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Soil physical characteristics and soil-tillage implement draft assessment for different variants of soil amendments

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Abstract. The article discusses the results of measurement of soil physical properties and implement draft that has been done within field trial established at Slověč in the year 2014. Different variants of treatment with substances for soil (PRP Sol) and manure (PRP Fix) amendment with organic fertilisers of various origins have been examined in terms of their influence on several parameters including energy demand for soil tillage. In the first stage, soil physical properties, i.e. soil bulk density and cone index, were measured. The results indicate that at soil upper layer, cone index of all the trial variants dropped relative to control regardless of the manure origin, manure treatment with PRP Fix, or the application of PRP Sol. Concerning soil bulk density, observed drop in values can be discerned with the application of cattle manure, and with majority of variants using pig manure where there are high dosage rates, but the drop was found also with PRP Sol alone. Subsequently, draft of chosen tillage implements was measured in order to assess potential decrease in energy demand of treated variants. There was almost 3% drop in aggregate unit draft after manure, and soil and manure activators' application compared to the control. The decrease was attained in all variants except three. Two of them were the variants of untreated manure (cattle and poultry origin) application and the third was the variant of poultry manure treated with PRP Fix with additional application of PRP Sol. Here though, the difference was minor only.

Key words: draft, activator of organic matter, manure application, soil properties.

INTRODUCTION

Since 2014, field trials have been carried out in order to verify the influence of application of fermented farmyard manures and substances for soil amendment (activators of organic matter) on the changes of physical, physical-chemical and biological soil characteristics, organic matter fixation, improvement of parameters of infiltration and water retention, decrease of soil erosion risks, and decrease of energy demand for soil tillage.

Soil compaction is one of the soil properties in question. It leads to loss in crop yield, since the compaction prevents plants' root system to penetrate through to deeper soil layers to reach water / nutrients. Soil compaction has also negative impact on the environment (Ball et al., 1999; Chyba et al., 2014) due to the reduced ability of the soil to absorb water. Chyba et al. (2014) verified significantly higher water infiltration rate in the non-compacted soil than in the compacted soil.

Soil compaction primarily affects the physical properties of soil, either in the short or long term. For example at higher soil moisture levels, passes of farm machinery can lead to excessive soil compaction. The results of Vero et al. (2012) indicate that higher soil moisture deficits (SMD) at the time of machinery trafficking resulted in smaller changes to soil characteristics and more rapid recovery from surface deformation than when trafficking occurred at lower SMD. According to the results of Ahmadi & Ghaur (2015), gradual increase in soil water content generally resulted in an increase in soil bulk density after tractor wheeling. The negative effect of soil compaction is manifested through increased bulk density, soil cone index, and other variables. This all leads to reduction in porosity, hydraulic soil properties, stability and other variables (Alakukku, 1996). All these parameters are connected together and influence crop yields. Celik et al. (2010) confirmed organic applications to significantly lower the soil bulk density and penetration resistance.

Effect of the use of substances for soil amendment (activators) on soil properties is a relatively unexplored phenomenon. Impact can be mainly expected on the physical and chemical properties of soil. Kroulík et al. (2011) suggested a beneficial effect of incorporation of organic matter on the physical properties of soil, on water infiltration into the soil and on partial elimination of the consequences of soil compaction beneath the tracks. It can be also assumed that changes in soil properties will be reflected in the long term rather than immediately after application. According to Podhrázská et al. (2012), repeated conventional tillage and application of PRP Sol did not demonstrate any improvement in soil physical properties (density, porosity, soil compaction, reduced water content in soil).

Another factor that influences the variables mentioned is soil structure and soil aeration. If the soil is loosened, water capacity is higher compared to the untilled soil (Ekwue & Harrilal, 2010). Each soil structure has its own typical values of bulk density, porosity, hydraulic characteristics and other variables. For example, sandy-loam soils have higher cumulative infiltration rate than clay-loam soils, the lowest values are observed in turn with clay soils (Ekwue & Harrilal, 2010).

