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Influence of manure and activators of organic matter biological transformation on selected soil physical properties of *Modal Luvisol*

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Abstract. Agricultural land in the Czech Republic threatened by a combination of water erosion, technogenic compaction and low level of soil carbon. The low levels of carbon in the soil interrelate also with the other threats mentioned. Application of organic matter into soil is one of the ways how to rectify this unfavourable condition. All of its forms can be supplemented by biological transformation's activators. The aim of this paper was to verify the effect of organic fertilizer with a conditioning activator added, i.e. manure from deep-litter housing of dairy cows with PRP Fix added, and the effect of an activator conditioning soil, i.e. PRP Sol, on the change of soil physical properties, i.e soil bulk density, infiltration ability, cone index. In this respect, field trial was established at locality Lázně Bělohrad. Soil infiltration capabilities were measured using a ring infiltrometer with a diameter of 0.15 meters. Cone index was another measured item provided by the registration penetrometer. Bulk densities of each trial variant were evaluated using Kopecky's cylinder. Concerning saturated hydraulic conductivity, all the variants treated with manure demonstrated its increase, namely with soil activators applied as well. Favourable effect on soil bulk density values could have been also observed. The change was often below the level of statistical significance. This could have been caused by a short only time of activator's activity. It can be assumed that the effect is going to be gradual and the verification should be carried out also in following trial years.

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

INTRODUCTION

Intensively cultivated land is permanently threatened by a loss of fertility. This is mainly due to the degradation of soil by erosion, compaction and reduction in levels of soil carbon. For the sustainability of agriculture, it is important that the level of soil carbon is maintained or increased (Smith, 2004). Decrease in levels of soil carbon is thus undisputed cause of soil degradation. The soil degradation affects soil physical properties. It for example increases soil bulk density, and thus leads to a reduction of soil water infiltration rate (Chyba et al., 2014). Decarbonised soil also loses its ability of infiltration and water retention in the soil profile (Wuest et al., 2005). The above mentioned risks have been emphasised by recent development.

Decarbonisation can be corrected by an application of organic matter to the soil (Six et al., 2000). The organic matter has usually a form of manure or compost. But its decomposition in soils with low levels of soil organic carbon may constitute a problem (Ames et al., 1984). This problem can be reduced with the help of activators of organic matter, e.g. substances added either to bedding, fresh dung, compost, slurry etc., or with the help of soil activators, i.e. substances applied directly to soil. These activators have several forms, i.e. a character of inoculant or of mineral elements. Biochar also is considered as a soil amendment that increases carbon sequestration and soil fertility (Mukherjee & Zimmerman, 2013). In general, studies of activators are often focused on the impact on soil properties and crop yields. The primary mechanism for these effects and the possible environmental consequences, such as organic contaminant or nutrient releases, are often unclear. Garcıa-Gil et al. (2000) reported a beneficial effect of biological activators contained in compost on organic carbon content in the soil, and also an increase in microbial activity in the soil. Subsequently, this increase improved the decomposition of the added organic matter in the soil. Liu et al. (2012) also 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. Pasda et al. (2005) used activators of organic matter for the decomposition of wood chips and rice husk.

The aim of this study was to verify the effect of manure from deep-litter housing of dairy cows, of activator of organic matter PRP Fix and of soil activator PRP Sol on the change of soil physical properties, i.e soil bulk density, infiltration ability and cone index. In this respect, field trial was established at locality Lázně Bělohrad in the year 2014. In the first place, a change in the physical properties of soil was a prerequisite here. The assumption was that an increased infiltration and decreased soil density and cone index should be observed.

MATERIALS AND METHODS

Field trial was established to demonstrate the influence of organic matter and its activators on soil physical parameters. It was located near Lázně Bělohrad in North Bohemia Region (GPS N 50°27.253', E 15°34.208') and started in 2014 after the wheat harvest. The topography of the experimental field was gently sloping, facing southwest, with the altitude of 410 m. Soil type on the location Lázně Bělohrad was *Modal Luvisol*. Soil texture in the field was silt loam. The content of particles under 0.01 mm was 30% of weight (depth 0–0.3 m). Some selected soil properties at the beginning of the experiment are presented in Table 1.

