Agronomy Research **18**(X), xxx–ccc, 2020
https://doi.org/10.15159/AR.20.196

Changes in soil properties and possibilities of reducing environmental risks due to the application of biological activators in conditions of very heavy soils

P. Šařec[1,*], O. Látal[2], P. Novák[3], J. Holátko[4], V. Novák[1], T. Dokulilová[4,5] and M. Brtnický [4,5]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Machinery Utilization, Kamýcká 129, CZ165 000 Praha 6 – Suchdol, Czech Republic
[2]Agrovýzkum Rapotín Ltd., Rapotín, Výzkumníků 267, CZ788 13 Vikýřovice, Czech Republic
[3]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Agricultural Machines, Kamýcká 129, CZ165 000 Praha 6 – Suchdol, Czech Republic
[4]Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Geology and Pedology, Zemědělská 1, CZ61 300 Brno, Czech Republic
[5]Mendel University in Brno, Faculty of AgriSciences, Department of Agrochemistry, Soil Science, Microbiology and Plant Nutrition, Zemědělská 1, CZ61 300 Brno, Czech Republic
[*]Correspondence: psarec@tf.czu.cz

Abstract. This study aims at verifying the effect of farmyard manure (FYM) and of selected activators (Z'fix and NeoSol) on changes of soil properties. Their application should lead to improvement of soil physical properties and of organic matter fixation, to reduction of environmental risks, e.g. of tillage energy requirements. Experimental variants (0.7 ha each) were as follows: I (FYM with Z'fix); II (FYM with Z'fix + NeoSol); III (FYM); IV (Control NPK only). FYM was applied at rates: 50 t ha^{-1} (2014); 30 t ha^{-1} (2016). Additional NPK fertilizer (I–IV) was applied according to annual crop nutrient normative. The agent Z'fix was used as an activator of FYM biological transformation (5.5 kg t^{-1}). The agent NeoSol was used as soil activator (200 kg ha^{-1}; annually). In order to verify the effect, cone index, bulk density, tillage implement draft and chemical soil components (Humus, C/N ration and N_{tot}) were measured annually. Compared to the control, the application of FYM combined with the mentioned agents (I–III) increased N_{tot} more than two times. Moreover, it decreased (I–III) bulk density by 8.7%. Tillage implement draft decreased by 3% after the application of FYM with Z’fix (I, II). The study confirmed that FYM application combined with utilization of activators positively influenced soil fertility and helped to reduce environmental risks.

Key words: cone index, implement draft, bulk density, nitrogen, humus, C/N ratio, farmyard manure.

INTRODUCTION

The requirements posed on agricultural production have been raising fast recently. Moreover, these demands are likely to continue rising even faster in the future. The pressure intensifies mostly due to decreasing area of the arable land, the climate change, reduction of livestock farming, changes in crop rotation. For example in the Czech Republic, cattle production has diminished to less than a half of the volume existing 30 years ago (Sálusová, 2018). One of the consequences, even boosted by the intensification of agriculture, is the shortage of valuable soil organic matter (SOM) that contributes to a declining soil production ability on the European scale (Stolte et al., 2016). According to Gardi et al. (2013), this trend leads to a decline of the soil fertility and farmland diversity, as well as to other degradation problems. Walsh & McDonnell (2012) claim that SOM is linked not only to the fertility, but also to other properties, e.g. soil structure. SOM is likewise regarded as inherently reducing soil compaction (Chakraborty & Mistri, 2017). It is a major issue not just in Europe, where around 33 million hectares are reported to be threatened by this phenomenon (Alaoui & Diserens, 2018). Alakukku (1996) claims that the compaction adversely affects hydraulic soil properties, porosity, stability and other soil characteristics. According to Stolte et al. (2016), the compaction significantly affects root growth of plants, because it adversely affects the soil settings important for movement of gas and water. The situation thus often results in reduced crop yields. Amplified soil cone index and bulk density can be detected as a result of harmful soil compaction. Therefore, they are frequently used options of soil compaction measurement (Odey, 2018).