For the evaluation of soil compaction, values of soil density and penetration measurements are commonly used. Penetration measurement is also known as the cone index, i.e. the value of soil resistance against a cone of known dimensions (angle and area). Measurement of cone index has advantages over measurements of density in a simple data acquisition from the entire soil depth (limited by penetrometer depth range), the process of penetration measurements can also be automated (Raper, 2005).

In terms of economy and operation, energy demand of soil tillage is one of the crucial elements. Tillage is the base operation in agricultural systems and its energy consumption represents a considerable portion of the energy consumed in crop production (Larson et al., 1995). McLaughlin et al. (2002), Liang et al. (2013) and Peltre et al. (2015) reported manure amendments to have significant effect on reduction in tillage implement draft. Prolonged application and higher rates brought advanced reduction.

The purpose of this study was to verify any changes in draft required for tillage after several years of treatment with substances for soil amendment and with fermented farmyard manure.

MATERIALS AND METHODS

In 2014, field trials examining effects of substances for soil amendment and fermented manure were established. In 2014, the measurements were done on 2nd October straightway after the barley harvest. Silage maize was grown in the field afterwards, and the measurements were completed on 1st September 2015 after its harvest. The trial field is located near Sloveč in the Central Bohemia (GPS: N 50°14.256', E 15°20.705', altitude: 273 m). The topography is gently sloping, facing southwest. Soil texture in the field is very heavy and the soil is thus difficult to cultivate. The content of clay particles under 0.01 mm is 62% of weight at the depth from 0 to 0.3 m. Some selected soil properties at the beginning of the experiment are presented in Table 1.

Table 1. Selected physical and chemical properties of soil at Sloveč (13th August, 2014)

	Soil depth [m]	
	0.00–0.30	0.30–0.60
clay (< 0.002 mm) [%]	48	60
silt (0.002–0.05 mm) [%]	32	39
very fine sand (0.05–0.10 mm) [%]	2	1
fine sand (0.10–0.25 mm) [%]	18	0
texture (USDA)	clay	clay
bulk density [g cm^{-3}]	1.46	1.48
total porosity [%]	46.15	43.99
volumetric moisture [%]	35.65	40.20
humus content [%]	3.89	1.44
pH (H_2O)	7.50	7.82
pH (KCl)	7.18	7.21
CEC – cation exchange capacity [mmol kg^{-1}]	278	272

The trial plot was a 140 meters wide and 630 meters long rectangle selected to be homogenous and to avoid headland. It was divided crosswise into individual 45 wide and 140 meters long variants where fertilizer application was carried out according to a plan. The plots' spatial distribution had to be simple due to an operational nature of the experiment. The fertilizers used were manures from cattle, pig, and poultry, and NPK 15-15-15 (Lovofert). As the soil activator, PRP Sol (PRP Technologies) was applied during stubble cultivation. PRP Sol is formed by a matrix of calcium and magnesium carbonate, and mineral elements. As the activator of biological transformation of manure, PRP Fix (PRP Technologies) was applied directly into bedding. PRP Fix is a granular mixture of mineral salts and carbonates. Both activators should not be regarded as fertilizers. They are supposed to improve conditions for the transformation of organic matter. Fertilization of individual variants is shown in Table 2. The variants differed by fertilizers used. Dosage of cattle manure was 50 t ha^{-1}, of pig manure 40 t ha^{-1}, of poultry manure 10 t ha^{-1}, of PRP Sol 200 kg ha^{-1}, and of NPK 200 kg ha^{-1}. The field was ploughed afterwards. In spring, seedbed preparation was carried out.

