords: cone index, tillage, water preferential flow.

Introduction

Tillage may consist of a wide range of practices, ranging from minimum and reduced tillage, say harrowing, and no-till practices for conservation systems in which a substantial part (at least 30 %) of the soil remains covered by previous crop residues to mouldboard ploughing as in traditional (or conventional) systems. Soil tillage practices can affect the water flow and solute transport processes dynamically in space and in time. Different tillage practices can explain the differences observed in the soil structure and, consequently, in the water flow and chemical transport in the soil [1]. There is considerable evidence, predominantly from outside Europe that conservation tillage can provide a wide range of benefits to the environment and wildlife, some of these being similar to that provided by set-aside [2].

In the recent years, the agricultural practices are starting to push the subsoilers (deep cultivators), also known as chisel plows. In terms of usage within primary tillage these machines provide deeper tillage and are often perceived as an alternative to the classical plough. Existing information about their function and impact on the soil is available mainly from the corporate materials. The number of constructional similar machines belonging to this category on the agricultural machinery market grows. Generally, in comparison with ploughing, subsoilers use is associated in area rating increase during soil processing with the possibility of loosening the deeper layers of the soil and manufacturers often pointed out their lower tensile resistance. Conservation agriculture is not equally suitable for all the European agroecosystems.

The need of soil and water conservation in Europe requires anticipating the ongoing process in order to improve its ecological and socio-economic sustainability. Priority would be to define, which regions in Europe are the most suitable for conservation agriculture taking into account climate and soil constraints, length of the growing period, water availability and quality, erosion hazards and farming conditions [3].

Materials and methods

As a part of the research activities of the Department of Agroecology and Biometeorology in cooperation with the Department of Agricultural Machines the effect of deep loosening conducted on the spatial arrangement of organic matter and soil infiltration capability was evaluated. For the evaluation the deep cultivator Diger 3 of Farmet Inc. was used with a working width of 3 m and total number of chisels of 7 in layout, 3 in the front row and 4 in the rear row. Depending on the soil conditions two versions of the machine were used.

Evaluation of Diger 3 (without a covering disk and with spike rollers) and Vidium work was performed on a plot situated in the eastern part of the Czech Republic. The measurement was performed on November 14, 2014. The measurement took place on stubble breaked plot after spring barley. Theoretical depth of work for both machines was 0.3 m. For the plough full moldboards with the working width for each element of 0.45 m were used. The effect of tillage on the cone index values, soil moisture content and brilliant blue dye tracer on the elevation profile of the surface was monitored. Evaluation of the mentioned values took place on November 28, 2014. The values were determined in transect perpendicular to the riding direction in the length of 1.5 m (5 repetitions per variant). Punctures of the penetrometer (PN-10 recorded values per 40 mm), the soil moisture content probe (FieldScout TDR 300 with length of tines of 0.2 m) and the altitude profile were carried out in the length range of 50 mm. The soil layers were measured by the penetrometer from the highest point within the elevation profile (it represents zero value). For the cone index measurement the cone angle 60º with area 1 cm^2 was used. For future details see the ASABE standard S313.3 [4].

Brilliant blue dye tracer values were determined on the profile of a length of 0.6 m. The blue color highlights the path of water infiltration to the soil. For brilliant blue dye tracing (infiltration) 0.3 % solution of E133 brilliant blue FCF colorant in water was prepared. First, the solution was poured in the amount of 10 litres per 1 m^2 of the surface of the soil by a watering can with a diffuser. The solution was poured gradually and slowly so as to avoid surface runoff and all of the solution was absorbed by soil. Then, after a period of 24 hours the hole was excavated so that it was possible to take photos of vertical slices of the soil profile. The photographed area was always bounded by a frame with gauges, which allows subsequent evaluation in software BMPTools.