Any organic matters supplied to a degraded soil generally help to rectify its physical attributes (Are et al., 2017). The share of SOM is obviously advanced by applying compost or manure (Panagos et al., 2015). Manure application thus helps to amend the chemical, biological and physical soil characteristics (Ludwig et al., 2007). Liang et al. (2013), McLaughlin et al. (2002) and Peltre et al. (2015) conveyed that manure treatment substantially diminished draft of soil tillage implements. Prolonged application and higher rates produced advanced reduction. It is important in terms of economy and operation, since according to Larson & Clyma (1995), soil tillage operations account for a considerable share of the energy spent in crop production.

In order to rectify soil properties, so-called activators could be applied into any organic material, e.g. deep litter bedding of cattle housing, or straightway to soil. For the present, their effect have been studied only partially. Latest findings nevertheless imply that conditions for cultivating plants may be improved through their use (Borowiak et al., 2016). On one hand, it conveys economic advantages such as a decrease of tillage implement draft resulting in lower fuel consumption (Šařec & Žemličková, 2016). On the other, it may help agriculture to become more sustainable (Šařec & Novák, 2017). On the other hand, repeated application of an activator directly to soil and continuing conventional tillage did not generate any enhancement in terms of physical properties of soil, e.g. water content in soil, soil compaction, density, porosity (Podhrázská et al., 2012). In general, the mentioned works suggest the activators to be verified in different conditions.

This study is focused on assessing the effect of activators and farmyard manure (FYM) on selected soil physical and chemical properties at a five-year field trial.

MATERIALS AND METHODS

During 2014–2018, a field experiment was accomplished at a site near Městec Králové in the Central Bohemia at the altitude 265 m above sea level. The subject of interest was the topsoil (0–0.3 m) from soil type Gleyic Phaeozem. The experimental plot entailed very heavy soil texture. Therefore, the field was hard to till. At the depth from 0 to 0.3 m, the content of clay particles of the size under 0.01 mm accounted for 62% of weight. Particular soil characteristics at the start of the field trial are presented in Table 1.

Table 1. Particular chemical and physical characteristics of soil in the trial field in 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
Soil texture (USDA)	clay	clay
Humus content (%)	3.89	1.44
Bulk density (g cm^{-3})	1.46	1.48
Total porosity (%)	46.15	43.99
Volumetric moisture (%)	35.65	40.20
CEC – cation exchange capacity (mmol kg^{-1})	278	272
pH (H_2O)	7.50	7.82
pH (KCl)	7.18	7.21

The experimantal plot had a rectangular shape, was about 150 meters wide, and was positioned to avoid headland and to be homogenous. The rectangle was divided lengthwise each 45 meters to form four 0.7 ha variants varying in fertilizer and activator application. The spatial distribution had to be kept basic due to an operational character of the trial. NPK 15-15-15 (Lovofert, Czech Rep.) and cattle manure were the fertilizers applied. NeoSol (PRP Technologies, France) and Z'fix (PRP Technologies, France) were the activators applied. NeoSol was used at the time of stubble cultivation as the activator of biological transformation of soil organic matter. NeoSol composes of a matrix of magnesium and calcium carbonates, and of mineral elements. Z'fix was put at a recommended weekly dose directly into bedding of cattle deep litter housing as the activator of biological transformation of manure. Z'fix is formed by a granular mixture of carbonates and mineral salts. Both these activators are assumed to enhance environment for the transformation of organic matter. They cannot be classified as fertilizers due to their low share of active substances. Different treatments of individual variants and the crops grown are shown in Table 2. Apart from these treatments, all the other operations carried out and material applied did not differ among the variants. Reduced soil tillage technology was employed consisting firstly from shallow disk harrowing and subsequent deeper soil loosening to the depth of at least 20 cm using a tine cultivator.

Table 2. Application rates of individual variants of field trial and crop rotation in the trial field

Variant	Fertilization	Application rates for production year and crop (t ha^{-1})			
		2014/15 silage maize	2015/16 spring barley	2016/17 winter wheat	2017/18 silage maize
I	FYM[A] with Z'fix	50	0	30	0
II	FYM with Z'fix + NeoSol[B]	50 + 0.2	0 + 0.2	30 + 0.2	0 + 0.15
III	FYM	50	0	30	0
IV	Control - NPK only	according to crop demand and local practice			

[A]Farmyard manure of cattle origin; [B]Modified activator NeoSOL has been used with a changed dosage from the year 2017 onwards (formerly PRP SOL).