The trial consisted of 6 variants. The trial plot was a 180 meters wide and 400 meters long rectangle selected to be homogenous and to avoid headland. It was divided lengthwise into six individual 30 wide and 400 meters long variants. The plots' spatial distribution had to be simple due to an operational nature of the experiment.

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

	Soil depth (m)	
	0.00–0.30	0.30–0.60
Clay (< 0.002 mm) (%)	15	21
Silt (0.002–0.05 mm) (%)	66	67
Very fine sand (0.05–0.10 mm) (%)	3	1
Fine sand (0.10–0.25 mm) (%)	16	11
Texture (USDA)	silt loam	silt loam
Bulk density (g cm^{-3})	1.56	1.52
Total porosity (%)	41.97	42.64
Volumetric moisture (%)	31.50	23.70
Humus content (%)	1.81	0.58
pH (H_2O)	6.26	6.23
pH (KCl)	4.99	5.09
CEC – cation exchange capacity (mmol kg^{-1})	110	120

The variants differed by fertilizers and activators used (Table 2). The fertilizers used were manure from deep-litter housing of dairy cows and NPK 15-15-15 (Lovofert). The manure was applied at the rate of 50 t ha^{-1} only in the autumn of 2014, and NPK at the rate of 200 kg ha^{-1} each production year.

Table 2. Fertilization of individual variants of field trial at Lázně Bělohrad

Variant	Fertilization
1	Manure with PRP Fix + NPK
2	Manure with PRP Fix + PRP Sol + NPK
3	Manure + NPK
4	Manure + PRP Sol + NPK
5	PRP Sol + NPK
6	NPK – control variant

As the biological transformation's activator of soil, PRP sol (PRP Technologies) was applied at the rate of 200 kg ha^{-1} using a common fertilizer spreader each autumn. It is a granulate containing 32% of CaO and 8% of MgO, which means that it is a calcium fertilizer with magnesium added, and also containing 3.5% of sodium (Na) and 3–5% of prefixes with 48 trace elements that should boosts the biological activity of the soil by stimulating soil microflora and enzyme activity. It can be used for all crops grown in the conventional and organic farming system, where the annual doses range between 150–300 kg ha^{-1}.

PRP Fix (PRP Technologies) served as the activator of the biological transformation of manure. It is a pellet formed by a matrix of calcium and magnesium carbonate with an active mixture of specific mineral salts that should help to control fermentation in solid or liquid organic substances. There were two cowsheds with loose box and deep litter housing, each containing 60 livestock units (1 LU = 500 kg) of dairy cows. In the first cowshed, the removal of fresh dung was done in 3–4 week intervals according to the condition of bedding, and spreading of straw 3 times a week. In the second cowshed with PRP Fix used, the removal of fresh dung was done 6–8 week intervals according to the condition of bedding, and spreading of straw and PRP Fix application 3 times a week. Weekly dose of PRP Fix was set at 0.7 kg per one livestock unit with respect to body weight of cows. After the removal from cowsheds and prior to the application in the experimental field, the manure stayed in separate dung hills for approximately two month. The samples of stall dung or manure were taken continuously two times a month from the cowsheds and once a month from the dung hills. At five locations in each cowshed, temperature of bedding and emissions of NH_3 at 0.25 m above the bedding surface were measured for the period of one hour every time the above mentioned samples were taken. Table 3 shows the results of chemical analysis and averages of ammonia emissions and maximum bedding temperatures.