Results and discussion

Based on the evaluation of the plot surface there were not found statistically significant differences between the plough and the cultivator, although the average values of the height differences between the highest and lowest point of the surface were lower after use of the cultivator (Table 1). Between the tested machines differences were not found even after graphical evaluation of altitude profiles of the plot surface (Fig. 1). The optimal soil conditions led not only to good soil crumbling after ploughing, but also the spike rollers provided high quality of work (Fig. 2). From the viewpoint of construction of the used spike rollers it is obvious that the primary effect is to re-compact the lover layer of the soil profile, minimizing the risk of removing crop residues from the soil profile and keep the topsoil layer loosened. The soil surface levelling effect strongly depends on the soil conditions and on the working speed. During intensive soil loosening by chisels the spikes penetrate deeper into the soil and the soil surface is also levelled by the smooth roller body. Higher working speed is also associated with sedimentation of finer soil particles. The question itself is the roller adjustment, which can be adjusted on both "the tip" and "the heel". This fact was not verified within the above experiment, but based on our experiment it can significantly affect the state of the soil surface.

Table 1

Average values of the height difference (m) between the highest and lowest point of the surface soil (transect perpendicular to the direction of the working travel, length 1.5 m) and standard deviation (σ) on the surface of the processed by the deep cultivator (Diger 3) and the plough, statistically significant difference at a significance level α = 0.05 (Tukey, ANOVA)

Machine	Height, m		σ
Plough	0.055	a	0.026
Deep cultivator	0.050	a	0.028

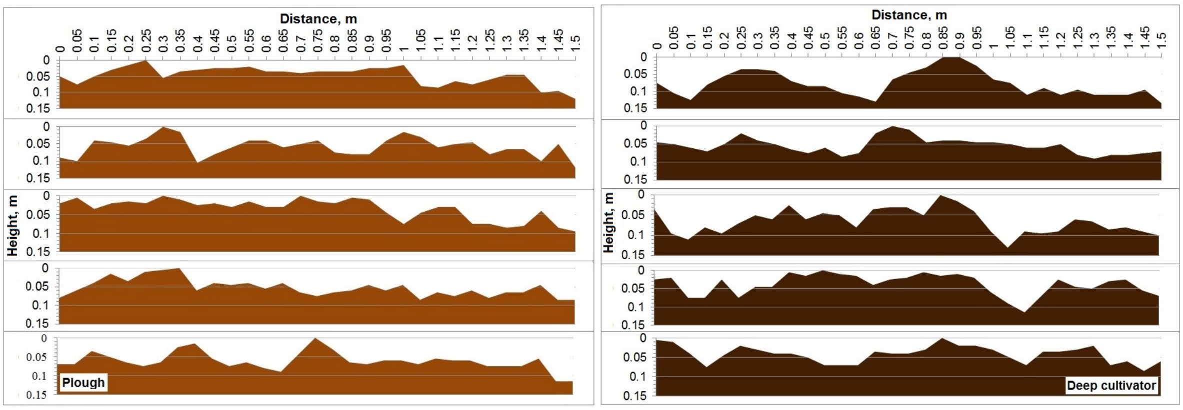

Fig. 1. **Graphical representation of the land surface elevation profile**

For roughness and profile description, Christiansen's coefficient was used. This coefficient determines a percentage deviation of each measurement and then an average value of these deviations from all measurements' arithmetic mean. When these deviations are small the value of the Christiansen's coefficient is close to 1 (100 %) and vice versa. This coefficient is calculated using the following formula:

$$Cu = 100 \cdot \left[1 - \left(\sum_{i=1}^{n} \left| i_{si} - i_m \right| / n \cdot i_m \right) \right], \quad (1)$$

where i_{si} – height of interval measurements, m;
i_m – arithmetic mean of i_{si} values, m;
n – number of samples.

Average Christiansen's coefficient for ploughing was 57.6 % and for deep cultivation it was 57.2 %. There was not observed statistical significant difference.

