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Soil physical properties and crop status under cattle manure and Z'Fix in Haplic Chernozem

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Abstract: A three-year experiment was conducted to investigate the effect of Z'Fix on soil physical properties and crop status. Z'Fix is an agent recommended as an addition to animal bedding to prolong its function and to lower ammonia emissions in stables. Concurrently, a positive effect on organic matter transformation in resulting manure is claimed. The experiment involved control, farmyard manure (FYM), and farmyard manure with Z'Fix (FYM_ZF) as variants. In-field sampling was conducted for cone index, water infiltration and implement a unit draft, where the latter two showed significant differences in favour of FYM_ZF. Also, concerning crop yields, FYM_ZF consistently attained the highest values, followed by FYM throughout all three seasons. Furthermore, remotely sensed data were analysed to describe crop status *via* normalised difference vegetation index where significant differences were found across all variants. Based on the study, FYM_ZF demonstrated positive effects both on soil properties and crop conditions.

Keywords: organic fertiliser; biological transformation; field experiment; pedocompaction; remote sensing

The positive effect of soil organic matter (SOM) on the physical, chemical and biological soil properties has already been well described. A high SOM level is related to improved soil properties resulting in higher water infiltration and nutrients accessibility. According to Lal (2020), SOM increases the available water capacity for all soil types. Besides others, such a list of benefits leads to increased biomass and eventually crop yields (Bauer and Black 1994, Berzsenyi et al. 2000, Önemli 2011). Farmyard manure is one of the most common ways to reintroduce quality organic matter to the soil. Compared to synthetic fertilisers, manure application strongly and positively affects the relative yield by increasing soil organic carbon storage, soil nutrients, and soil pH (Cai et al. 2019, Voltr et al. 2021). However, due to various socio-economic changes over the recent 30 years, there has been a significant decrease in animal husbandry in the Czech Republic. The numbers of cattle were reduced by 60% (Czech Statistical Office 2021). Therefore, the amount of produced organic fertiliser is limited nowadays. Together with still more intensive agricultural practice, it results in a serious lack of SOM that is further related to a number of other environmental issues, for example, to low water infiltration ability leading to surface

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runoff and related soil erosion (Matula 2003). In contrast with the benefits in the form of quality organic matter, it is necessary to pay attention to the negative aspects of livestock breeding as well. According to the estimates, livestock farming accounts for 18% of greenhouse gases. The largest source of these gases is cattle breeding, which accounts for about 65% (Gerber et al. 2013). The optimisation of organic fertiliser production with respect to their environmental footprint is therefore undeniably necessary. Manure agents are the substances that are used by farmers to enhance the welfare of animals, control produced odours, and eventually increase fertiliser value (Cluett et al. 2020). Z'Fix (Olmix Group, Bréhan, France) is one representative of such agents. It is a dust-free pearled pellet, which can be added to deep animal bedding, but it is applicable to all types of farm fertilisers (manure, slurry, compost). Some studies already evaluated the effect of Z'Fix both on animal welfare and organic fertiliser properties. When applied directly to straw bedding, the fermentation process is enhanced, resulting in better manure quality. The higher nutrient content was also determined (Šařec et al. 2017a). In combination with pig slurry, it is trusted to increase crop yield and micronutrients content (Mozdzer and Chudecka 2017). Nevertheless, the exact impact on major soil physical properties was not yet sufficiently described. Reduced bulk density after application of manure treated by Z'Fix was examined by Šařec et al. (2017b), where the conclusion confirmed the positive effect of Z'Fix compared to control (NPK) on heavy soils. Since this activator is claimed to positively influence SOM, the objective of this study is to verify this statement in a three-year study conducted in real conditions. Hypotheses that are about to be verified are related to (a) reduction of cone index and implement a unit draft, and (b) increase of the infiltration ability of the soil. Moreover, the secondary impact of Z'Fix on crop status is about to be examined *via* spectral index derived from remotely sensed data.

MATERIAL AND METHODS

Farmyard manure agent Z'Fix. Z'Fix is an activator of the biological transformation used in stables to enhance the quality of bedding by controlling the fermentation process of organic matter. The primary benefit here is animal welfare; the manufacturer, however, claims that there is also a secondary effect for resulting organic fertiliser. Z'Fix is produced in the form of granules based on calcium and magnesium carbonates with an admixture of micro- and macro-elements (potassium, sodium, sulphur, iron, manganese), which is designed to regulate fermentation processes in manure and compost. The composition of Z'Fix is: organic matter – 5%, Ca – 26.8%, Mg – 2.7%, Na – 2.88%, S – 0.28%, K – 0.42%, P – 0.04%, Fe – 2 000 ppm; Mn – 150 ppm, Zn – 30 ppm. The patented MIP (mineral inducer process) technology uses bioactive properties of minerals and specific trace elements in order to stimulate the biological reactions of the plant and the microflora within the soil.

