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Physical properties of a soil under a pig slurry application and organic matter activators

Václav Novák[1], Petr Šařec[1], Kateřina Křížová[1,2]*

[1]*Department of Machinery Utilization, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic*

[2]*Division of Crop Protection and Plant Health, Crop Research Institute, Prague, Czech Republic*

**Corresponding author: novakvaclav@tf.czu.cz*

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Abstract: To investigate the effects of organic matter activators combined with a pig slurry on a soil's physical properties, a field experiment was carried out in a monoculture of corn (2015–2017). Three pig slurry application variants complemented with the activators in question, i.e. with PRP SOL spread directly on the soil surface (*SOL*), with Z'fix added to the slurry during the pig housing (*ZF*) and with a combination of both PRP SOL and Z'fix (*ZF_SOL*), were compared with just the pig slurry (*C*) under an equal dose of nitrogen and a uniform growing technology. According to the results, a positive effect of the penetration resistance with the pig slurry and the activators of organic matter (Z'fix and PRP SOL) was not proven. The saturated hydraulic conductivity was demonstrably better achieved with the Z'fix activator, but PRP SOL activator also provided a certain improvement. The largest change in the unit draught was observed in the *ZF_SOL* application (20% increase). The results seem ambiguous; however, they give a good indication of the activators' effect in practice. Nevertheless, the findings would certainly benefit from further verification.

Keywords: agricultural management; field experiment; penetration resistance; soil organic matter; unit draught

Currently, crop production is limited due to various challenges, such as the growing population, a decrease in the total agricultural area, climate change related issues, soil erosion, or lack of soil organic matter. At the same time, when farmers deal with the implementation of Agriculture 4.0 practices, it is necessary to also focus on the elementary issues and solve them with respect to the environment and sustainability. Regarding the soil conditions, many biological and physical properties are related to the content of the soil organic matter as one of the key soil components (Smith et al. 1999; Manna et al. 2007). From a long-term point of view, the use of organic fertilisers returns organic matter to the soil, where it ensures increased biological activity and, thus, increases crop yields. The positive influence of organic fertilisers on a soil's physical, chemical, and physicochemical properties has been confirmed many times (Barzegar et al. 2002; Herencia et al. 2007). Rational fertilisation management can improve not only soil porosity, infiltration capacity, and hydraulic conductivity, but it also usually helps to decrease the soil bulk density (Haynes and Naidu 1998).

In the Czech Republic, a decline in animal production can be observed in recent times. It is undeniably associated with a reduced production of organic matter that could be returned to the field in the form

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of an organic fertiliser. According to the Czech Statistical Office (2020), cattle breeding has decreased to the current 40% level compared to the 1990 level, the situation with pigs is even worse, which currently sits at 31% of the 1990 level. This phenomenon is very likely one of the reasons for the significant soil organic matter losses. Thus, it is necessary to look for new technologies of sustainable land management. One of these approaches may be the utilisation of soil amendments. Also, activators of biological transformation of organic matter might have great potential, since they are claimed to improve soil properties. According to the manufacturer, PRP SOL is a soil conditioner and should boost the biological activity of the soil and, thus, improve its fertility (PRP Technologies, France). Z'fix is a dust-free pearled pellet designed to enhance the agronomic quality of manure, slurry, and compost (PRP Technologies, France). Nevertheless, the role of these substances still has not been sufficiently described. The positive effect of PRP SOL on the soil enzymatic activity was confirmed by the study of Niewiadomska et al. (2018). Although this product cannot be considered a conventional fertiliser, PRP SOL can replace the traditional fertilisation of spring barley without a negative effect on the grain yield (Sulewska et al. 2016). There is a great lack of scientific studies regarding the activators, although a few do exist. In one of the previous studies, an increase in the soil bulk density, and also in the implemented draught of the machine, was detected. Concurrently, an increase in the yield of silage maize was observed (Šařec et al. 2019). These results are also confirmed by the study of Šindelková et al. (2019) who concludes that the use of these products leads to a better water management and nutrient uptake. Therefore, activators should provide convenient conditions for organic matter decomposition in the soil and, thus, to affect the soil properties. In terms of the economy, soil activators help to reduce the actual energy demand by various management tasks, such as the soil tillage (Novák and Šařec 2017).

