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The effect of soil conditioner on the spatial variability of soil environment

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Abstract. The aim of the study was to assess and evaluate the effect of soil conditioner on the spatial variability of soil environment. Activator PRP-SOL conditioning soil properties was selected as a field of study. Assessment of soil environment was done through the evaluation of selected soil properties, namely, tensile resistance of the soil and soil infiltration ability. Two dose of PRP-SOL application was done twice in year 2015 (Autumn and Spring) and once in 2016 (Spring) with application rates 150 kg ha^{-1} and 140 kg ha^{-1}, respectively. The area was divided into blocks where stimulators were applied and none treated as a control. The evaluation of recorded values showed that treatability and tillage itself was significantly better on the area which was treated by application of PRP-SOL activators. In addition, tensile resistance was decreased by 5.71% in comparison with non-treated area of experimental field. Since the infiltration ability is among the very important soil properties which have an effect on soil moisture regime as well as surface runoff and therefore soil erosion. The evaluation of recorded values has revealed the effect of treatment by PRP-SOL activators on soil infiltration ability and therefore it results in increases infiltration of precipitation as well. Overall increase of infiltration was recorded at value 2 mm h^{-1}. It can be concluded that application of soil activators may increase the soil conditions and therefore not only conserve soil fertility but even increase it from the long term perspective.

Key words: soil conditioning, activators, PRP-SOL, infiltration, tension resistance, tillage.

INTRODUCTION

Worsening situation in crop production in Slovakia, where quality of agricultural land started to decline rapidly due to impacts of using more and more heavy and complex machinery, gradually forced both professionals and laymen to look for and propose new possibilities of solving of adverse effects and impacts of machinery technique on soil culture, what finally results in low crop yield. Soil compaction is one of the soil properties in question. Strudley et al. (2008) stated that soil tillage practices can affect soil hydraulic properties and processes dynamically in space and time with consequent and coupled effects on chemical movement and plant growth. It leads to loss in crop yield (Ahmadi & Ghaur, 2015), since the compaction prevents plants' root system to penetrate through to deeper soil layers to reach water/nutrients (Šařec & Novák, 2017a and 2017b). 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 (Angulo-

Jaramillo et al., 2000). Chyba et al. (2014) verified significantly higher water infiltration rate in the non-compacted soil than in the compacted soil. Soil compaction, erosion and creation of spell of drought are factors which affect and cause soil degradation to the greatest extent, while they significantly influence its properties (Šařec & Novák, 2017a and 2017b). It for example increases soil bulk density, and thus leads to a reduction of soil water infiltration rate (Chyba et al., 2014). According to Strudley et al. (2008) understanding of soil pore geometry and structure is fundamental to identification of tillage effects on soil physical and hydraulic properties. Kay & Angers (2002) provided standard definitions (e.g., weak to strong soil structure), classifications (e.g., macropores > 75 μm), and a useful discussion of factors affecting soil structure, including texture and mineralogy, organic matter, inorganic materials, pore fluid, microorganisms, soil fauna, plants, climate, and management. The organic matter may be applied in various forms (Šařec & Novák, 2016; 2017a; 2017b). Manure or compost is commonly used, but it is possible to use also other forms (Wang et al., 2015). Especially on heavy and decarburized soils, there is a problem with the decomposition of applied organic matter (Fontaine et al., 2003; Sarec et al., 2017). It remains in the soil without decomposition and does not affect positively other properties of the soil, e.g. the physical and chemical ones (Steinbeiss & Gleixner 2005). On numerous locations, negative effects are underestimated and their interaction causes irreversible damage to soil fertility (Wilhelm et al., 2007). As a result, there is also a decrease in biomass yield of crops and grasslands (Shahzad et al., 2012). Of course, the problem of soil organic carbon loss may be stopped by applying sufficient quantities of organic matter (Johnson et al., 2006). Manure (or other forms of organic matter) can be supplemented by activators of biological transformation (Šařec & Novák, 2016). The use of activators for the decomposition of organic matter was also recommended by Parr et al. (1986). In their case, activators were applied within the composting. Barzegar et al. (2002) confirmed a positive impact of the compost treatment of as well, i.e. increased wheat yields and improved soil physical properties. Soil compaction primarily affects the physical properties of soil, either in the short or long term (Šařec & Novák, 2017a; 2017b). For example at higher soil moisture levels, passes of farm machinery can lead to excessive soil compaction (Kroulík et al., 2009). 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 (Blanco-Canqui et al., 2017). 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 (Indoria et al., 2016). Celik et al. (2010) confirmed organic applications to significantly lower the soil bulk density and penetration resistance.