Fig. 2. **Surface condition after the deep cultivator and the plough**

Table 2 documents the impact of tillage on the soil moisture content (soil layer 0-0.2 m). Statistically significant higher volumetric moisture content of soil was determined on loosened surfaces in comparison to the plough (Table 2). Higher values of volumetric moisture content are likely related to the lover loosened subsoil layer in comparison to the ploughed areas (Table 3). The ploughshare at the given working depth is intensively loosening the soil to a depth of 0.15 m. In the second part of the soil profile lifting and crumbling of the soil and creation of larger cracks in the soil occurred. Intensive loosening in the upper layer of the soil profile contributed to nearly one hundred percent incorporation of postharvest residues into the soil (Fig 3) even without covering disks. Based on video recordings the incorporation of postharvest residues was involved primarily by the legs after which the soil was raised and by cutting boards mounted on the leg partially divided. For a given type of plow the crop residues were found partly in the bottom of the furrow and then in the space between the hunk.

The wings positioned at the bottom of the chisel contributed to intensive lifting of the soil (Fig. 3), its reverse drop after passage of the chisel led to the effect of breaking or crumbling. This effect could be the reason for higher homogeneity of the soil at the bottom of the soil profile (Fig. 4) compared to the plough. The homogeneity of the soil profile in the figure is expressed by the cone index coefficient of variation. The plough, of course, reflected an increase in heterogeneity of the soil cone index in the lower layers, particularly in areas of hunks abutment (Fig. 4). The homogenous distribution of organic matter in the lower layers of the soil profile can play an important role in terms of the development of the plant root system in relation to water raise. Warm winters with inadequate freezing of soil also reduce the process of disintegration of larger soil particles generated during tillage in the lower layers of soil.

Table 2

Average values of volumetric soil moisture content (% soil profile 0 - 0.2 m) and standard deviation (σ) on the surface processed by the deep cultivator and the plough. Statistically significant difference at a significance level α = 0.05 (Tukey, ANOVA)

Machine	Soil moisture content, % vol.	σ
Plough	19.5 a	3.8
Deep cultivator	22.9 b	3.6

Table 3

Average values of penetration resistance of the soil (MPa) and standard deviation (σ) on the surface processed by the deep cultivator and the plough. Statistically significant difference at a significance level α = 0.05 (Tukey, ANOVA)

Machine	Depth, m						
	0.08	0.12	0.16	0.20	0.24	0.28	0.32
Plough	0.21 b	0.27 b	0.32 a	0.33 a	0.40 a	0.47 a	0.44 a
Deep cultivator	0.08 a	0.17 a	0.30 a	0.41 b	0.51 b	0.58 b	0.71 b