In order to assess soil physical properties, cone index and bulk density were measured in spring, while tillage draft was measured after harvest each year. Apart from the tillage draft, there were ten repetitions performed annually for each of the variants and variables. The tillage draft measurement was of continuous nature resulting in thousands of records. Only data from starting and final year were evaluated in this article. In order to measure cone index, the PEN 70 penetrometer constructed at the CULS Prague was used. Penetrometer was designed to meet the ASABE standards, i.e. with a tip cone angle of 30°, and tip area of 100 mm^2. Kopecky cylinders (volume of 100 cm^3) were employed in order to acquire undisturbed soil samples and subsequently soil bulk density. The sampling depth reached 0.05 to 0.10 m. The volumetric moisture was attained using Theta Probe (Delta-T Devices Ltd, UK). The draft of chosen farm cultivation machinery was evaluated using drawbar dynamometer with strain gauges S-38 /200 kN/ (LUKAS, the Czech Republic). The measurement was performed after harvest and prior to the first soil tillage operation, i.e. disk harrowing, each year. The drawbar dynamometer was positioned between two tractors. The sample rate of data acquisition system NI CompactRIO (National Instruments Corporation, USA) was set at 0.1 s. Within each variant, multiple machinery passes were performed. The measurements were carried out with the tillage implement either working or towed only. This enabled to discern among the implement draft, rolling resistance, and surface incline influence. The working speed was maintained constant. Acquired data were processed using Trimble Business Center (Trimble, USA), MS Excel (Microsoft Corp., USA) and Statistica (Statsoft Inc., USA).

Soil samples for chemical analysis were taken at two depths (0–0.15 m and 0.15–0.30 m) at the beginning and at the end of the vegetation period, but only the topsoil was assessed in the paper. Soil auger was used to take four summary samples composed of eight partial samples from each variant. The summary samples were dried, cleared of plant and animal residues, sieved and homogenized. The final sample (1 kg) was obtained from the summary samples by quartering.

RESULTS AND DISCUSSION

The paper is focused mainly on comparing starting conditions, i.e. the year 2014, with the resulting conditions after the five trial years, i.e. the year 2018. Fig. 1 display precipitation and monthly average temperatures of the year 2018 compared to the year 2014. In 2018, the weather was both remarkably warm and arid over the entire vegetative period. The preceding years 2016 and 2017 were also warm and short of precipitations.

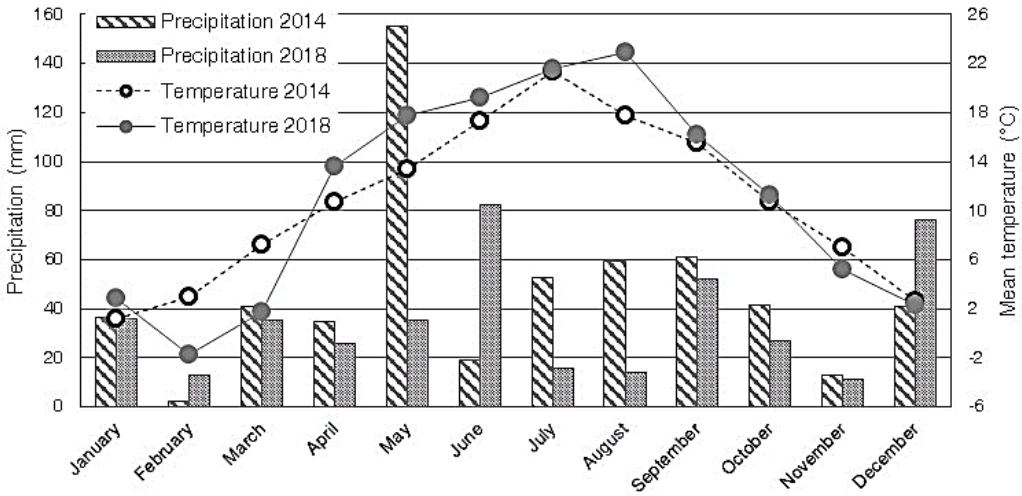

Figure 1. Graph of monthly precipitation and mean temperatures at the experimental site in the years 2014 and 2018.