Table 2. Fertilization of individual variants of field trial at Sloveč

Variant	Fertilization
I a	cattle manure with FIX + NPK
II a	cattle manure with FIX + SOL+ NPK
III a	cattle manure+ NPK
IV a	cattle manure + SOL+ NPK
V a	SOL + NPK
VI a	NPK (Control)
I b	pig manure with FIX + NPK
II b	pig manure with FIX + SOL+ NPK
III b	pig manure+ NPK
IV b	pig manure + SOL+ NPK
I c	poultry manure with FIX + NPK
II c	poultry manure with FIX + SOL+ NPK
III c	poultry manure+ NPK
IV c	poultry manure + SOL+ NPK

Selected soil physical properties have been measured in the trial fields. Two basic methods were used. Firstly, undisturbed soil samples were taken using Kopecky's cylinders of a volume of 100 cm^3. Secondly, cone index measuring method was used. The registered penetrometer PEN 70 developed at the CULS Prague was employed. Moisture was measured by Theta Probe (Delta-T Devices Ltd, UK). The draft of selected soil tillage implements was measured by means of the method of drawbar dynamometer with strain gauges S-38 /200 kN/ (LUKAS, the Czech Republic) between two tractors (see Fig. 1). Data acquisition system NI CompactRIO (National Instruments Corporation, USA) was employed, and its sample rate was set at 0.1 s. Several machinery passes were carried out for each variant. Firstly, the tillage implement was working at a set-up working depth and at a constant speed in order to measure the overall draft of the pulled tractor and implement working. The working depth was verified by its measurement for each pass. Secondly, the measurement was done with implement not working in order to measure the rolling resistance and the force induced by potential field gradient. These were deduced from the overall draft in order to calculate the implement draft. Direction of passes, i.e. downhill and uphill, was therefore taken into account. Trimble Business Center 2.70 (Trimble, USA) was used to assign acquired data to individual trial variants. Data were then processed by the programmes MS Excel (Microsoft Corp., USA) and Statistica 12 (Statsoft Inc.,USA). Finally, the measured draft values were compared to the values calculated using ASAE D497.7 standard (ASABE Standards 2011). This standard uses a simplified draft prediction equation:

$$D = F_i \cdot (A + B \cdot S + C \cdot S^2) \cdot W \cdot T \quad [N] \qquad (1)$$

where D is the implement draft force; F_i is a dimensionless soil texture adjustment parameter with different values for fine, medium and coarse textured soils; A, B and C are machine-specific parameters; S is field speed; W is implement width; and T is tillage depth.

Figure 1. Photo of draft measurement of chisel plough Strom Terraland TN 3000 at Sloveč in autumn 2014.

RESULTS AND DISCUSSION

Table 3 shows the overall average values of the basic physical properties of soils. There is a clear difference in volumetric soil moisture between the two years due to exceptionally dry weather over the whole vegetative period of the year 2015. Fig. 2 shows lower precipitation and higher temperatures of the year 2015 compared to the year 2014 during the periods preceding the measurements. This clearly increased the values of cone index which dependants on soil moisture. Illustrative aggregate values at three different depths are presented in the Table 3.

Table 3. The overall averages of soil moisture and bulk density, and operating conditions and overall results of measurement of soil tillage implement drafts at Sloveč in autumn of 2014 and 2015

	Fall 2014	Fall 2015
Soil properties		
vol. moisture at 0.00–0.05 m [%]	35.16	15.24
cone index at 0.08 m [10^6 Pa]	1.124	1.186
cone index at 0.12 m [10^6 Pa]	1.326	1.850
cone index at 0.16 m [10^6 Pa]	1.571	2.500
bulk density at 0.05–0.10 m [g cm^{-3}]	1.763	1.547
red. bulk density at 0.05–0.10 m [g cm^{-3}]	1.367	1.291
Draft measurement		
tractor	NH TG285	JD 9560 RT
engine power [HP]	285	570
implement	chisel plough	tine cultivator
implement type	Strom Terraland TN 3000	Köckerling Vario 480
working width [m]	3	4.8
working depth [m]	0.117	0.080
working speed [$km.hour^{-1}$]	7.81	8.04
overall implement draft [N]	37 594	42 511
ASAE predicted draft [N]	23 929	32 260
unit draft [N m^{-2}]	107 187	110 707