Currently, the main objective becomes increasing of soil fertility in line with selection of minimization technologies of soil treatment taking into account soil conditions (Peltre et al., 2015). Suitable selection of these technologies combined with their rational application also contributes to disruption of these adverse effects significantly (Šařec & Novák, 2017a and 2017b). Gradual use of obtained knowledge resulted in designing and development of protective measures which effectively not only restrain these adverse effects, but may also have positive impact on soil structure under certain conditions (Kay & Angers, 2002), so they directly affect fertility and expected yields of agricultural crops. Each soil structure has its own typical values of bulk density, porosity, hydraulic characteristics and other variables (Six et al., 1999; Šařec & Novák, 2017a). 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). Liu et al. (2012) confirmed this positive effect in their further study where they showed a beneficial effect on maize growth, soil organic matter content, nutrients levels, and water-storage capacity in sandy soils. The most important thing for the future is to keep up the rising trend in this area and to search for new methods that could successfully eliminate these adverse effects in order to prevent further deterioration of soil environment (Ahmadi et al., 2015). Effect of the use of substances for soil amendment (activators) on soil properties is a relatively unexplored phenomenon (Šařec & Novák, 2017a; 2017b). 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 (Šařec & Novák, 2017a; 2017b). 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). In terms of economy and operation, energy demand of soil tillage is one of the crucial elements (Liang et al., 2013). 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 current pressure and need of increasing soil structure, its conservation and increase of soil fertility leads to increased research efforts and various soil biological activators were developed. According to this efforts it was addressed a field experimental research. The aim of the study was to assess and evaluate the effect of soil conditioner on the spatial variability of soil environment.

MATERIALS AND METHODS

Our research was carried out in 2015 – 2016 on one plot divided to two parts in the selected agricultural farm Agrodružstvo TP, ltd. Palárikovo, which consists of 57 soil units and a structure of soil fund represents 2,420 ha of agricultural land. One part was treated by the material (48.041713, 18.042425) for soil structure treatment and the other part was a control part (48.038541, 18.043567). PRP-SOL material for soil structure treatment was applied to the plot widely. In terms of the objective defined, field experiments were carried out in this selected location and measurements were carried out under operational conditions. A term material for soil structure treatment means activator of soil vital functions PRP SOL. Auxiliary soil materials do not remove consequences, but create favourable conditions for biological life in soil what reflects in lower consumption of used agricultural chemistry. Therefore, PRP SOL is suitable for minimization which supports biological life in the upper part of soil horizon. Infiltrometer (Fig. 1) consists of polycarbonate tube with a diameter of 31 mm and height of 327 mm which is divided into two parts. Both parts are filled with water. Upper part serves for setting of air suction. Water filled in the bottom part infiltrates to soil through semi-permeable stainless steel diaphragm. Suction of air can be set according to soil type. There is a scale in the bottom part of the tube of infiltrometer on which a value of water volume is read in ml after 30 seconds. Measured results are processed by PC. It is important to choose a suitable place for measurement. An important pre-requisite is to make measurement on surface of soil without cracks. After selection of a suitable place, it is important to prepare surface of soil for measurement carefully, because it must be flat and smooth, so the whole diaphragm will be in contact with soil surface (Decagon Devices, 2005). Speed of infiltration v_i is expressed by a ratio of water quantity absorbed through a unit of area of soil surface per a time unit (Velebný et al., 2000).