Since the actual impact of the above-mentioned soil amendments is not described sufficiently yet, this study aims at verifying the effect of organic matter activators combined with a pig slurry on a soil's physical properties. The activators under investigation should, due to their composition and to their succeeding effect in the soil profile, amplify the positive influence of the organic matter and, therefore, provide more convenient conditions in terms of the soil management and crop growth. The penetration resistance and bulk density were studied as important pedocompaction indicators in real farm conditions with the assumption that their values were expected to decrease with the activators used. The other variables in question were the implemented draught, since soil tillage is one of the most energy-intensive operations in agriculture, and the saturated hydraulic conductivity, which is one of the most important hydrophysical characteristics. As a matter of fact, the unit draught, penetration resistance, and bulk density were expected to decrease, while the saturated hydraulic conductivity should have increased under the effect of the used activators.

MATERIAL AND METHODS

Site and crop management. The study experiment was established in 2014 near the village of Paseka in the Olomouc region, in the Czech Republic (49°47'170"N, 17°13'143" E, 270 m a.s.l.). The 6.3 ha agricultural plot was divided into smaller parcels in order to apply the different agricultural management and crop rotating systems. The terrain on the experimental area has practically no sloping. The soil type is classified as Cambisol. According to the United States Department of Agriculture (USDA 2019), the soil texture is Silt Loam at a depth of 0–0.3 m and Sandy Loam at a depth of 0.3–0.6 m. From an agronomic point of view, this is a poor-quality soil with a high skeleton content. The soil properties at the beginning of this experiment are given in Table 1. The crop rotation over the study period started with winter wheat (2014) followed by a monoculture of maize (2015–2017) variety LM GENER FAO 250. The fact that the agricultural business runs, as many others do, a biogas plant, and is, thus, forced to in-

Table 1. Chemical and physical soil properties at the beginning of field experiment (2014)

Soil property	Soil depth (cm)	
	0–30	30–60
Clay (< 0.002 mm) (%)	7.00	5.00
Silt (0.002–0.05 mm) (%)	61.00	23.00
Very fine sand (0.05–0.10 mm) (%)	4.00	8.00
Fine sand (0.10–2 mm) (%)	28.00	64.00
C:N	6.72	7.08
Humus content (%)	2.15	0.38
pH (KCl)	5.81	6.11

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Table 2. Pig slurry chemical analysis for "*C*" as the pure untreated pig slurry, and "*ZF*" representing pig slurry treated by Z'fix

Variant	Dry matter (%)	N (NH_4^+)	N ($kg \cdot t^{-1}$)	P_2O_5 ($kg \cdot t^{-1}$)	K_2O ($kg \cdot t^{-1}$)	CaO ($kg \cdot t^{-1}$)	MgO ($kg \cdot t^{-1}$)	pH
C	5.9	0.61	4.7	3.0	1.9	3.4	0.72	7.6
ZF	5.9	0.83	5.6	3.6	2.4	4.2	1.05	9.0

C – pig slurry + NPK; *ZF* – pig slurry treated by Z'fix + NPK

creasingly grow maize, led to the particular crop rotation. Four plots 50 m × 100 m (0.5 ha) were treated each year by a pig slurry (Table 2) and by the selected activators in the combinations described below.

PRP SOL is a soil activator manufactured by the PRP technologies company (France) on the basis of dolomitic limestone, limestone and calcareous sediments and produced in the form of a brown-coloured granulate. This composition of calcium, magnesium and trace elements is claimed to improve the soil fertility by positively influencing the soil structure and its biological activity. Crops cultivated on plots treated by PRP SOL should ingrain faster and, thus, have a richer root system. The vegetation should also emerge easier, and the canopy is then evenly well-balanced. Secondly, the organic matter Z'fix activator was investigated. It is a granulate constructed on the basis of calcium and magnesium carbonates with an addition of other macro- and micronutrients (potassium, sodium, sulfur, iron, manganese). Z'fix is manufactured by PRP Technologies as well. It is produced under a patented technology, MIP (mineral inducer process), that ensures regulation of the fermentation processes in organic fertilisers and composts.

The Z'fix treatment involves the application of the activator to the pig slurry first. Here, the dosage was 0.33 $kg \cdot head^{-1} \cdot month^{-1}$. The yearly dosage of PRP SOL was 200 $kg \cdot ha^{-1}$ of agricultural plot. The pig slurry itself was applied in a yearly dose of 50 $m^3 \cdot ha^{-1}$. The NPK dose corresponded to a nutrient normative, that is 170 $kg \cdot ha^{-1}$ of nitrogen, 35 $kg \cdot ha^{-1}$ of phosphorus, and 200 $kg \cdot ha^{-1}$ of potassium.

For the purpose of this study, the treatment variants are labelled as follows: *C* (pig slurry + NPK); *SOL* (pig slurry + PRP SOL + NPK); *ZF* (pig slurry treated by Z'fix + NPK); *ZF_SOL* (pig slurry treated by Z'fix + PRP SOL + NPK).