Table 3. The averages of soil physical properties, and of draft of tillage implements for 2014 and 2018 regardless of trial variants

		2014	2018	Index	*p*
Soil physical properties in spring:					
Vol. moisture at 0.00–0.05 m (%)		17.305[a]	15.570[b]	0.90	0.02992
Bulk density at 0.05–0.10 m (g cm^{-3})		1.384[a]	1.235[b]	0.89	0.00104
Cone index (MPa)	at 0.04 m	0.608[a]	0.540[a]	0.89	0.45405
	0.08 m	0.875[a]	1.333[b]	1.52	0.00025
	0.12 m	1.067[a]	1.450[b]	1.36	0.01236
	0.16 m	1.200[a]	1.746[b]	1.46	0.00487
	0.20 m	1.675[a]	2.087[a]	1.25	0.05361
	0.24 m	2.158[a]	2.568[a]	1.19	0.11921
	0.28 m	2.517[a]	3.061[b]	1.22	0.00524
	0.32 m	2.783[a]	3.422[b]	1.23	0.00103
Draft measurement after harvest:					
Tractor		JD 9570 RT	JD 9570 RT		
Engine power (HP)		570	570		
Implement		tine cultivator	tine cultivator		
Implement type		Köckerling Vario 480	Köckerling Vario 480		
Working width (m)		3	3		
Working depth (m)		10.358[a]	16.529[b]	1.60	0.00000
Working speed (km hour^{-1})		7.026[a]	11.300[b]	1.61	0.00000
Overall implement draft (N)		74.821[a]	78.492[b]	1.05	0.02157
Unit draft (N m^{-2})		240.775[a]	158.290[b]	0.66	0.00000

Concerning statistical evaluation, *t-test* at the significance level of 0.5 was used.

Elementary physical characteristics of soil are depicted in Table 3. Springtime volumetric soil moisture exhibited a statistically significant difference between the two years. This clearly increased the values of cone index, which was susceptible to soil moisture. Illustrative aggregate values at different depths presented in Table 3 display statistically significant differences except at the depths of 0.20 and 0.24 m. On the other hand, overall soil bulk density across the variants decreased. The difference was also significant. Concerning draft measurement after harvest in autumn, immediate conditions were exceptionally favourable for tillage in 2018. Machinery used was the same in both years, but working depth could have been set by 60% deeper in 2018 and the working speed reached by 61% higher value. The overall implement draft thus attained higher value, but the unit draft allowing for the working width and depth was significantly lower in 2018.

Since the conditions substantially differed over the monitored period, the differences of the parameters relative to the average of the control Variant IV provide more information than their absolute values.

Implement draft was measured in a stubble field after the harvest. Manure and other material was applied afterwards. Draft values were evaluated in comparison to the control Variant IV, as is shown in Fig. 2.

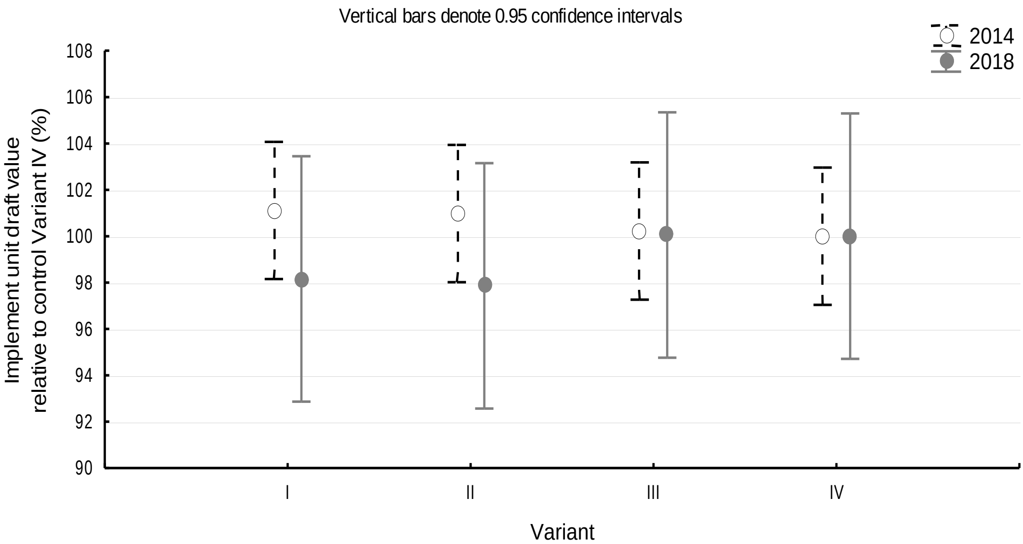

Figure 2. Graph comparing relative differences of implement unit draft values for individual variants in autumn 2014 and 2018 (Variants: I – FYM with Z'fix; II – FYM with Z'fix + NeoSol; III – FYM; IV – Control as 100%).