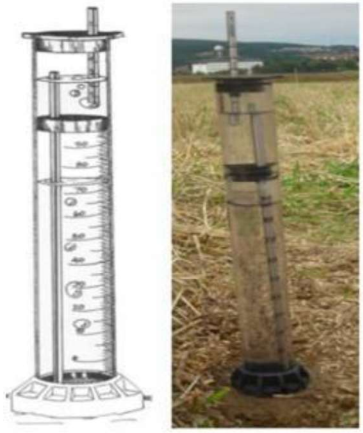

Figure 1. Infiltrometer Mini disc.

$$v_i = \frac{dV}{A \cdot dt}, (\text{mm s}^{-1}) \qquad (1)$$

where dV – elementary volume of infiltrated soil per time unit dt (m^3); A – area through which water volume dV is infiltrated (m^2).

The result is not often expressed by height of water layer infiltrated to soil per time unit (mm s^{-1}). Total amount of water V infiltrated to soil per time Δt through unit of area of soil surface from the beginning infiltration is called cumulative (total) infiltration i (Velebný et al., 2000). Cumulative infiltration per time t can be expressed as follows:

$$i = \frac{V_{(t)}}{A}, (\text{mm s}^{-1}) \qquad (2)$$

where $V_{(t)}$ – water volume (m^3); A – area through which water volume dV is infiltrated (m^2).

Tension force was measured during ploughing by 5-mouldboard plough to the depth of 22 cm by a tensometric apparatus in two parts of the plot, while one part was treated by a material and the other part was a control. In technical practice, tensometric measurements present effective method for detection of actual operating tensions. In addition, tensometric apparatus is also widely used in design of sensors of force, pressure, torque, etc. A set for measurement of tension resistance contained measuring instruments and devices (Tractor John Deere 8300, fifth-wheel plough 5PHX 35 and measuring system Hottinger Baldwin Messtechnik Spider-8). Measurements were performed on the plot - both on treated part and control part. The apparatus records values of tension force in N in intervals of 0.2 seconds. Results were recorded during the same time of run in two repetitions with identical plough setting. HBM Spider 8 (Fig. 2) actuating device meets requirements of operating systems with the aim to ensure transfer of data and its operational accuracy. In case of trailing ploughs, dynamometer (tensometer) is located between a tractor and plough. Force measured on dynamometer directly corresponds to tension force *FT = FX (N)*.

Figure 2. Mechanical part of a measurement apparatus used for measuring of a tension force.

RESULTS AND DISCUSSION

The measurements were conducted on field trial held in Agrodružstvo TP, ltd, Palárikovo. The field conditions were characterised as mostly flat relief with maximum elevation difference 1.1 m. The field has significant soil heterogeneity with a very good production potential and fertility. Majority of the field is formed by Chernozem and it is considered as heavy or very heavy soils. The measurements were conducted in years 2015–2016. Fig. 3 shows the climatic condition during the seasons of observation. As it is indicated at Fig. 3 the climatic conditions during the vegetation period was relatively stable and warm, however in case of precipitation year 2015 was significantly drier that year 2016 where the volume of precipitations were recorded significantly lower. Indoria et al. (2016) reviewed how the different management technologies like integrated nutrient management, tillage practices, mulching, addition of clay, surface compaction, conservation tillage, use of polymers, etc. can favourably modify the soil physical properties like bulk density, porosity, aeration, soil moisture, soil aggregation, water retention and transmission properties, and soil processes like evaporation, infiltration, run-off and soil loss for better crop growth and yield. Moreover, it was suggested that if appropriate soil management technologies are adopted in rained areas for the improvement of soil physical health, the productivity of rained crops can be significantly improved (Indoria et al., 2016).

During the first year of measurements the soil analysis was performed in order to define starting conditions of experiments and subsequent comparison of soil profile structure (Fig. 4). In the analysis of soil structure the soil clods diameters and distributions was considered according to Shaojie et al. (2016). The samples were collected from two horizons in depths from 0.00–0.15 and 0.15–0.30 m in three replications. Every structural fraction was weighted individually and the percentages were calculated subsequently. For evaluation was introduced and calculated the coefficient of soil structure which characterise the relation between valuable from point of agronomical view (0.25–10 mm) and less valuable structural elements (> 10 and < 0.25 mm) shown in Table 1.