Table 3. Averages of chemical analysis of manure samples treated with PRP Fix and of control manure samples with no activator added, and averages of ammonia emissions and maximum bedding temperatures (8/2014–11/2016)

	PRP Fix	Control	Index	P
No of samples	120	125	–	–
Dry matter [%]	23.6	23.1	–	–
N total [kg t^{-1}]	6.90	5.63	1.23	0.0294
$N\text{-}NH_4^+$ [%]	0.43	0.32	1.34	–
P_2O_5 [kg t^{-1}]	4.10	3.70	1.42	0.0563
K_2O [kg t^{-1}]	8.10	6.90	1.17	0.0479
C : N	18.1:1	22.3:1	0.82	–
NH_3 [ppm]	15.20	23.38	0.65	0.0223
T max [°C]	27.00–29.00	43.00–46.00	–	–

During the autumn of 2014, fertilizer application was carried out according to the plan (Table 2) and autumn ploughing to a depth of 0.25 m was implemented. The soil was prepared by a seedbed combinator during the spring 2015. Maize was sown on all variants in the production year 2014/15. After germination of maize in May 2015, measurements were done after growth stage of plants BBCH 10, i.e. after first true leaf had emerged. Ploughing was done after the maize harvest in October 2015. In the March 2016, spring barley was sown in the trial field. Measurements were carried out again after the growth stage BBCH 10. There were three basic methods of measurements. Soil infiltration abilities were measured using a ring infiltrometer with a diameter of 0.15 m. The method used was simplified falling-head (Bagarello et al., 2004). Bagarello et al. (2006) converts infiltration into saturated hydraulic conductivity. A known amount of water was poured into an infiltrometer, and soak time was measured (20 repetitions for each variant).

Cone index was another measured item provided by the registration penetrometer PN-10 with a cone having an angle of 30° (area of 100 mm^2), with a depth range from 0.04 to 0.72 m, and with a maximum of 7 MPa. Soil bulk density was measured at three different depths, i.e. 0.05–0.1 m, 0.1–0.15 m, and 0.15–0.2 m, by taking undisturbed soil samples using Kopecky's cylinders of 100 cm^3 that were subsequently analysed in the laboratories of the CULS Prague. Volumetric soil moisture was measured by Theta Probe (Delta Devices). Data were processed by the programmes MS Excel (Microsoft Corp., USA) and Statistica 12 (Statsoft Inc.,USA). Concerning statistical evaluation, a single factor analysis of variance at the probability level of 0.05 was used with a post hoc *Tukey HSD* test.

RESULTS AND DISCUSSION

This paper contains the results of measurements from the seasons 2015 and 2016. Fig. 1 shows weather development in the years 2014–2016 and a ten-year average. Generally, the winters were warmer than the ten-year average. Particularly in the year 2015, the weather was exceptionally dry over the whole vegetative period.