Data acquisition and processing. The soil's physical properties were studied twice a year in the three-year experiment period during field visits. Mostly, spring and autumn terms were chosen; however, the data acquired in the spring term were preferred because the soil profile was more likely to be evenly saturated by water. Figure 1 summarises the rainfall conditions during the 2015–2017 period compared to the long-term normal. A PEN 70 penetrometer (CULS Prague) was used for the evaluation of the penetration resistance. The penetration resistance profiles at ten evenly distributed sampling points were recorded for each variant. Per variant, three undisturbed soil samples for the bulk density evaluation were taken by Kopecky cylinders (volume 100 cm^3). These samples were analysed according to CSN EN ISO 17892-2. The unit draught was measured by a dynamometer with an S-38/200kN strain gauge (Lukas, Czech Republic). The dynamometer was placed between two tractors, where the working tractor was a Case Maxxum with a disc harrow – tillage depth of 8.5 cm in 2015; a New Holland T7.270 with a disc harrow – tillage depth of 8 cm in 2016, and a New Holland T7.270 with a tine cultivator at a tillage depth of 19 cm in 2017. For the data collection, the NI CompactRIO system (National Instruments Corporation, USA) was used with a sampling frequency of 0.1 seconds. The GPS position for these data was recorded by the Trimble Business Center 2.70 software (Trimble, USA). The soil infiltration capacity was measured with the circular infiltrometers (each 0.15 m in diameter) according to the simplified falling-head (SFH) method that enabled one to convert the infiltration into the saturated hydraulic conductivity. A known amount (0.5 L) of water was applied to the infiltrometer. The time of the infiltration was measured alongside the soil moisture before and after the water application. The soil moisture was measured by a ThetaProbe (Delta-T Devices Ltd., UK), with ten sampling points per variant. The spatial distribution of the sample points was a rectangular matrix corresponding to the number of samples taken for the individual variables.

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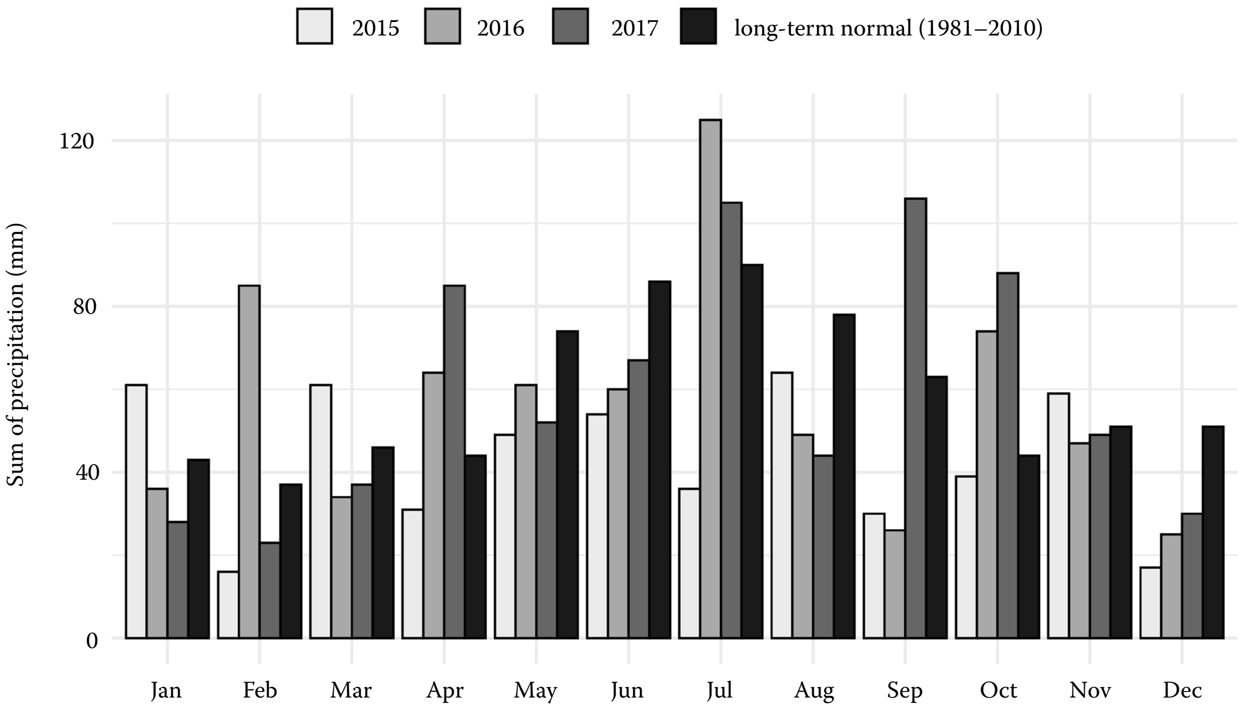

Figure 1. Rainfall conditions reported by the Czech Hydrometeorological Institute during cropping seasons 2015, 2016 and 2017 compared to a long-term normal

The acquired dataset was further processed in R (R Core Team, 2020) using the packages tidyverse, reshape2 and psych; MS Excel (Microsoft Corporation, USA), and Statistica 12 (Statsoft Inc., USA). Since the normality of the data was not met, the non-parametric Kruskal-Wallis variance test was used to determine the potential differences in the soil properties between the experimental variants and activators.