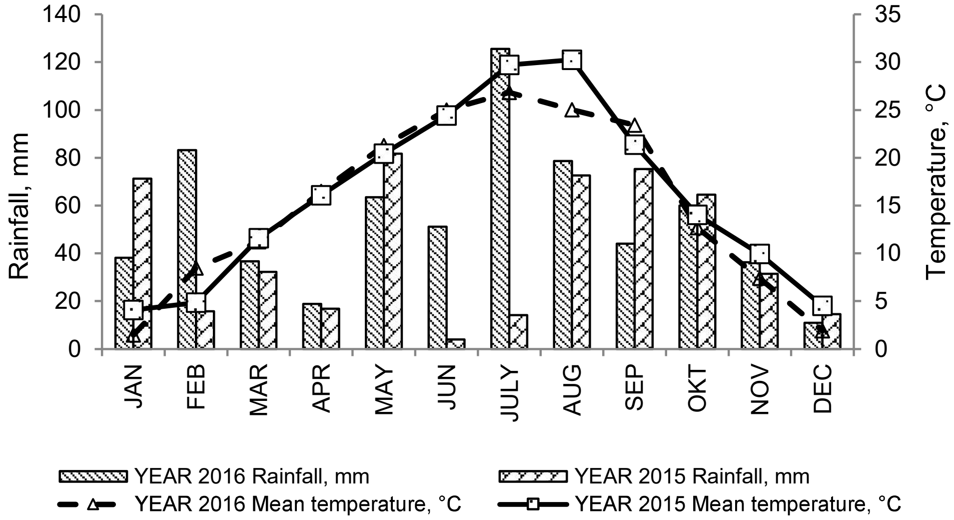

Figure 3. Rainfall represented monthly as sum of precipitations and temperature records for Palárikovo, Slovakia.

Figure 4. Example of comparison of soil profiles (Control and PRP Sol) from year 2015.

Table 1. Comparison of structural elements – in Palárikovo, autumn 2015

Variant	Depth, m	Structural elements, %						Coefficient of structure
		> 10	5–10	2–5	0.5–2	0.25–0.5	< 0.25	
Control	0.00–0.15	38.22	20.22	16.98	15.95	1.69	5.32	1.32
	0.15–0.30	42.54	25.63	17.81	11.31	1.32	2.41	1.23
	Average	**40.38**	**22.92**	**17.40**	**13.63**	**1.50**	**3.86**	**1.27**
PRP SOL	0.00–0.15	24.75	30.70	22.53	17.50	1.62	3.90	2.60
	0.15–0.30	30.51	34.21	13.95	17.90	0.85	2.40	2.80
	Average	**27.63**	**32.45**	**18.24**	**17.70**	**1.23**	**2.56**	**2.34**

From the observed values it can be concluded that the soil conditioner PRP Sol has a positive effect on soil properties and arability and can positively affect the compaction of arable horizon down to 0.30 m. The greatest differences in case of soil structural analyses were observed at soil structural elements above 10 mm where in case of PRP Sol conditioner was calculated value 27.63% in comparison with control part at 40.38% which means the difference 12.75% in average. In case of smaller soil structural elements from 0.25 to 0.5 mm the differences in both parts of experimental areas were only small and not significant. Similar observation was obtained also in case of soil structural elements below 0.25 mm. In the case of utilization of biostimulators also biochar is considered as an alternative. For example, Blanco-Canqui (2017) has reported that biochar generally reduces soil bulk density by 3 to 31%, increases porosity by 14 to 64%, and has limited or no effects on penetration resistance. Biochar increases wet aggregate stability by 3 to 226%, improves soil consistency, and has mixed effects on dry soil aggregate stability. It increases available water by 4 to 130%. Further study shows that saturated hydraulic conductivity decreases in coarse-textured soils, and increases in fine-textured soils following biochar application (Blanco-Canqui, 2017). In addition, Sajjadi et al. (2016) investigated the relations between infiltration rate and soil texture, moisture and compaction and it was shown the effect of soil properties and their relations on infiltration rate by using non-linear regression.

Later on in our study the selected physical properties of soil were observed and are shown in Table 2.