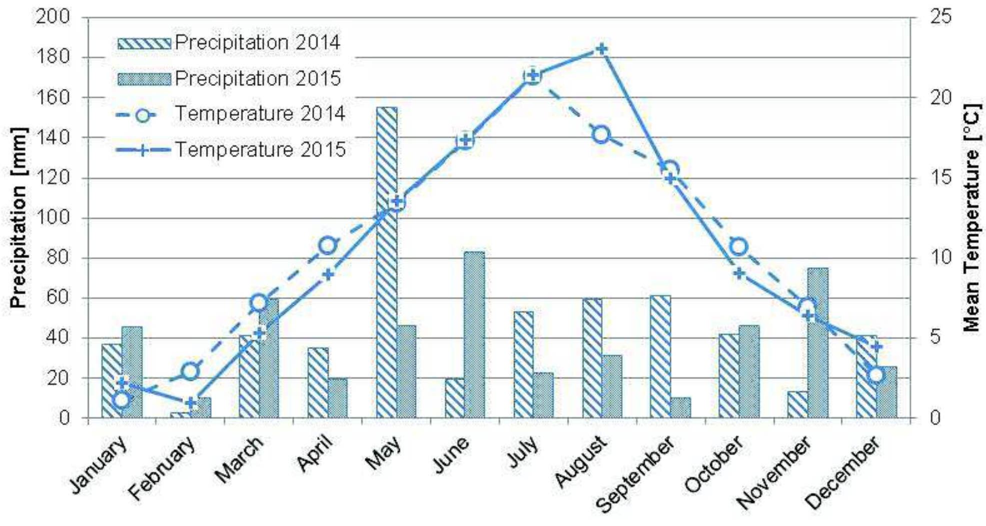

Figure 2. Graph of monthly precipitation and mean temperatures at Slověč in the years 2014 and 2015.

Since the climatic conditions were drastically different in both years, more interesting than the absolute values are the relative differences to the control variant VIa.

Year-on-year changes in relative cone index values at upper soil layer are presented in Fig. 3 and 4. Cone index of all the trial variants dropped relative to control regardless of the manure origin, manure treatment with PRP Fix, or the application of PRP Sol.

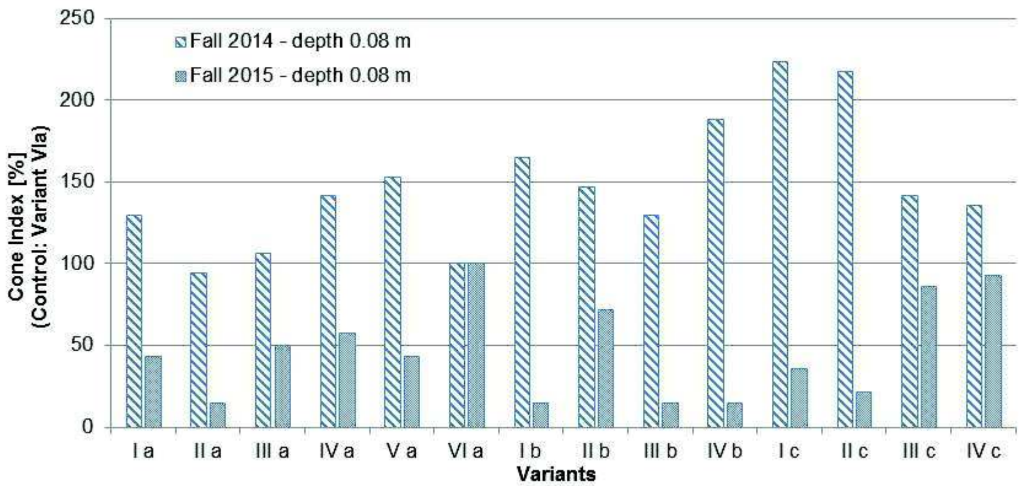

Figure 3. Graph comparing relative differences of soil cone index values at the depth of 0.08 m at Slověč in autumn 2014 and 2015 (Variant VIa – 100%).

