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Influence of soil cultivation and farm machinery passes on water preferential flow using brilliant blue dye tracer

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Abstract. Objective of this study was the investigation of water preferential flow into the soil by brilliant blue dye tracer, under different soil tillage treatment and different soil compaction caused by farm machinery passes. Brilliant blue dye tracer measurement was supported by cone index measurement. Measurement was carried out on land divided into several options: a) controlled traffic farming (CTF) with loosening, b) CTF with deep loosening before plot establishment, c) ploughing, d) ploughing with deep loosening before plot establishment. For the mentioned measurement options the measurements were performed inside and outside of the track lines of agricultural machinery. Representation of the brilliant blue dye tracer inside of the track lines significantly decreases at a depth of 5–10 cm for all variants. This trend is stabilised between depths of 0.10 m to 0.4 m with colour coverage ranging between 10 and 20%. An interesting fact was that the colour coverage outside of the tracks without deep loosening before plot establishment was higher than measurement with deep loosening. The largest statistically significant differences occurred at a depth of 0.3 m, while the most homogeneous groups (from a total of four groups) were found at depths of 0.05 to 0.1 m and 0.25 to 0.3 m. Cone index measurement confirmed almost 100% increase in penetration resistance inside of traffic lines (2. MPa) in comparison with measurements outside of the traffic lines (1. MPa) in the range of depth from 0–0.16 m.

Key words: soil compaction, soil cultivation, dye tracer, infiltration, cone index.

INTRODUCTION

Soil is an important material in human life, whether it is to walk upon, build structures on, or to grow crops. Growing of plants is linked to technologies of soil tillage and crop seeding. One issue associated with new and larger working tools is an increase in weight and also increases in the demand for energy resources, as tractors need to be powerful enough to move large agricultural equipment around fields. Soil compaction is caused primarily by effects of the wheels on the soil surface by pressure and shear stress of the casters. The shear stress occurs due to the slip of the wheels of agricultural vehicles (Johnson & Bailey, 2002).

Besides the influence of the wheels, soil compaction may occur during some operations, such as mouldboard plough tillage (especially during the subsequent ploughing processes to the same depth) when there is a compaction layer under the bottom of furrows. Soil compaction leads to yield losses, because it prevents crop root systems penetrating through the compacted soil and reaching the water, compaction also has adverse impacts on ecology (Ball et al., 1999; Hůla et al., 2009). There is a decrease in the ability of soil to absorb water and when there is intense rainfall this leads to surface water runoff. For lighter soils there is an increased risk of soil erosion due to runoff (Liebig et al., 1993; Ball et al., 1999). Another consequence of soil compaction is an increase in energy intensity on soil treatment, which adversely affects the germination of subsequent crops (Chamen et al., 1992; Ishaq et al., 2001; Defossez & Richard, 2002; Gelder et al., 2006; Hůla et al., 2009).

Another factor that affects the named values is soil structure and its aeration. In the event that soil is loosened the soil has greater water capacity than non-loosened soil (Kroulik et al., 2007; Qingjie et al., 2009; Ekwue & Harrilal, 2010).

In order to identify and characterise mechanisms and preferential flow of water in the soil, dye tracers are used. The dye tracers can help in tracking and quantifying the transfer of water and the chemicals in the soil (Weiler, 2005), as through monitoring of preferential flow (Alaoui & Goetz, 2008) of water, penetration of harmful substances through the surface of the soil into groundwater may be predicted (Öhrström et al., 2004). Using photographs of soil horizons and an appropriate program to filter the soil component covered and not covered with blue dye the preferential flow of water can be recorded. It is also possible to monitor and characterise the relationship between morphological and physical properties of soils and characterise heterogeneity of water flow in the soil (Morris & Mooney, 2004; Schlather & Huwe, 2005; Wang et al., 2006; Wang et al., 2009). It was found that water reaches deeper layers in structured soils, while in unstructured soils such depths are not reached (Yasuda et al., 2001).

To evaluate soil compaction, measurement of soil bulk density and cone index is usually used. Cone index is the value of soil resistance against penetration of the cone of known angle and dimensions. Cone index has the advantage (over bulk density measurements) of a simple data acquisition from the entire soil profile and this process can be also automated (Raper, 2005).

MATERIALS AND METHODS

Measurements of soil bulk density and water infiltration rate were conducted on the school farm plot of Czech University of Life Sciences in Prague. On this plot is a clay soil type. Climatic area is slightly warm, slightly dry with mostly mild winters. Experiment area is 6.7 ha and modular width of tool is 4 m. Plot was divided into several options: a) controlled traffic farming (CTF) with loosening, b) CTF with deep loosening (DL) before plot establishment, c) ploughing, d) ploughing with DL before plot establishment.