The *Analysis of Variance* did not confirm any significant differences with respect to the variants, measurement date and the combination of both factors. Generally, average implement draft values decreased relative to the control particularly after the application of FYM with Z'fix (Variants I and II), where the relative decrease attained 3% in average. The findings of Liang et al. (2013), McLaughlin et al. (2002), and Peltre et al. (2015) on draft reduction after manure application are consistent with the trial results, where it was intensified by the influence of activators.

Fig. 3 shows bulk density values related to the average value of respective control Variant IV. As the above mentioned Table 3 already suggested, they differed significantly according to the measurement date. However according to the *Analysis of Variance*, bulk density values did not differ significantly with regard to the variant, nor with regard to its combination with the measurement date. Nevertheless, there is a visible relative bulk density decrease particularly after the application of FYM (Variant III) by 13.4% and after the application of FYM with Z'fix combined with the application of NeoSol (Variant II) by 8.8%. The application of FYM treated with Z'fix (Variant I) presented the lowest decrease. The production of manure using Z'fix requires fewer straw. The manure is consequently more decomposed and thicker. The results are in accordance, though not statistically verified, with Schjønning et al. (1994), who claimed that prolonged time without any fertiliser treatment caused increased soil bulk density and soil strength than manure or inorganic fertilizer treatments, and Jehan et al. (2020), who reported soil bulk density and soil strength having decreased with increase in level of dairy manure. Also Bogunovic et al. (2020) observed a decrease in bulk density after FYM application. On the other hand, Chen et al. (2020) detected no such changes.

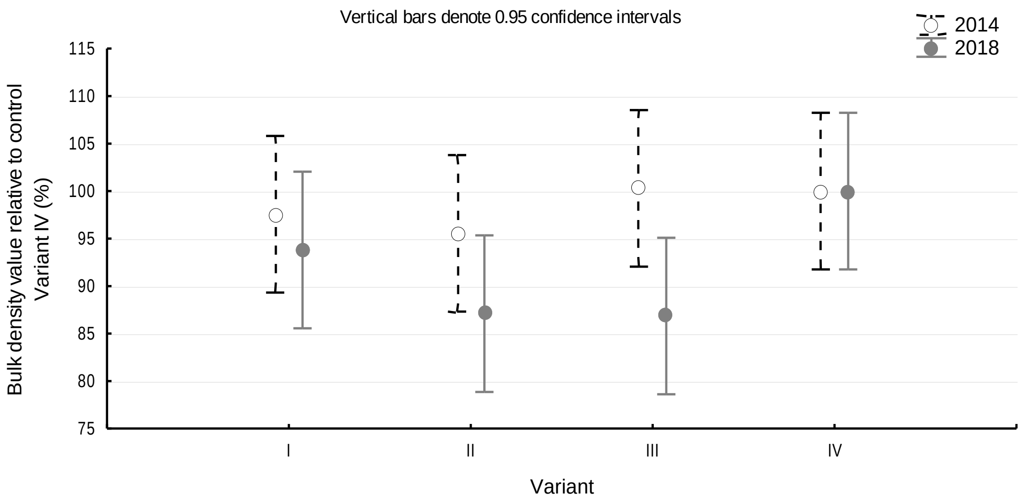

Figure 3. Graph of relative soil bulk density values from the depth of 0.05 to 0.10 m for individual variants in spring 2014 and 2018 (Variants: I – FYM with Z'fix; II – FYM with Z'fix + NeoSol; III – FYM; IV – Control as 100%).

Since cone index depends intensely on soil moisture, it was measured also in spring, when soil moisture was more probable to be homogenous. Cone index values were yet again compared to the control Variant IV, as is presented in Fig. 4. Though actual values increased from 2014 to 2018 (see Table 3), relative differences compared to Variant IV decreased. The *Analysis of Variance* did not find any significant difference for the combination of all the factors in question, i.e. measurement date, variant and depth, nor for the separate factors except for the measurement date. When considering the combinations of the measurement date with the depth or with the variant, differences were statistically significant.