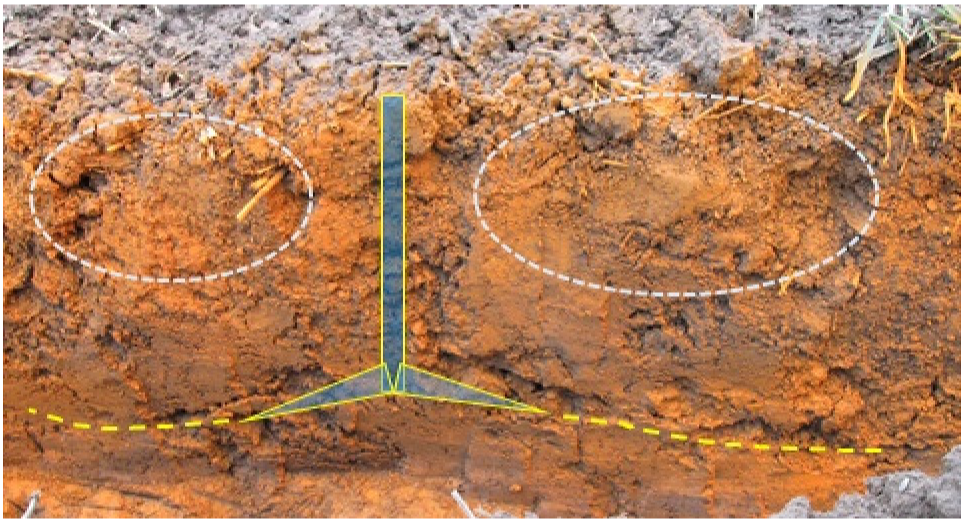

Fig. 3. **Soil profile after processing by the deep cultivator**

Dye infiltration showed that the place of the leg trajectories creates primary paths for infiltration of water (Fig. 5). Width of the loosening chisel and power of the chisel itself create a significant furrow in the soil, which is then filled by fine particles or there are inter-soil spaces present. However, due to the side wings water is distributed into the lower part of the soil profile, i.e. towards the grooves formed by the wings, which increases the retention capacity of soil. Between the chisels places may be formed where the soil is less disturbed and in these places the infiltration effect lowers (Fig. 5). Their creation is greatly influenced by the state of the soil during tillage. Using the plough the infiltration was on the cross section more uniform. However, in the evaluated profiles of the ploughed soil significant effect of lateral movement of water was not found as it was observed for the cultivated soil by Diger 3 (Fig. 5).

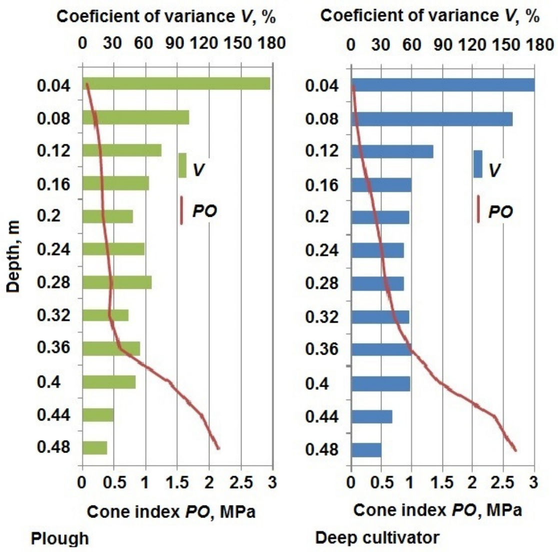

Fig. 4. **Average cone index values (*PO*, MPa) and coefficient of variation (*V*,%) on the surface processed by the deep cultivator and the plough**

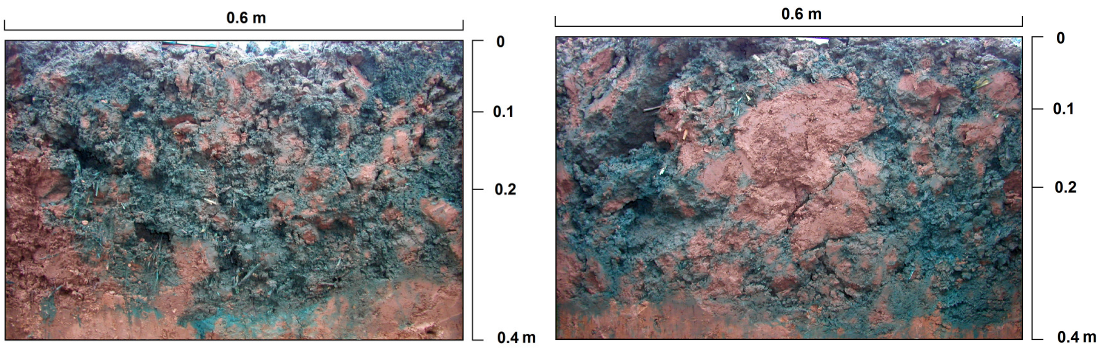

Fig. 5. **Simulation of water infiltration into the soil by dye tracer:**
plough – left, deep cultivator – right

Conclusions

Based on our results it is obvious that the use of deep cultivators offers another option of tillage to farmers, who prefer conventional tillage using the plough and also those, who perform soil tillage by different tillage systems without the effect of turning the soil mass (shallow or deep loosening). For farmers, who manage larger areas of arable land, it is possible to use these machines as an alternative of ploughing or deep loosening according to the condition of soil, weather condition and ensure observance of agro-technical terms. However, the choice of the tillage technology must be based on the particular needs of the agricultural subject in relation to the soil and climatic conditions, and agro-technical requirements, which are based on the structure of crops and cultivation goals.

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