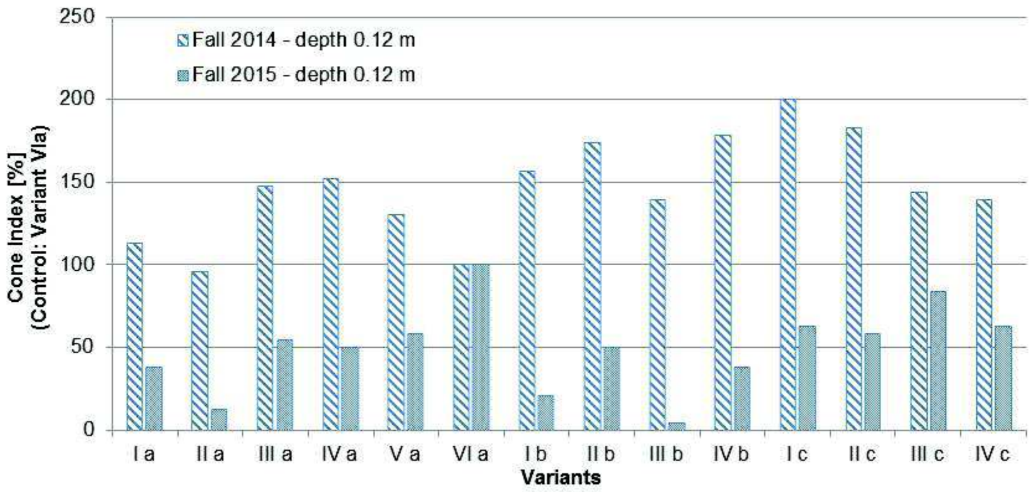

Figure 4. Graph comparing relative differences of soil cone index values at the depth of 0.12 m at Slovеč in autumn 2014 and 2015 (Variant VIa – 100%).

On the other hand, overall soil bulk density values decreased, although moderately only. Fig. 5 demonstrates relative comparison to the control variant. A drop can be discerned with the application of cattle manure, and with majority of variants using pig manure. No major differences can be recognized after the application of poultry manure. Bulk density of these variants had been lower than the control even before the manure application. Lower dosage rate of poultry manure could be another reason.

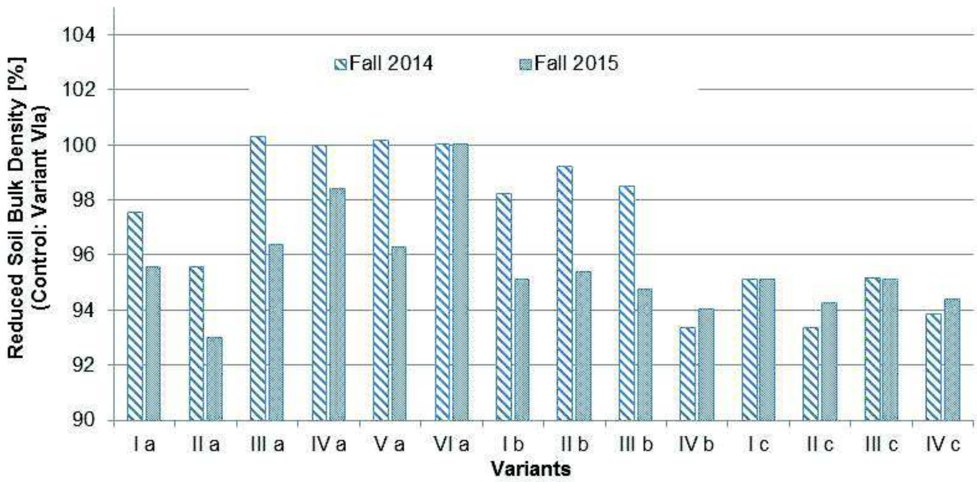

Figure 5. Graph comparing relative differences of reduced soil bulk density at Slovеč in autumn 2014 and 2015 (Variant VIa – 100%).