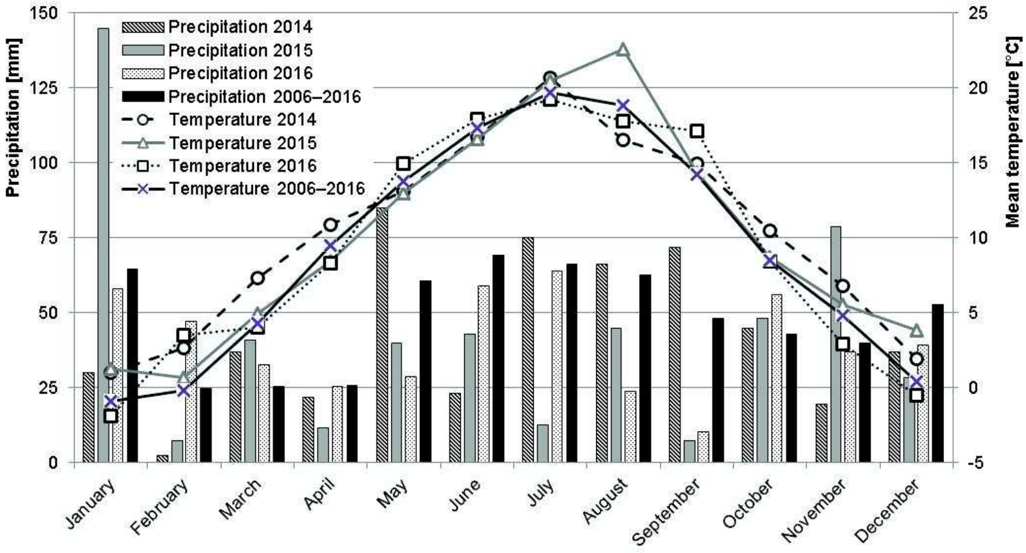

Figure 1. Graph of monthly precipitation and mean temperatures at Lázně Bělohrad in the years 2014–2016 and ten-year averages.

Fig. 2 displays results of saturated hydraulic conductivity measurements. There are noticeable differences among the variants, particularly in the year 2015. These were however lower than the initial prediction, where a statistically significant increase had been expected within the variants with PRP Fix treatment, i.e. Variants 1 and 2. The short exposure of activators and applied manure was probably the cause why it was not possible to clearly demonstrate a beneficial effect of activators on saturated hydraulic conductivity after the first year. Even favourable impact of manure application on this parameter could not be proven clearly. Results of *Tukey HSD* test ($\alpha = 0.05$) showed a statistically significant difference only between the variants 4 and 5 in the season 2015.

In the season 2016, advanced effect was discernible with regard to the measurement of saturated hydraulic conductivity. In comparison with the previous year, increased values, in particular for Variants 1, 2 and 4, were noticeable. The hydraulic conductivity of the control (Variant 6) remained unchanged though. This suggested a beneficial effect of application of organic matter and the activators. Results of *Tukey HSD* test ($\alpha = 0.05$) showed a statistically significant difference only within Variant 4. This extreme increase in the values of Variant 4 could have been caused by an undistributed and slowly (without PRP Fix) decomposing macro-particles of manure, as was observed on site. Macro-particles could significantly increase water infiltration into the soil (Kvítek &

Tippl, 2005). This, however, was not confirmed by Variant 3. All the variants treated by PRP Sol demonstrated an increase in saturated hydraulic conductivity, namely with manure applied as well. Generally, saturated hydraulic conductivity in all variants reached very high levels (Janeček, 2005). Light-textured soil of the trial plot was probably the cause. Subsoil beneath the topsoil drained water quickly into the lower layers, which is typical for light soils (Janeček, 2005). Results of *Tukey HSD* test ($\alpha = 0.05$) did not prove any statistically significant difference in the season 2016.