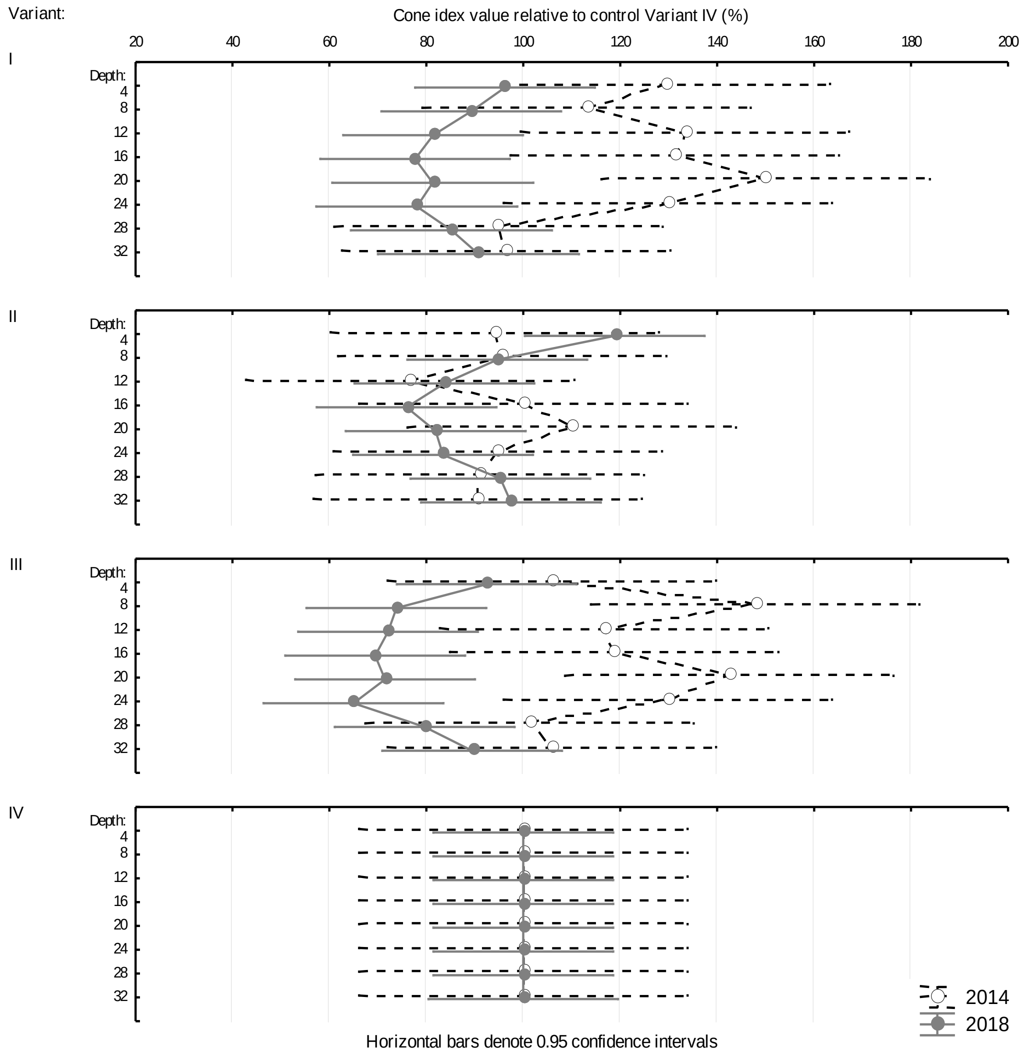

Figure 4. Graph comparing relative differences of cone index values to the depth up to 0.32 m for individual variants in spring 2014 and 2018 (Variants: I – FYM with Z'fix; II – FYM with Z'fix + NeoSol; III – FYM; IV – Control as 100%).