When measuring draft force (Table 3), two different implements were engaged. Both overall implement draft values were rather high and surpassed predictions (ASAE D497.7 MAR2011 standard) by 33% in the case of the chisel plough, and by 24% in the case of the tine cultivator. Very heavy soil at Sloveč probably falls outside the soil texture adjustment parameter range. Nevertheless, the difference still fits within the ±50% range allowed for by the ASAE standard. Overall implement draft was recalculated to unit draft in order to allow for working width and depth of tillage. Values of unit draft of both implements are rather similar.

Fig. 6 presents aggregate unit draft values compared to the control. Due to the different climatic conditions and soil tillage implements used, absolute values cannot be considered. The ratio of individual measured unit draft values to the average value of the control variant is therefore used for evaluation. There is almost 3% drop in unit draft after manure and soil and manure activators. The difference is statistically highly significant (p = 0.000000000661).

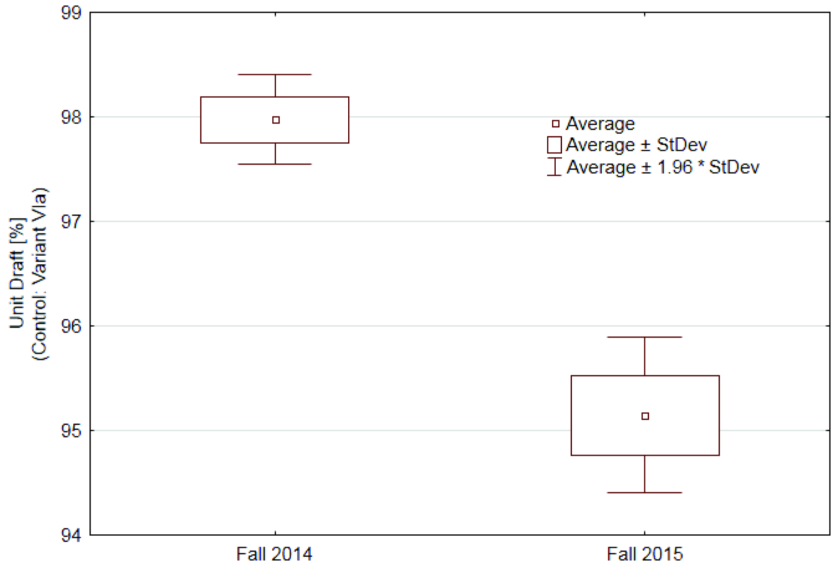

Figure 6. Graph comparing relative differences of implement unit draft related to control at Sloveč in autumn 2014 and 2015 (control variant VIa excluded).

When taking into account relative differences of individual variants (Fig. 7), the decrease was attained in all cases except three. Two of them were the variants of untreated manure (cattle and poultry origin) application and the third was the variant of poultry manure treated with PRP Fix, and with additional application of PRP Sol. Here though, the difference was minor only.

Initial research assumptions were mostly confirmed. As Celik et al. (2010) suggested, cone index values decreased largely compared to the control. With higher application rates of manure, soil bulk density decreased as well. This is consistent with Schjønning et al. (1994) who reported that long term without fertiliser application lead to greater soil strength and soil bulk density than manure or inorganic fertilizer treatments. To date, application of PRP Sol brought improvements as well. Findings of Podhrázská et al. (2012) were thus not confirmed so far.