Table 2. Selected physical properties of the soil

Variant	Depth of soil, m	Density red., g cm^3	Porosity, %	Current content		Max. capillary capacity	Min. air capacity
				Water	Air	% volume	
				% volume			
Control	0.0–0.1	1.27	51.77	10.66	40.87	37.56	14.77
	0.1–0.2	1.45	44.28	21.50	23.21	35.21	8.95
	0.2–0.3	1.51	40.75	24.92	14.99	35.12	5.90
	Average	**1.41**	**45.60**	**19.02**	**26.35**	**35.96**	**9.87**
PRP SOL	0.0–0.1	1.29	51.30	18.59	31.67	38.85	10.99
	0.1–0.2	1.55	43.95	25.21	18.98	34.61	8.10
	0.2–0.3	1.41	45.90	22.42	24.25	37.10	9.69
	Average	**1.42**	**47.05**	**22.07**	**24.96**	**36.85**	**9.59**

Measurements focused on comparison of speed of infiltration of water into soil. The plot area was 21 ha with 10 monitoring points where each monitoring point was calculated from ten repetitions. Volume of infiltrated water was measured in both parts of the plot, it means the part treated by PRP SOL material (48.041713, 18.042425) and control part (48.038541, 18.043567), and in ten repetitions during the same time period in the depth of 10 cm. Values of soil humidity were also measured in the control soil probes in 10 cm intervals. A measurement of volume soil humidity in surface zone to 10 cm was carried out in five repetitions for control.

Table 3 shows the statistical comparison of observed values for cumulative soil infiltration rate between untreated and treated part of the field experimental area by soil conditioner PRP Sol.

Table 3. Descriptive statistics of cumulative infiltration

Variant	Average	Max.	Median	Min.	Percentile 25	Percentile 75	Standard deviation
Control	0.14	0.23	0.15	0.03	0.10	0.19	0.06
PRP SOL	0.18	0.26	0.18	0.06	0.13	0.23	0.07

Result of measurements was a difference in average percentage of soil humidity content in the part of the plot treated by PRP SOL material with a value of 37.7% compared to the value of 39.4% in control part. Easy to say, water in treated area moved downwards vertically to lower zones of soil profile during the same time from the last rain more quickly. Speed of infiltration set according to retention curves and their trend lines from average measured values is graphically displayed in the Fig. 5.

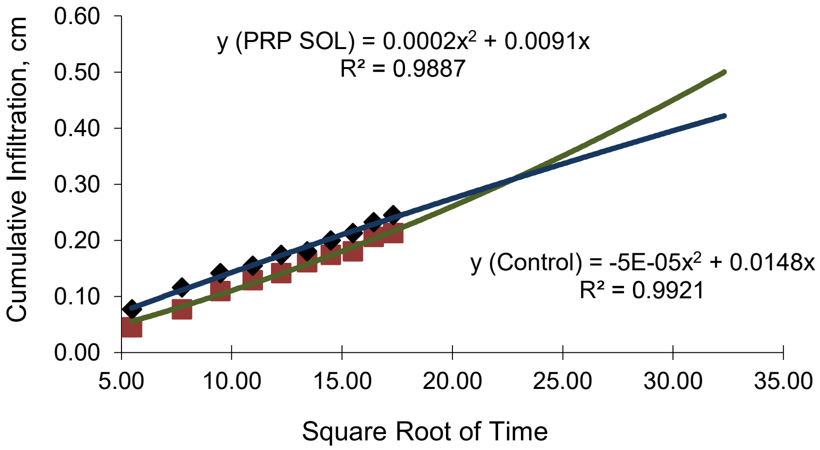

Figure 5. Speed of infiltration.

Blanco-Canqui et al. (2017) has reported that tillage treatments affected pounded infiltration only. Mouldboard plough significantly increased pounded infiltration rate by 21.6 cm h^{-1} at 5 min and by 8.8 cm h^{-1} at 60 min compared with no-till. However, when compared with disk and chisel, mouldboard plough increased pounded infiltration rates at all measurements times, which lasted 3 h. Regarding cumulative infiltration, mouldboard plough increased cumulative infiltration by 26.9 cm to 39.0 cm after 3 h compared with other tillage systems. Similarities in tension infiltration suggest that the higher pounded infiltration for mouldboard plough was most likely due to the presence of voids or fractures (> 125 µm) created by full inversion tillage. Total porosity, saturated hydraulic conductivity, and water retention among the treatments did not differ (Blanco-Canqui et al., 2017). In these relations, tillage affects the infiltration speed in soil levels and application of soil activators may also positively affects the speed of infiltrations as well.