With the *Analysis of Variance* performed separately for each variant using the measurement date and depth as the only factors, the differences were more comprehensible. Within Variant I (FYM with Z'fix) and II (FYM with Z'fix + NeoSol), data formed one homogeneous group. In the case of Variant III (FYM) though, there was a statistically significant difference for the combination of both mentioned factors (*ANOVA*, $n = 160$, $p = 0.04198$) and data formed three homogeneous groups (see Table 4). Compared to the year 2014, the decrease of relative cone index values of the year 2018 for Variant III (FYM) at the depths of 0.08, 0.20 and 0.24 m was statistically significant. This result matches with those of Šařec & Žemličková (2016), Celik et al. (2010) and Luo et al. (2020).

Table 4. Homogenous groups of relative cone index values of Variant III (FYM) according to *Turkey HSD test* (*ANOVA*, n = 160, P > 0.05)

Trial date	Depth (cm)	Mean cone index value relative to the control Variant IV (%)	Homogenous groups		
			1	2	3
2018	24	64,9682	****		
2018	16	69,4444	****		
2018	20	71,4859	****	****	
2018	12	72,0930	****	****	
2018	8	73,8255	****	****	
2018	28	79,6460	****	****	
2018	32	89,4479	****	****	****
2018	4	92,4528	****	****	****
2014	28	101,2821	****	****	****
2014	4	105,8824	****	****	****
2014	32	105,8824	****	****	****
2014	12	116,6667	****	****	****
2014	16	118,7500	****	****	****
2014	24	129,8246		****	****
2014	20	142,5000			****
2014	8	147,8261			****

Table 5 presents the results of soil chemical analysis. It is apparent that pH changed particularly when the activators, i.e. Z'fix and NeoSol, were used. The pH reaction could be assessed as neutral to alkaline. The content of total nitrogen increased mainly after FYM with Z'fix application (Variants I and II). C/N ration can be evaluated as high to good and decreasing again particularly after FYM with Z'fix application. Humus content can be rated as good to high one. The FYM combination with the soil activator NeoSol had a beneficial effect on its creation. When considering the humus type, the increased humic over fulvic acids ratios of the Variants I to III can be regarded as beneficial.

Table 5. Results of chemical analysis of soil samples for individual variants in 2014 and 2018 (Variants: I – FYM with Z'fix; II – FYM with Z'fix + NeoSol; III – FYM; IV – Control)

Variant	Year	pH (KCl)	N_{tot} (%)	C/N ratio	Humus (%)	HA/FA ratio[A]
I	2014	6.98	0.3	9.45	4.84	1
I	2018	7.44	0.62	4.43	4.76	1.08
I	*Index*	*1.066*	*2.067*	*0.469*	*0.983*	*1.080*
II	2014	7.07	0.27	10.56	5.01	0.99
II	2018	7.48	0.67	4.57	5.23	1.02
II	*Index*	*1.058*	*2.481*	*0.433*	*1.044*	*1.030*
III	2014	7.1	0.32	9.07	4.94	1.01
III	2018	7.44	0.54	4.92	4.55	1.08
III	*Index*	*1.048*	*1.688*	*0.542*	*0.921*	*1.069*
IV	2014	7.17	0.32	8.66	4.76	1.02
IV	2018	7.01	0.4	6.6	4.55	0.98
IV	*Index*	*0.978*	*1.250*	*0.762*	*0.956*	*0.961*

[A]Humic to Fulvic acids ratio.

The activators of organic matter and their outcomes relate to the topics that are not thoroughly studied. Since the type of organic fertilizers used is altering, i.e. more compost and waste from biogas plants instead of manure and slurry, the increased significance of such activators of organic matter can be anticipated

CONCLUSIONS

The research aimed at the influence of organic fertilizers and activators on particular soil physical and chemical properties was carried out. Generally, the farmyard manure (FYM) and the activators showed positive effect, although not always statistically significant. Significant proved the differences in cone index values compared to the control when applying untreated FYM, where there was a reduction at the depths of 0.08, 0.20 and 0.24 m. After the application of FYM treated with Z'fix, unit implement draft decreased by 3% compared to the control variant. This difference was not confirmed statistically though, and neither were the following ones mentioned. Nonetheless given the average tractive efficiency of around 50% and the fuel requirements of tillage at the level of 20 L ha^{-1}, the 3% reduction in draft would represent 0.3 L ha^{-1} of fuel savings. This application of FYM treated with Z'fix also most of all increased the total nitrogen content. On the other hand, bulk density was mostly reduced by applying untreated FYM. The activators of organic matter should examined further on and at more locations in order to verify the results.