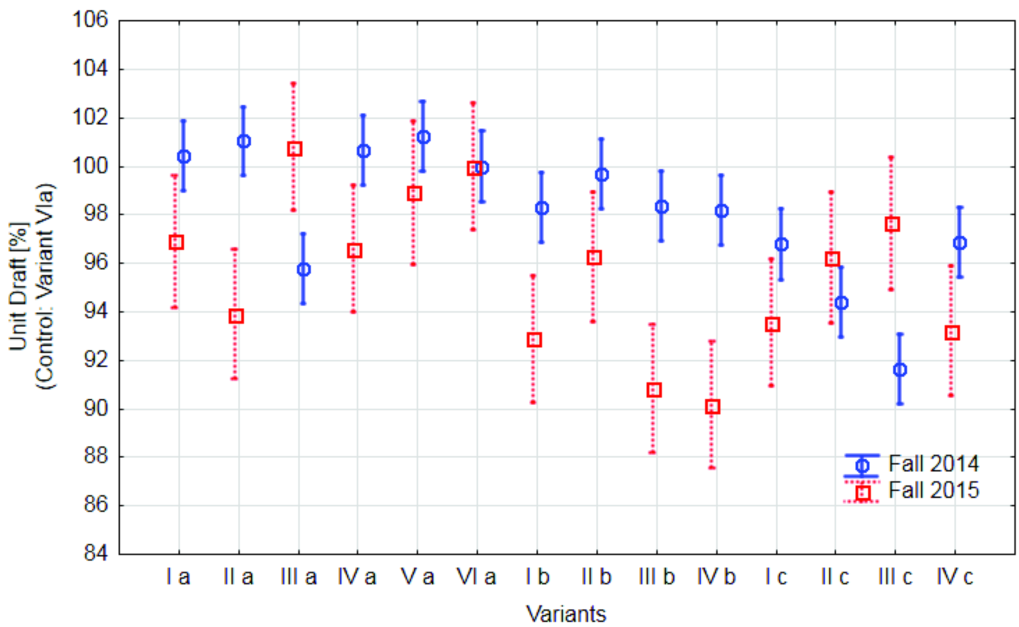

Figure 7. Graph comparing relative differences of implement unit draft with respect to individual variants at Slověč in autumn 2014 and 2015 (Variant VIa – 100%; vertical lines depict 0.95 confidence intervals).

Conclusions of McLaughlin et al. (2002), Liang et al. (2013) and Peltre et al. (2015) on manure application influence on implement draft reduction are consistent with the trial results. The effects of activators of organic matter are among the less explored topics. In connection with changing composition of organic fertilizer (fewer manure and slurry but more compost and waste from biogas plants), the increased importance of activators of organic matter can be expected. Measurements were certainly affected by a short duration of the experiment. It can be assumed that the effect is going to be gradual and the verification should be carried out also in following trial years, when there will be enough data to carry out thorough statistical analysis.

CONCLUSIONS

So far, the work has demonstrated the beneficial effect of substances for soil (PRP Sol) and manure amendment (PRP Fix) and of organic fertilisers of various origins on soil bulk density, cone index and on implement draft force reduction. A longer duration of the experiment would though enable to draw more detailed conclusions. At soil upper layer, cone index of all the trial variants dropped relative to control regardless of the manure origin, manure treatment with PRP Fix, or the application of PRP Sol. Concerning soil bulk density, a drop in values can be discerned with the application of cattle manure, and with majority of variants using pig manure where there are high dosage rates, but the drop was found also with PRP Sol alone.

Subsequently, draft of chosen tillage implements was measured. There was almost 3% drop in aggregate unit draft after manure, and soil and manure activators' application compared to the control. The decrease was attained in all variants except three. Two of them were the variants of untreated manure (cattle and poultry origin) application and the third was the variant of poultry manure treated with PRP Fix with additional application of PRP Sol. Here though, the difference was minor only.