It was also concluded by Šařec & Žemličková (2016) that 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. Moreover, Strudley et al. (2008) concluded that differences in temporal variability depend on spatial locations between rows, within fields at different landscape positions, and between sites with different climates and dominant soil types. Most tillage practices have pronounced effects on soil hydraulic properties immediately following tillage application, but these effects can diminish rapidly. Long-term effects on the order of a decade or more can appear less pronounced and are sometimes impossible to distinguish from natural and unaccounted management-induced variability (Golchin et al., 1994).

Set values of retention curves and their trend lines point to the fact confirming a difference of soil humidity measurement in surface zone of soil profile that rain water in the surface treated by PRP SOL material was infiltrated more quickly. Difference in speed of infiltration to the depth after treatment by PRP SOL material was 2 mm per 1 hour. Sarec et al. (2017) observed the favourable effect of soil activators on the bulk density and other physical soil properties during the measurement of the physical properties of soil. Vegetation indices were another consideration for rating. They suggest a beneficial effect of application of bio-activators. The following values were measured by tensometer force sensors which recorded value (Table 4) of tension force and a measurement unit Hottinger Baldwin Messtechnik Spider-8. During driving of machinery, total measured tension force stopped on the value of 83,735 N in the plot which was used as a control part (Fig. 6). We measured lower values on the treated plot. Maximum tension force measured while driving on the plot treated by the material was 78,911 N (Fig. 7). Also Šařec & Žemličková (2016) 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.

Table 4. Descriptive statistics of tension force

Variant	Average	Max.	Median	Min.	Percentil 25	Percentil 75	Standard deviation
Control	64.03	83.73	66.25	-5.94	63.11	68.84	12.55
PRP SOL	54.89	78.91	56.19	-0.40	50.88	62.10	13.10

In addition, Šařec & Novák (2017b) concluded that the impact of the manure and the activators on the value of saturated hydraulic conductivity is difficult to precisely define. One of the factors may be the duration of the experiment. Another, probably more relevant, is the soil texture of the trial field. All the variants treated with manure demonstrated increase of saturated hydraulic conductivity, namely with PRP Sol applied as well. Moreover, Bagarello et al. (2006) reported that difficulties of measuring saturated hydraulic conductivity on light soils were found. At high levels of conductivity, the effects of soil tillage, fertilization or the influence of cultivated crops cannot be clearly demonstrated. In accordance with authors' assumptions, Celik et al. (2010) confirmed organic applications to significantly lower the soil bulk density and penetration resistance. However, the assumption was not verified by the results so far. Beneficial effect of activated organic matter on soil properties and on production potential was confirmed by Barzegar et al. (2002). Bernal et al. (1998) pointed to the gradualness of changes in the soil and to the need for long-term exposure to carbon fixation and microbial activity.

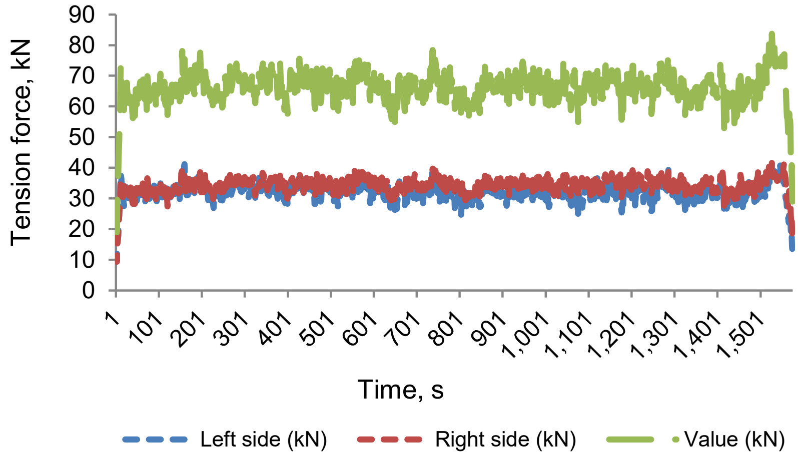

Figure 6. Record about measurement of tension force during ploughing in the control part (maximum generated force is 83.7 kN).