RESULTS AND DISCUSSION

Although this study focuses primarily on the physical properties of the soil, the potential effect of the investigated activators should have been reflected in the crop yield also. As shown in Table 3, there was no obvious increase in the yield among treated variants in the first year of the experiment. However, in the following two years, the activator treated variants' yield was higher compared to the control, while the best performing treatment, in terms of the yield, appeared to be the combination of both activators (*ZF_SOL*).

Bulk density. The values of the reduced bulk density are shown in Figure 2. Compared to the initial state, there was an increase in the reduced bulk density in all the variants. The most significant increase was observed by the variant with the pig slurry treated by Z'fix. These results were similar to a study (Rimovsky and Bauer 1996) in which the reduced soil bulk density increased after a slurry application. The treatment by Z'fix, in opposite to the original assumption, seemed to boost this increase. According to the USDA (2019), in the case of this particular soil texture, reduced bulk density values of less than 1.4 $g \cdot cm^{-3}$ are considered convenient for plant growth, a value exceeding 1.55 $g \cdot cm^{-3}$ already affects the root growth and values greater than 1.65 $g \cdot cm^{-3}$ restrict the root growth

Table 3. Maize yield (33% dry matter) achieved in investigated treatment variants for investigated cropping seasons

Variant	2015 ($t \cdot ha^{-1}$)	2016 ($t \cdot ha^{-1}$)	2017 ($t \cdot ha^{-1}$)
C	33.7	37.6	37.6
SOL	32.6	38.4	38.4
ZF	32.3	38.6	39.6
ZF_SOL	32.9	39.2	42.7

C – pig slurry + NPK; *SOL* – pig slurry + PRP SOL + NPK; *ZF* – pig slurry treated by Z'fix + NPK; *ZF_SOL* – pig slurry treated by Z'fix + PRP SOL + NPK

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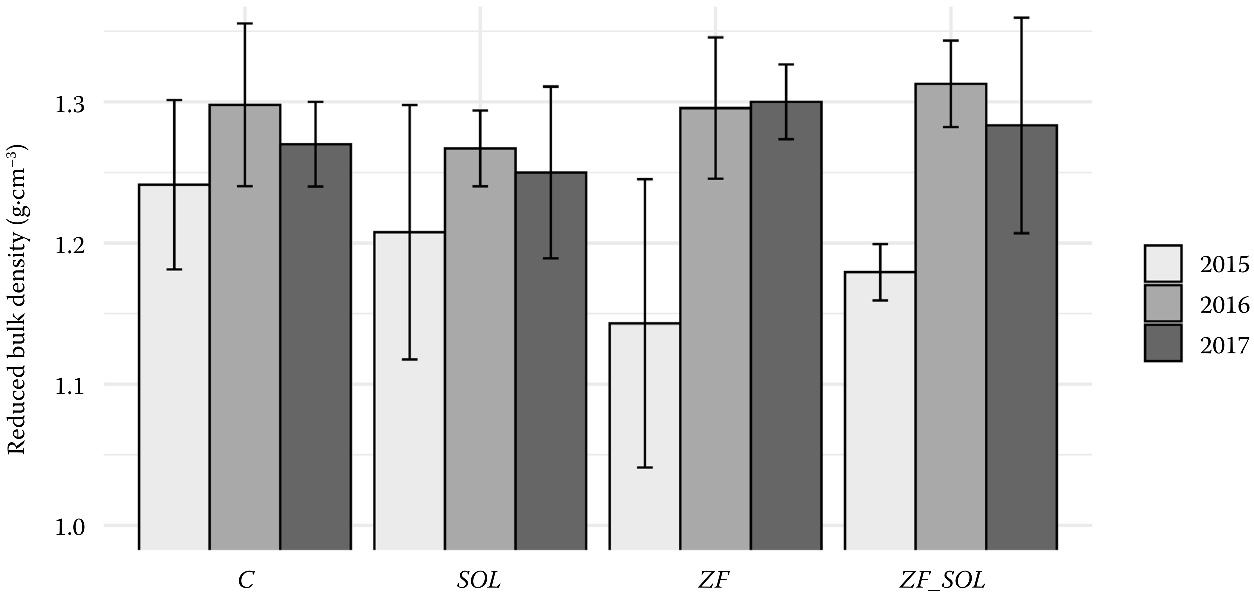

Figure 2. Reduced bulk density acquired using the Kopecky's cylinders (100 cm^3), error bars representing the standard deviation

entirely. From the point of view of the soil density, it is, therefore, clear that the soil of the experimental location does achieve ideal values for root growth. However, the results were not statistically evaluated due to the insufficient number of samples for the statistical analysis.