For brilliant blue dye tracing (infiltration) a 0.3% solution of E133 brilliant blue FCF colourant was prepared in water. First, the solution was poured in 10 litres per 1 m^2 of soil surface (which was bordered by a frame) of the soil by watering can with diffuser. The solution was poured gradually and slowly so as to avoid surface runoff and all of the solution was absorbed by 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 soil profile. The photographed area was always bounded by a frame with gauges which allowed subsequent evaluation. Images were then processed by software BMP Tools, which divides the soil background and brilliant blue solution in two different colours. One of the colours represents the brilliant blue solution which shows percentage of infiltrated brilliant blue dye for the known area. In this case the image was divided into several horizontal images (each represented one depth range) and then they were processed by BMP Tools software which calculated the percentage of blue colour on the image. Five tests were conducted for each variant.

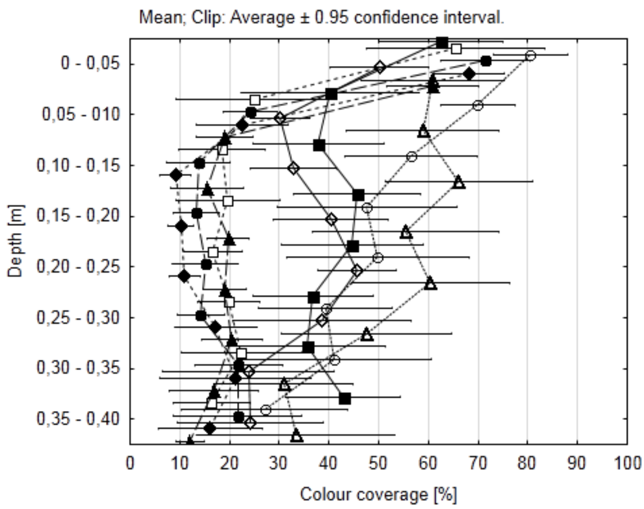
For the cone index measurements a 60° cone angle with an area of 1 cm^2 was used when using penetrometer PN 100. For future details see ASABE standard S313.3 (ASAE Standards, 2004).

STATISTICA 10 with analysis ANOVA was used for statistical evaluation of results. The graph tool showing means and standard deviations was also used in this software. R statistics was used for cone index evaluation.

RESULT AND DISCUSSION

The results obtained based on the brilliant blue dye tracer tests at each depth are shown in:

The Fig. 1 shows that the measured mean values of the coloured surface percentage of non-compacted soils are higher than in the case of compacted (trafficked) soil.



Ploughing, outside of the tracks + DL, Ploughing, inside of the tracks + DL, Ploughing, outside of the tracks, Ploughing, inside of the tracks, CTF, outside of the tracks + DL, CTF, inside of the tracks + DL, CTF, outside of the tracks, CTF, inside of the tracks

Figure 1. Relationship between coloured surface and soil depth.

Tukey´s HSD test of homogenous groups for non-compacted soil is show in in Table 1. From these results it is evident that soil compaction has a significant effect on the number of homogeneous groups in the measured soil horizon. The most variability was showed in the depth from 0 to 0.10 m. At depths in excess of 0.30 m no statistically significant differences were found between options with the exception of ploughing outside of the tracks with DL, which reached significantly higher values of dye coverage.

Table 1. Tukey´s HSD test of homogenous groups for the selected depth of brilliant blue dye tracer measurement

	Depth [m]	0.05–0.10				0.10–0.15			0.20–0.25		0.25–0.30			
Dye coverage	Groups	1	2	3	4	1	2	3	1	2	1	2	3	4
Lowest	CTF, in tracks	**				**			**		**			
	CTF, in tracks + DL	**	**			**			**		**			
	Ploughing, in tracks	**	**			**			**		**	**		
	Ploughing, in tracks + DL	**	**			**			**		**	**	**	
	CTF, out of tracks + DL	**	**				**			**		**	**	**
	Ploughing, out of tracks + DL		**	**			**			**		**	**	**
	CTF, out of tracks			**	**			**		**			**	**
Highest	Ploughing, out of tracks				**			**		**				**

Values of cone index for a CTF variant are shown in Fig. 2. From figure it is possible to identify where the soil was run over and where not.

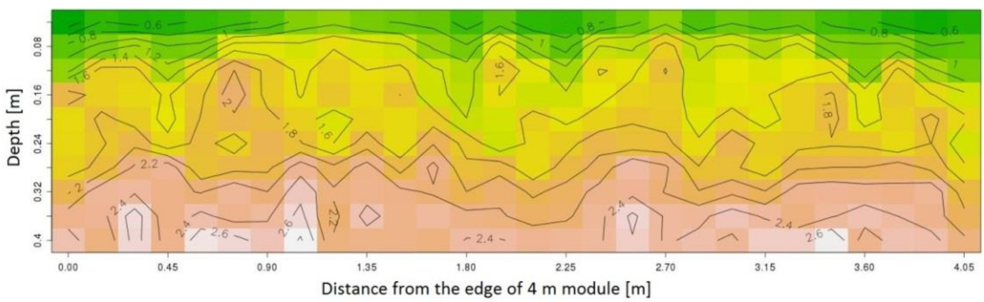


Figure 2. Cone index measurement for CTF variant (values in the figure are given in MPa).