The necessity of long-term examination of the effects of activators of organic matter should be emphasized. Research needs to be validated in more locations in order to eliminate the influence of the local environment.

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REFERENCES

Ahmadi, I. & Ghaur, H. 2015. Effects of soil moisture content and tractor wheeling intensity on traffic-induced soil compaction. *Journal of Central European Agriculture* **16**(4), 489–502.

Alakukku, L. 1996. Persistence of soil compaction due to high axle load traffic. I. Short-term effects on the properties of clay and organic soils. *Soil and Tillage Research* **37**, 211–222.

ASABE Standards 2011. ASAE D497.7 MAR2011, *Agricultural Machinery Management Data*. ASABE, St. Joseph, MI, USA.

Ball, B.C., Parker, J.P & Scott, A. 1999. Soil and residue management effects on cropping conditions and nitrous oxide fluxes under controlled traffic in Scotland. *Soil & Tillage Research* **52**, 191–201.

Celik, I, Gunal, H., Budak, M. & Akpinar, C. 2010. Effects of long-term organic and mineral fertilizers on bulk density and penetration resistance in semi-arid Mediterranean soil conditions. *Geoderma* **160**, 236–263.

Chyba, J., Kroulík, M., Krištof, K., Misiewicz, P. & Chaney, K. 2014. Influence of soil compaction by farm machinery and livestock on water infiltration rate on grassland. *Agronomy Research* **12**, 59–64.

Ekwue, E.I. & Harrilal, A. 2010. Effect of soil type, peat, slope, compaction effort and their interactions on infiltration, runoff and raindrop erosion of some Trinidadian soils. *Biosystems Engineering* **105**, 112–118.

Kroulík, M., Kvíz, Z., Kumhála, F., Hůla, J. & Loch, T. 2011. Procedures of soil farming allowing reduction of compaction. *Precision Agriculture* **12**, 317–333.

Larson, D.L. & Clyma, H.E. 1995. Electro-osmosis effectiveness in reducing tillage draft force and energy forces. *Transactions of ASAE* **38**, 1281–1288.

Liang, A., McLaughlin, N.B., Ma, B.L., Gregorich, E.G., Morrison, M.J., Burtt, S.D., Patterson, B.S. & Evenson, L.I. 2013. Changes in mouldboard plough draught and tractor fuel consumption on continuous corn after 18 years of organic and inorganic N amendments. *Energy* **52**, 89–95.

McLaughlin, N.B., Gregorich, E.G., Dwyer, L.M. & Ma, B.L. 2002. Effect of organic and inorganic soil nitrogen amendments on mouldboard plow draft. *Soil & tillage research* **64**, 211–219.

Peltre, C., Nyord, T., Bruun, S., Jensen, L.S. & Magid, J. 2015. Repeated soil application of organic waste amendments reduces draught force and fuel consumption for soil tillage. *Agriculture, Ecosystems and Environment* **211**, 94–101.

Podhrázská, J., Konečná, J., Kameníčková, I. & Dumbrovský, M. 2012. Survey of the impact of PRP SOL subsidiary substance on the hydrophysical properties of soil at cultivation of sugar beet. *Listy cukrovarnické a řepařské* **128**, 128–133.

Raper, R.L. 2005. Agricultural traffic impacts on soil. *Journal of Terramechanics* **42**, 259–280.

Schjønning, P., Christensen, B.T. & Carstensen, B. 1994. Physical and chemical-properties of a sandy loam receiving animal manure, mineral fertilizer or No fertilizer for 90 years. *European Journal of Soil Science* **45**, 257–268.

Vero, S.E., Antille, D.L., Lalor, S.T.J. & Holden, N.M. 2012. The effect of soil moisture deficit on the susceptibility of soil to compaction as a result of vehicle traffic. In: *American Society of Agricultural and Biological Engineers Annual International Meeting 2012*. Dallas, TX, United States, ASABE 7, 5419–5434.