Penetration resistance. The results of the penetration resistance measurements are illustrated in Figure 3. The results attained at the beginning of the experiment (2015) did not show any statistically significant differences among the variants. In 2016, significant differences were registered at the depths of 0.08 and 0.16 meters. At both depths, the penetration resistances between the variants *ZF* (pig slurry treated by Z'fix) and *C* (pig slurry) differed significantly with the value of the *ZF* variant being higher. In a similar manner, the value of the *ZF* variant at 0.08 m differed significantly when also compared to the variant *ZF_SOL* (pig slurry treated by Z'fix + SOL). In 2017, a significant difference was only observed at a shallower depth of 0.04 meters. Compared to the control variant, there was a statistically

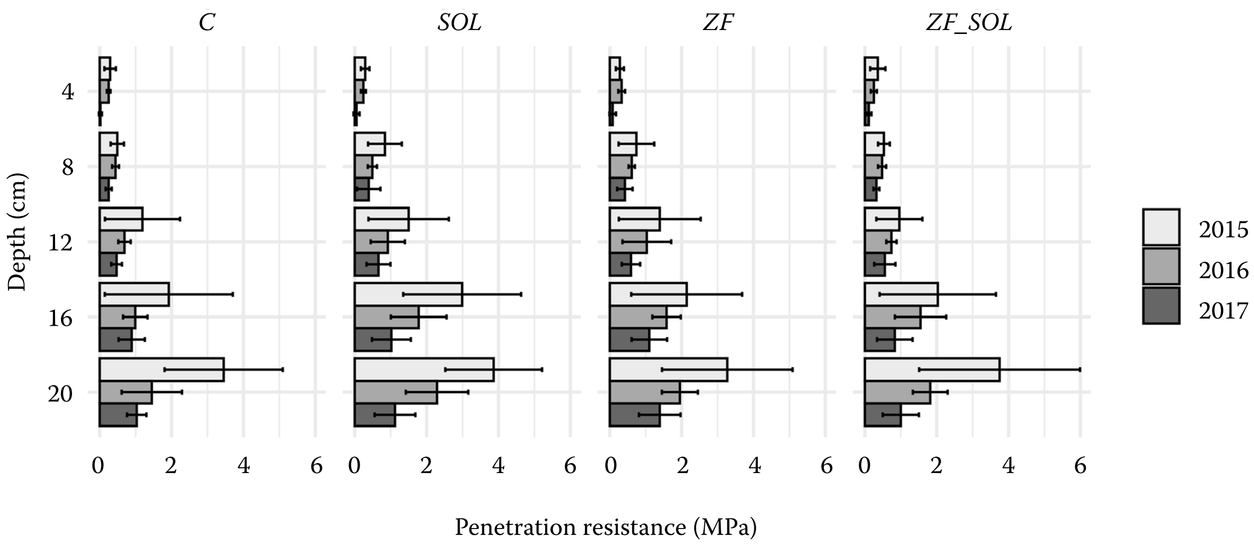

Figure 3. Penetration resistance in specific soil profile depths, acquired by the penetrometer PEN, error bars representing the standard deviation

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significant increase in the penetration resistance within the *ZF_SOL* variant. De Smet et al. (1991) described an increase in the soil penetration resistance after a pig slurry application. Podhrázská et al. (2012) stated that there was no improvement in the soil compaction in topsoil after the use of PRP SOL. According to the results of this study, the positive effect of the activators on the organic matter, i.e. Z'fix and PRP SOL, was not proven. On the contrary, instead of ameliorating the negative impact of the slurry on the penetration resistance, Z'fix particularly seemed to aggravate it.