ACKNOWLEDGEMENTS. This study was supported by Research Project of the Technology Agency of the Czech Republic No. TH02030169, and by the Faculty of Engineering, Czech University of Life Sciences Prague under internal grant IGA 2019: 31180/1312/3104.

REFERENCES

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.

Alaoui, A. & Diserens, E. 2018. Mapping soil compaction – A review. *Current Opinion in Environmental Science & Health* **5**, 60–66.

Are, K.S., Adelana, A.O, Fademi, I.O. & Aina, A.O. 2017. Improving physical properties of degraded soil: Potential of poultry manure and biochar. *Agriculture and Natural Resources* **51**, 454–462.

Bogunovic, I., Pereira, P., Galic, M., Bilandzija, D. & Kisic, I. 2020. Tillage system and farmyard manure impact on soil physical properties, CO2 emissions, and crop yield in an organic farm located in a Mediterranean environment (Croatia). *Environmental Earth Sciences* **79**(70), 1–11.

Borowiak, K., Niewiadomska, A., Sulewska, H., Szymanska, G., Gluchowska, K. & Wolna-Maruwka, A. 2016. Effect of PRP SOL and PRP EBV nutrition on yield, photosynthesis activity and soil microbial activity of three cereal species. *Fresenius Environmental Bulletin* **25**, 2026–2035.

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.

Chakraborty, K. & Mistri, B. 2017. Estimation of soil compaction from bulk density and its effect on crop production. *Indian Journal of Spatial Science* **8**, 101–107.

Chen, S., Zhang, X., Shao, L., Sun, H., Niu, J. & Liu, X. 2020. Effects of straw and manure management on soil and crop performance in North China Plain. *Catena* **187**, 1–11.

Gardi, C., Jeffery, S. & Saltelli, A. 2013. An estimate of potential threats levels to soilbiodiversity in EU. *Global Change Biology* **19**, 1538–1548.

Jehan, S., Iqbal, M., Zahir, Z.A. & Farooq, M 2020. Role of dairy manure in improving wheat yield under deficit irrigation. *Pak. J. Bot.* **52**, 639–644.

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.

Ludwig, B., Schulz, E., Rethemeyer, J., Merbach, I. & Flessa, H. 2007. Predictive modelling of C dynamics in the long-term fertilization experiment at Bad Lauchstadt with the Rothamsted Carbon Model. *European Journal of Soil Science* **58**, 1155–1163.

Luo, J., Lin, Z.L., Li, S.Y., Que, Y.X., Zhang, C.F., Yang, Z.Q., Yao, K.C., Feng, J.F., Chen, J.F. & Zhang, H. 2020. Effects of different soil improvement measures on soil physicochemical properties and microbial community structures in mechanically compacted acidified sugarcane field. *Acta Agronomica Sinica(China)* **46**, 596–613.

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.

Odey, S.O. 2018. Overview of engineering problems of soil compaction and their effects on growth and yields of crops. *European Journal of Advances in Enineering and Technology* **5**, 701–709.

Panagos, P., Borelli, P., Meusburger, K., Alewell, C., Lugato, E. & Montanarella, L. 2015. Estimating the soil erosion cover-management factor at the European scale. *Land Use Policy* **48**, 38–50.

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.

Sálusová, D. 2018. *Czech agriculture from the viewpoint of statistics.* Prague: Czech Statictical Office. 85 pp. (in Czech).

Šařec, P. & Novák, P. 2017. Influence of manure and activators of organic matter biological transformation on selected soil physical properties of Modal Luvisol. *Agronomy Research* **15**, 565–575.

Šařec, P. & Žemličková, N. 2016. Soil physical characteristics and soil-tillage implement draft assessment for different variants of soil amendments. *Agronomy Research* **14**, 948–958.

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.

Stolte, J., Tesfai, M., Øygarden, L., Kværnø, S., Keizer, J., Verheijen, F., Panagos, P., Ballabio, C. & Hessel, R. 2016. *JRC Scientific and Technical Reports - Soil Threats in Europe.* Luxembourg: JRC Science Hub. 206 pp.

Walsh, E. & McDonnell, K.P. 2012. The influence of added organic matter on soil physical, chemical, and biological properties: a small-scale and short-time experiment using straw. *Archives of Agronomy and Soil Science* **58**, 201–205.