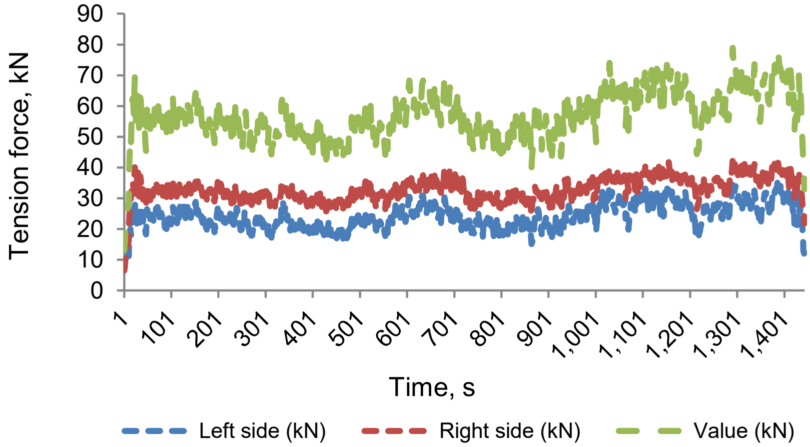

Figure 7. Record about measurement of tension force during ploughing on the plot after application of the material (maximum generated force: 78.9 kN).

By comparison of measured and calculated values of tension force caused by tools used in the soil and total need of work it was proven that degree of workability of soil is significantly better on the plot treated by the material than in the control part. Simple analysis of these results confirm a fact that improved function of biological activity and so structure of soil caused decrease of tension force for 5.71% compared to untreated plot (Table 4). According to Strudley et al. (2008) development of soil structure and aggregation are dynamic properties that depend upon soil parent material in addition to climate and management factors. Shrink/swell clays may play an important role in both the natural variability of soil structure and potential responses of soil hydraulic properties to management practices (Horn et al., 1994; McGarry et al., 2000). Changes in soil pore structure in swelling clays have been evidenced in studies of gas and water flow (Angulo-Jaramillo et al., 2000; Horn & Smucker, 2005) and solute transport (Bouma & Woesten, 1979). Swelling clays may also account for some reversal of soil disturbances, such as self-healing of cracks (Eigenbrod, 2003; McDonald et al., 2006) and re-formation of surface cracks upon drying (Radford et al., 2000). Smiles (1995; 2000) provided reviews of the physics of swelling soils, noted here for general reference. Moreover, as Strudley et al. (2008) pointed out, Smiles (2000) has never been cited before, which points to the lack of active advances in this area, with the exception of the few studies cited here on interactions of tillage with the shrink/swell behaviour of soils.

CONCLUSIONS

Tension force measurements were performed during ploughing by 5-mouldboard plough 5PHX 35 to the depth of 22 cm. The experiment itself was carried out in both parts of the plot, namely in the part treated by material and control part. The value of tension force was recorded by tensometer sensors and data were recorded by a measurement unit Hottinger Baldwin Messtechnik Spider-8. During driving of machinery, total measured tension force was 83,735 N in the plot which was used as a control part. We measured lower values on the treated plot. Maximum tension force measured while driving on the plot treated by the material was 78,911 N.

By comparison of measured values of tension force caused by tools used in the soil and total need of work it was proven that degree of workability of soil is significantly better on the plot treated by the material than in the control part. Simple analysis of these results confirms a fact that improved function of biological activity and so structure of soil caused decrease of tension force for 5.71% compared to untreated plot.

Infiltration of soil can be measured by several methods. One of the fastest and simplest methods is measurement by Minidisk infiltrometer. We can state that by using of infiltrometer we found out that speed of infiltration depends on compactness of soil, where some layers of soil infiltrate water faster, and parts of soil with compacted layer infiltrate water more slowly.

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