Saturated hydraulic conductivity. There are several methods for measuring the saturated hydraulic conductivity, Chyba et al. (2017), in their study, emphasised the convenience of the SFH method for use in practice. At the beginning of the experiment (2015), the variants *SOL* and *ZF_SOL* reached the highest values (Figure 4). However, the differences in the values that year were not statistically significant. In the following experimental years, the values of the saturated hydraulic conductivity, with the exception of variant *ZF*, gradually decreased. Since the control variant showed the biggest drop, it proved to be significantly different when compared to all the three variants with the activators in 2017 (Table 4). Urbanovičová et al. (2018), in their study, mentioned that the soil infiltration increased by 2 mm·h^{-1} in a soil treated by PRP SOL. The variant where PRP SOL was applied showed the highest infiltration values. Dumbrovský et al. (2011) mentioned the fact that the use of PRP SOL does not demonstrably improve the properties of the soil infiltration, but in comparison with the untreated soil, it stabilises these values more. According to the results of this study, the Z'fix treatment demonstrated the most beneficial effect concerning the saturated hydraulic conductivity. PRP SOL also produced an improvement though.

Unit draught. Tillage is one of the most energy-intensive operations in agriculture. Figure 5 shows the values of the unit draught in 2015, 2016 and 2017. Since the measurement conditions and tillage implements differed among the individual years, the assessment of the values relative to the control variant should be stressed. The results in the first year of the experiment were certainly influenced by the previous management system. It is possible to observe significant differences between the variants with the untreated pig slurry (*C* and *SOL*), and the variants with the pig slurry treated by Z'fix (*ZF* and *ZF_SOL*), with the latter having lower values. In 2016, the unit draught of variant *ZF_SOL*

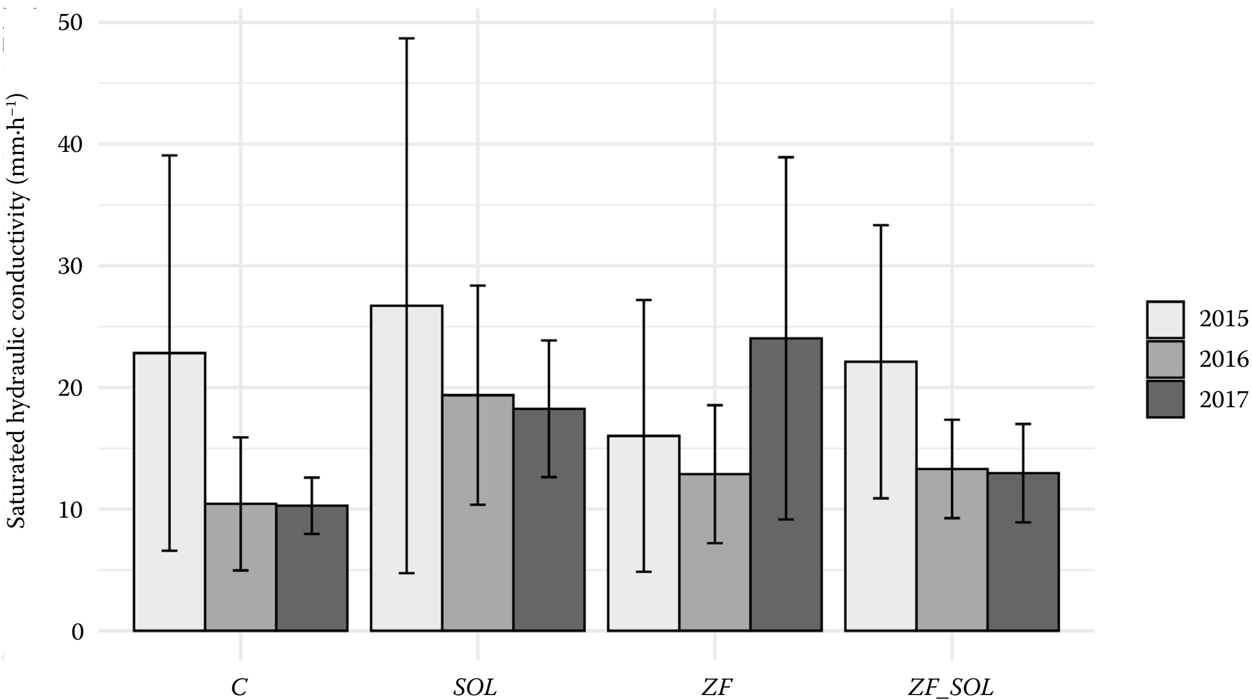

Figure 4. Saturated hydraulic conductivity measured according to the SFH method, error bars representing the standard deviation

SFH – simplified falling-head method

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Table 4. Mean values of investigated physical soil properties, and results of Kruskal-Wallis variance test