Results of CTF variant with deep loosening (DL) before plot establishment is shown in Fig. 3. The figure shows influence of DL, which is reflected by the reduction of cone index values.

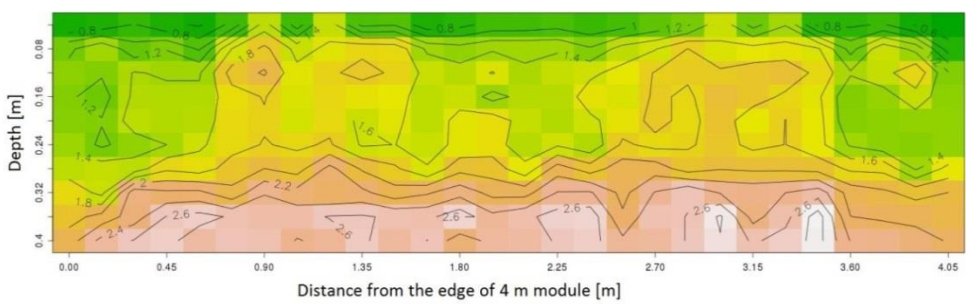


Figure 3. Cone index measurement for CTF with DL variant (values in the figure are given in MPa).

Fig. 4 shows values of cone index where the ploughing was conducted. Ploughing influence and subsequent soil compaction is evident mainly at the depth of 0.08 m.

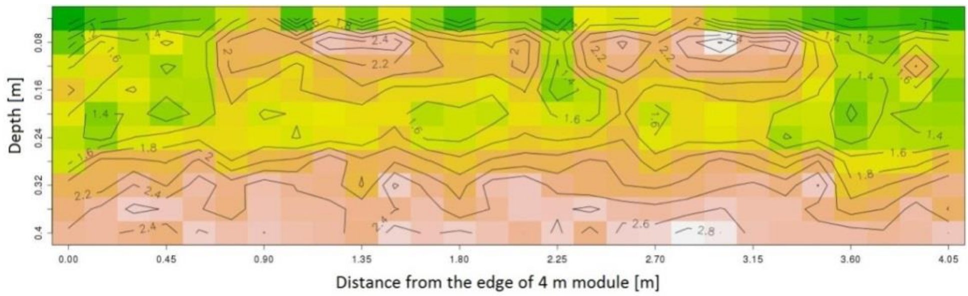


Figure 4. Cone index measurement for ploughing variant (values in the figure are given in MPa).

Final cone index measurement is shown in Fig. 5 where ploughing with DL was performed. As in the case of CTF with DL is a noticeable decrease of cone index values. As well as in the case of ploughing it is apparent that the ploughed and subsequently compacted layer is most noticeable at the depth of 0.08 m.

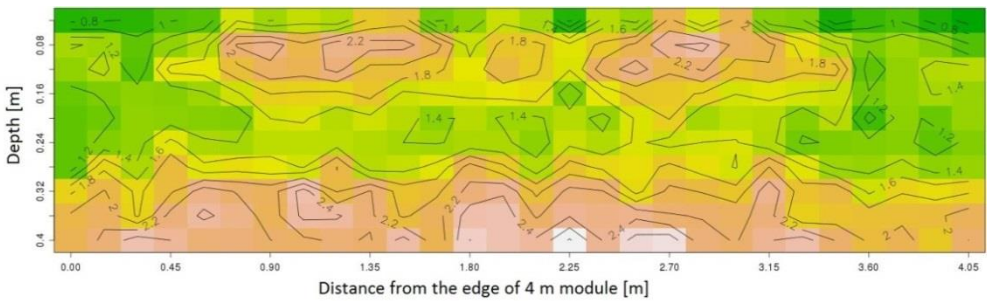


Figure 5. Cone index measurement for ploughing with DL variant (values in the figure are given in MPa).

CONCLUSIONS

As is evident from the above results the infiltration and cone index are influenced by soil cultivation and soil compaction. Mainly on the basis of dye tracer results it is possible to say that the soil compaction is a factor that affects soil more than soil cultivation. Similar conclusion applies to the cone index. When comparing different types of cultivation, there is a discrepancy between the values of dye tracer and cone index method. Dye tracer showed the best results for ploughing and CTF than for ploughing with DL and CTF with DL. Cone index measurement showed that the mentioned variants with DL have better results than variants without DL.

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