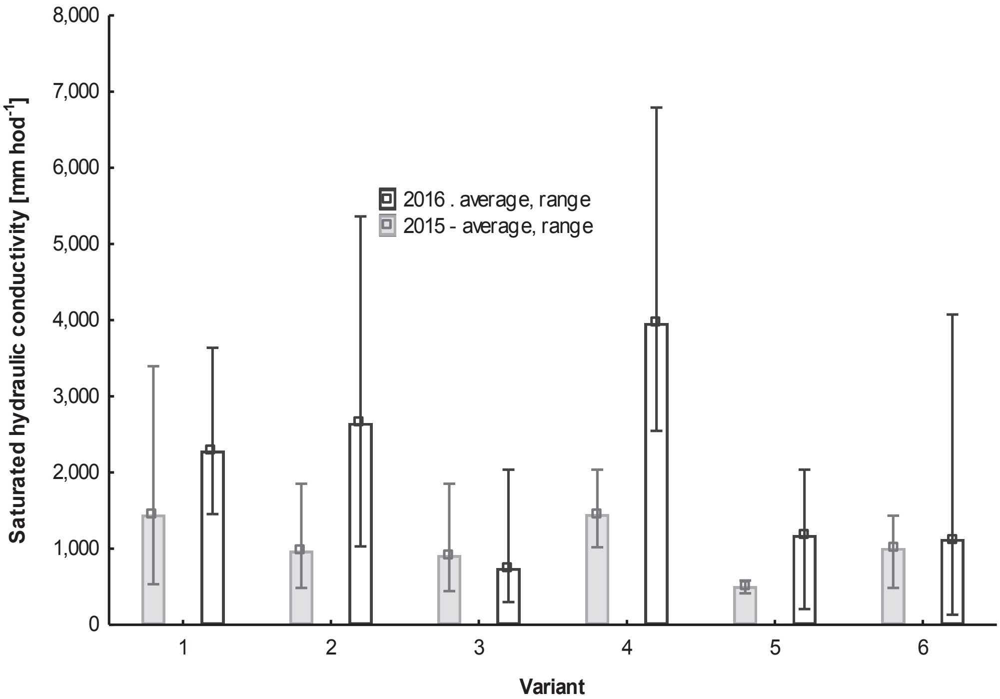

Figure 2. Saturated hydraulic conductivity of all the variants at Lázně Bělohrad in May, 2015 and April, 2016 (mean, minimum–maximum range).

Table 4 presents the values of bulk density of soil in three depths. The figures confirm the initial hypothesis. There is a noticeable positive effect particularly at the surface layer. Bulk density values decreased within the variants, which were influenced by the application of manure and/or activators. Compared to the control variant, the relative drop in values was noticeable particularly in the first year after application at Variants 1 and 2 with manure treated by PRP Fix. From the results, a decrease of soil bulk density with the relation to the application of manure treated by PRP Fix was indicated, though it was not statistically significant.

Table 4. Bulk density at Lázně Bělohrad

Variant	1	2	3	4	5	6
Depth [m]	Bulk density [g cm^{-3}] 15.10.2014					
0.05–0.1	1.35	1.46	1.33	1.33	1.44	1.55
0.1–0.15	1.51	1.47	1.46	1.35	1.41	1.50
0.15–0.2	1.55	1.52	1.55	1.37	1.39	1.61
Depth [m]	Bulk density [g cm^{-3}] 11.5.2015					
0.05–0.1	1.16	1.36	1.25	1.34	1.40	1.53
0.1–0.15	1.37	1.34	1.29	1.32	1.39	1.53
0.15–0.2	1.37	1.44	1.42	1.30	1.36	1.60
Depth [m]	Bulk density [g cm^{-3}] 14.4.2016					
0.05–0.1	1.28	1.36	1.34	1.33	1.35	1.30
0.1–0.15	1.18	1.37	1.26	1.29	1.28	1.34
0.15–0.2	1.39	1.38	1.39	1.30	1.42	1.34

Figs 3–5 describe cone index values of individual variants. The graphs show a similar pattern of cone index development depending on the depth. Measurements from spring were evaluated when possible, i.e. in the years 2015 and 2016, because of more homogeneous soil moisture distribution. In the year 2014, where autumn measurement was the only one available, cone index reached higher values at lower depths. At a depth of about 0.24–0.28 m, a sharper increase in cone index values may have been observed in each season. This increase was caused by the common depth of tillage (loosening). In the year 2014, cone index values were still affected more by the previous way of farming on the land than by the experimental manure application and the use of activators. Simultaneously, cone index values showed absence of compacted layers that could affect ability of water infiltration into the soil. Otherwise, there would have been a sudden increase of cone index values in the rate of MPa (Javůrek & Vlach, 2008). In the next two years, the values of cone index could not prove any positive effect of the application of manure and activators. This was again initiated by the soil type on the property (*Modal Luvisol*). Generally, this soil type shows relatively small values of cone index and a low binding.

Because the absolute values of cone index are influenced by soil moisture, the values were evaluated with regard to the control (Variant 6). Soil moisture measured was the volumetric one, and at the superficial layer of 0.00–0.1 m, its average values were 34.6% during the measurement in October of 2014, 12.3% in May of 2015, and 29.5% in April of 2016. The low volumetric soil moisture value in May of 2015 may imply higher values of cone index. But since volumetric soil moisture accounts also for the volume of air, porous soil would provide lower moisture values than the more compacted one at the same feed of water. This was probably the case of generally lower cone index values in May of 2015.