Penetration resistance (MPa) at depth	variant	2015				2016				2017			
		mean	*C*	*SOL*	*ZF*	mean	*C*	*SOL*	*ZF*	mean	*C*	*SOL*	*ZF*
0.04 m	*C*	0.29	–	–	–	0.25	–	–	–	0.02	–	–	–
	SOL	0.29	0.89	–	–	0.24	1	–	–	0.05	0.517	–	–
	ZF	0.28	0.97	0.89	–	0.33	0.14	0.14	–	0.08	0.236	0.517	–
	ZF_SOL	0.36	0.85	0.85	0.85	0.25	1	1	0.16	0.11	**0.042**	0.236	0.517
0.08 m	*C*	0.49	–	–	–	0.44	–	–	–	0.25	–	–	–
	SOL	0.84	0.26	–	–	0.49	0.52	–	–	0.39	0.33	–	–
	ZF	0.74	0.7	0.7	–	0.61	**0.014**	0.078	–	0.42	0.13	0.38	–
	ZF_SOL	0.53	0.7	0.26	0.7	0.48	0.383	0.969	**0.034**	0.32	0.28	0.63	0.56
0.12 m	*C*	1.19	–	–	–	0.69	–	–	–	0.47	–	–	–
	SOL	1.50	0.67	–	–	0.92	0.74	–	–	0.66	0.53	–	–
	ZF	1.39	0.91	0.77	–	1.03	0.24	0.74	–	0.59	0.53	0.78	–
	ZF_SOL	0.96	0.91	0.67	0.89	0.74	0.51	1	0.47	0.56	0.74	0.62	0.62
0.16 m	*C*	1.92	–	–	–	0.99	–	–	–	0.89	–	–	–
	SOL	2.99	0.66	–	–	1.78	0.056	–	–	1.02	0.76	–	–
	ZF	2.14	0.74	0.69	–	1.58	**0.026**	0.622	–	1.10	0.76	0.76	–
	ZF_SOL	2.03	0.74	0.69	0.74	1.55	0.189	0.622	0.849	0.83	0.76	0.76	0.76
0.20 m	*C*	3.45	–	–	–	1.45	–	–	–	1.03	–	–	–
	SOL	3.87	1	–	–	2.29	0.084	–	–	1.12	0.76	–	–
	ZF	3.27	1	1	–	1.95	0.084	0.303	–	1.39	0.72	0.72	–
	ZF_SOL	3.75	1	1	1	1.82	0.151	0.296	0.595	1.00	0.76	0.76	0.72
Infiltration (mm·h^{-1})	*C*	22.82	–	–	–	10.43	–	–	–	10.27	–	–	–
	SOL	26.71	0.76	–	–	19.36	0.11	–	–	18.24	< **0.001**	–	–
	ZF	16.02	0.71	0.71	–	12.87	0.42	0.23	–	24.04	< **0.001**	0.739	–
	ZF_SOL	22.11	0.76	0.85	0.71	13.30	0.23	0.23	0.8	12.95	**0.021**	0.02	0.08
Unit draft (kN·m^{-2})	*C*	29.31	–	–	–	39.09	–	–	–	53.82	–	–	–
	SOL	29.98	0.414	–	–	39.44	0.798	–	–	56.75	**0.0307**	–	–
	ZF	25.09	< **0.001**	< **0.001**	–	34.53	< **0.001**	< **0.001**	–	51.60	**0.048**	< **0.001**	–
	ZF_SOL	26.53	**0.0277**	**0.0039**	0.156	39.08	**0.042**	0.203	< **0.001**	59.47	< **0.001**	0.086	< **0.001**
Bulk density (g·cm^{-3})	*C*	1.24	–	–	–	1.30	–	–	–	1.27	–	–	–
	SOL	1.21	–	–	–	1.27	–	–	–	1.25	–	–	–
	ZF	1.14	–	–	–	1.30	–	–	–	1.30	–	–	–
	ZF_SOL	1.18	–	–	–	1.31	–	–	–	1.28	–	–	–

Statistically significant on a significance levels α = 0.05 in bold; *C* – pig slurry + NPK; *SOL* – pig slurry + PRP SOL + NPK; *ZF* – pig slurry treated by Z'fix + NPK; *ZF_SOL* – pig slurry treated by Z'fix + PRP SOL + NPK

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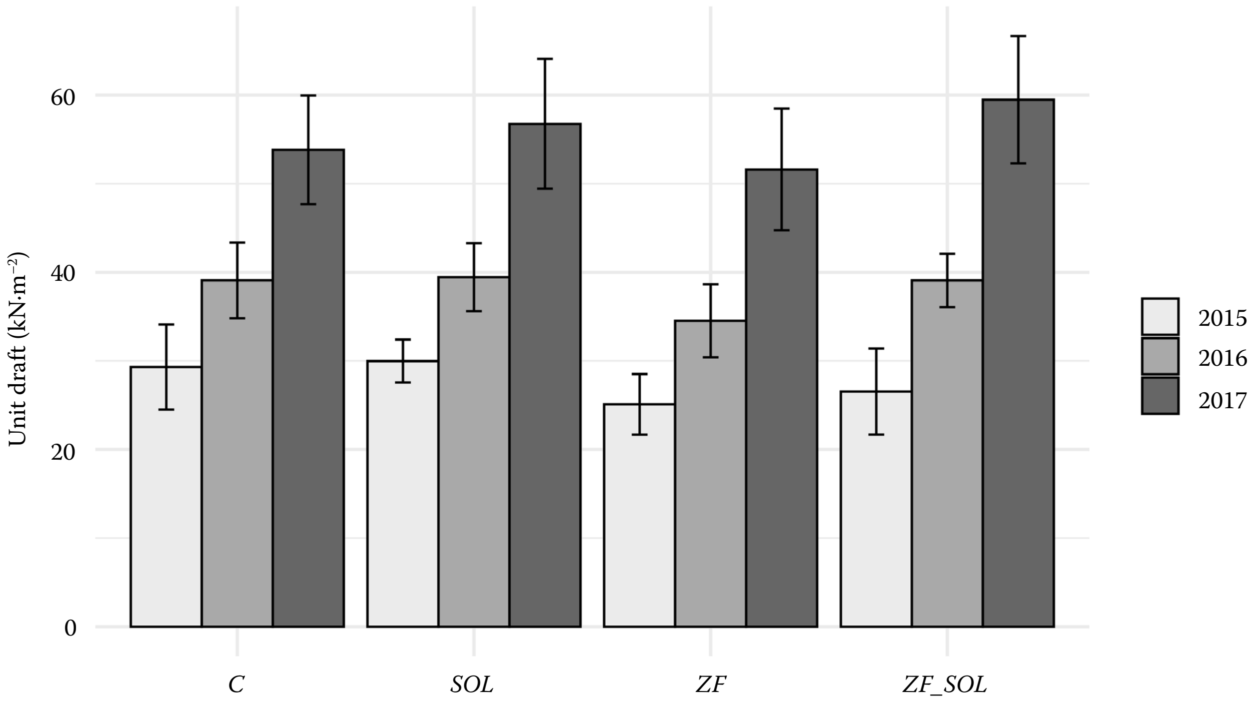

Figure 5. Unit draft obtained by dynamometer with strain gauge S-38/200kN, error bars representing the standard deviation

raised to the level of variants *C* and *SOL*, thus, only leaving the variant *ZF* to be significantly different. In 2017, the variant *ZF_SOL* continued its increase relative to the control variant, and the variant *SOL* also joined this trend. All three variants presented significant differences compared to the control variant, with the variants *SOL* and *ZF_SOL* having higher values and the variant *ZF* having lower values. The largest change could be observed in *ZF_SOL*, where the increase in the unit draught value was 20% relative to the control variant between the years 2015 and 2017. In a similar way, an increase of 10.3% was attained concerning the variant *ZF*, and mere 3.2% increase within the variant *SOL*. The study written by Urbanovičová et al. (2018) mentioned a decrease in the energy intensity for the soil treatment by 5.71% during the soil treatment with PRP SOL, which was, therefore, not confirmed.

CONCLUSION

The results evaluate the effect of using organic matter activators alongside a pig slurry application, which was taken as the control. After three years of applying the activators together with the pig slurry, significant differences among the variants were observed in some cases. Contrary to the initial assumption, the effect was mostly adverse, i.e. increasing values, concerning the soil bulk density, penetration resistance, and unit draught. Namely, the variant with the pig slurry treated by Z'fix (*ZF*) increased the values of the soil bulk density and penetration resistance. The unit draught of the tillage implement was amplified particularly when applying the pig slurry treated by Z'fix and *SOL* (*ZF_SOL*). On the other hand, the activators had a significant positive effect, i.e. increasing values, on the soil infiltration. Particularly in the case of the *SOL* and *ZF* variants. The results seem ambiguous, but provide a good indication of the effects of the activators in practice. It must be taken into consideration that the study does not provide a thorough assessment of the activators, but is aimed merely at their impact on the soil's physical properties. For instance, the study does not assess the effect of the Z'fix activator on the pig housing welfare, nor the effect of the activators on the crop yield. In order to explore the ways of operation of the activators in the soil, a thorough laboratory experiment would have to be accomplished. Since only a few studies on this topic can be found, and regarding the results proving certain impacts on the soil's physical properties, it is highly recommended to focus on selected soil amendments in the fvuture to acquire long-term results.

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