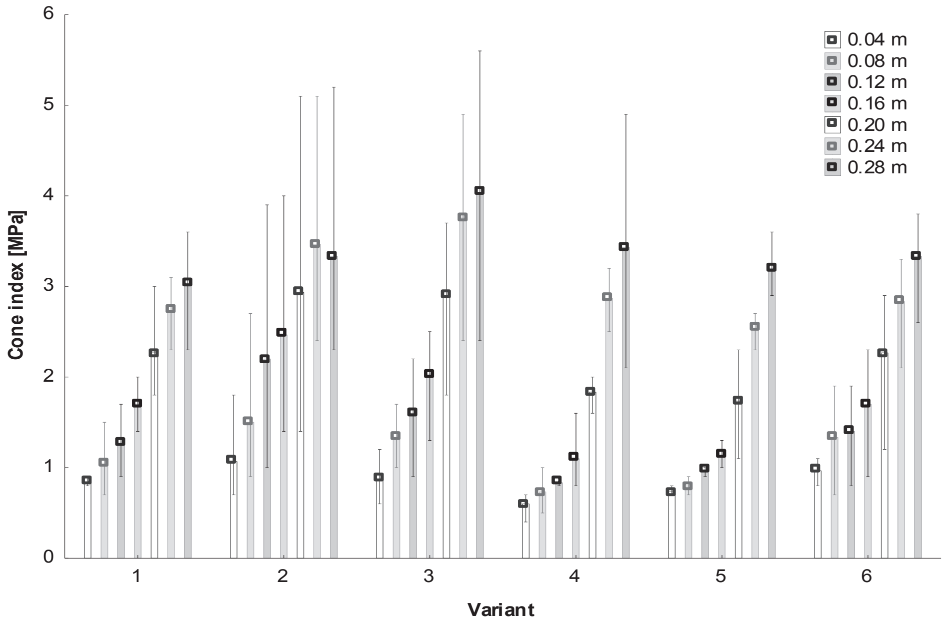

Figure 3. Cone index of all variants at Lázně Bělohrad in October, 2014 (mean, minimum–maximum range).

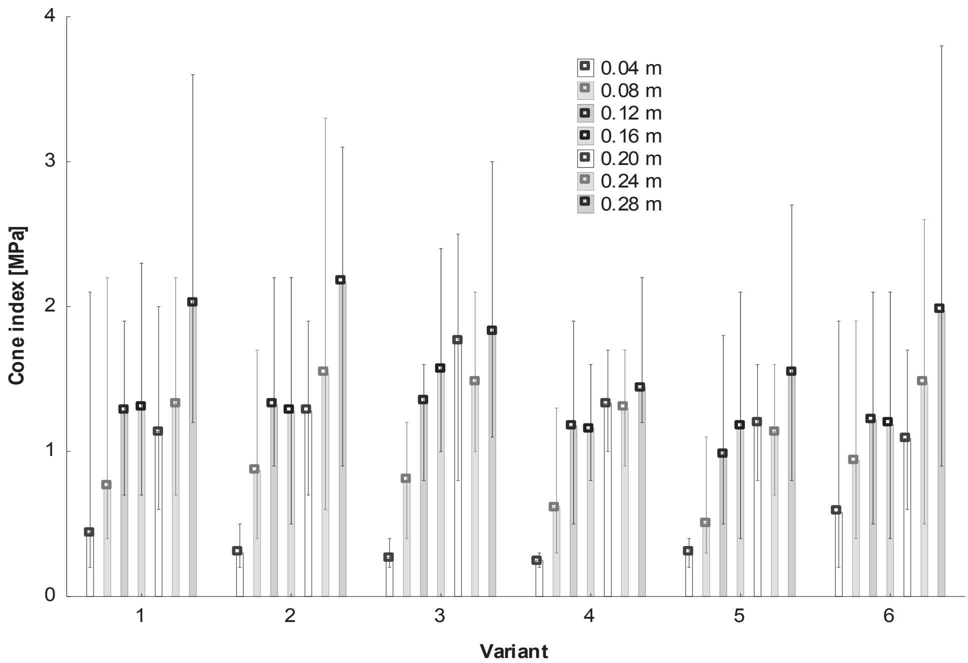

Figure 4. Cone index of all variants at Lázně Bělohrad in May, 2015 (mean, minimum–maximum range).

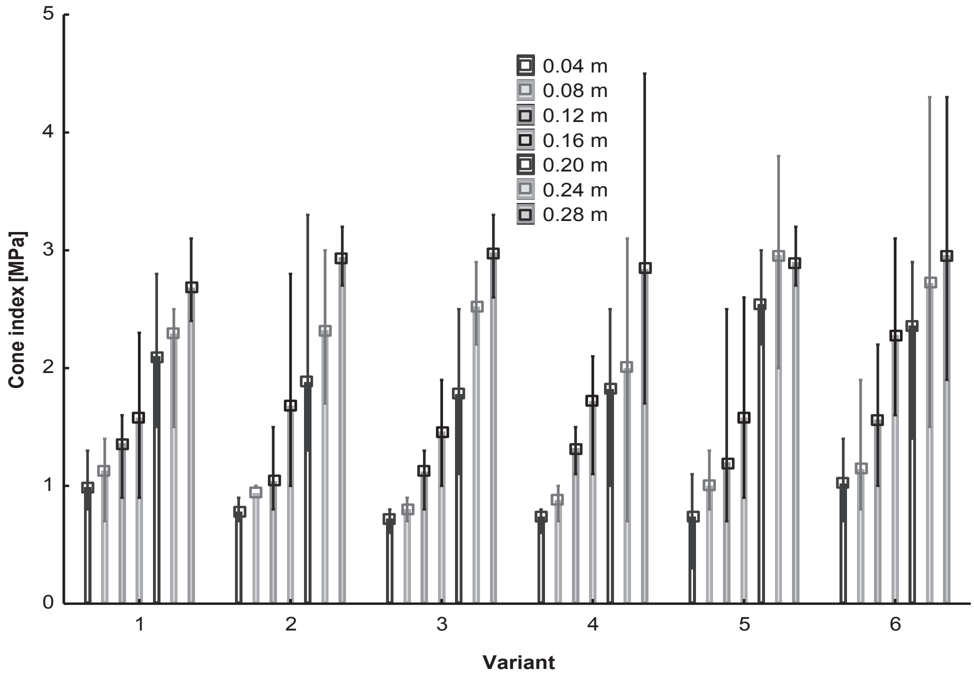

Figure 5. Cone index of all variants at Lázně Bělohrad in April, 2016 (mean, minimum–maximum range).

Light soils, like that of the trial filed, have by themselves exceptionally high rates of water infiltration, and the differences are thus difficult to register. This is consistent with the outcomes of Bagarello et al. (2006) where 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.

CONCLUSIONS

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. Generally, saturated hydraulic conductivity in all variants including the control reached very high levels, probably due to the light-textured soil of the trial plot.

Changes in soil properties are generally very slow. Favourable effect on soil bulk density was nevertheless observed. This effect was however not confirmed entirely by the cone index values measured. It was not possible to clearly demonstrate the beneficial effects of manure and activators on all three soil physical properties in question. There were two key factors. The first one was the light soil texture of the trial plot, and the second a relatively short duration of the experiment. In order to overcome these problems, the experiment has to be extended to following years and to multiple locations with different soil types. Research requires to be validated in more locations in order to eliminate the influence of the local environment (soil conditions). For future measurements, also other methods may be helpful to use. A brilliant blue dye tracer method appears perspective in this respect for evaluation of infiltration.

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