The site and crop management. The field experiment was conducted near the town of Městec Králové, Central Bohemian Region, Czech Republic (50°12'56.8''N, 15°19'50.6''E, 235 m a.s.l.) during 2018–2020 cropping seasons. The experimental field of the farm company ZS Slověč, a.s. involved three smaller plots according to the agricultural management. The area of the control variant (C) was 1 ha, while the variant with pure farmyard manure (FYM) and farmyard manure treated by Z'Fix (FYM_ZF) had 5 ha. The distribution of experimental variants was performed with respect to the dimensions of the field.

According to the national system, the soil type is Haplic Chernozem. According to the USDA triangle diagram, it is clay loam soil. Selected chemical properties of the soil on the monitored plot are shown in Table 1.

NPK fertiliser was applied at the rate corresponding to the farm-specific agricultural standards concerning crop demand for pure nutrients. Cattle manure (FYM and FYM_ZF) dosages were as follows: 2017 – 50 t/ha; 2019 – 30 t/ha. Concerning the FYM_ZF variant, Z'Fix was applied at the rate of 1 kg/head/week directly to deep bedding. The composition characteristics of manure and manure treated by

Table 1. Chemical soil properties

		Soil depth (cm)	
		0–30	30–60
C	(%)	3.1	2.7
C/N ratio		9.7	6.9
pH_{KCl}		7.1	7.2
K	(ppm)	797	697
Ca		7 532	8 036
Mg		350	337
P		159	123

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Table 2. Cattle manure chemical analysis for variants FYM (farmyard manure) and FYM_ZF (farmyard manure with Z'Fix)

Variant	Dry matter	N	C:N	P	K	Ca	Mg	pH
	(%)			(%)				
FYM	23.1	0.56	22.3:1	0.162	0.573	0.35	0.096	8.4
FYM_ZF	23.6	0.69	18.1:1	0.179	0.739	0.458	0.12	9.4

Z'Fix are shown in Table 2. The crop rotation system during the investigated seasons was as follows: sugar beet (2018), poppy (2019), and winter wheat (2020). Since soil properties are strongly influenced by water content, the information about precipitation is given in Figure 1.

Data acquisition and processing. To assess the physical soil properties, two field visits were accomplished each year. Cone index (CI), water infiltration (WI), and implement unit draft (IUD) were investigated. CI was measured in spring terms when the soil profile was more likely to have been evenly saturated with water. The measurements of the IUD and WI took place in the autumn terms, i.e., it followed the crop harvest, as it was a common practice for this kind of measurements.

CI is a staple indicator of pedocompaction, where higher values negatively impact the crop's ability to penetrate the soil profile and thus create a rich root system. CI is basically a measure of soil resistance against a cone with precisely described geometric properties (angle, area). To obtain such data, the penetrometer PN70 was developed at the Czech University of Life Sciences Prague. This custom-made device meets all requirements of the agriculture normative ASAE S313.3 (ASABE). Measurements of CI were conducted in the spring term of each cropping season with ten repetitions per variant.

WI was examined using a rain simulator. This instrument was designed to measure not only parameters of erosion but also soil infiltration characteristics using a color dye. Usually, blue dye as a solution of water and brilliant blue (E 133) is used to spray the surface by the rain simulator for a period of 1 h. Such an application is followed by a 5 h break, during which the blue dye penetrates the soil profile. Afterwards, the soil profile is removed to a depth of approximately 40 cm and photographed. This method of infiltration characteristics assessment is based on image analysis (Figure 2). In the case of this study, the measurement was repeated three times per each variant. The soil profile was captured by a digital camera and further analysed by computer software Gwyddion 2.30 (Brno, Czech Republic). The pre-processing procedure involved cutting the image according to precisely located pins in order to analyse the exact same area recurrently, determining colour zones, and eliminating low-size soil particles to avoid errors caused by reflection. Further, the image was converted to a binary image, where the black colour defined the soil profile, and the white colour indicated the infiltrated area. In

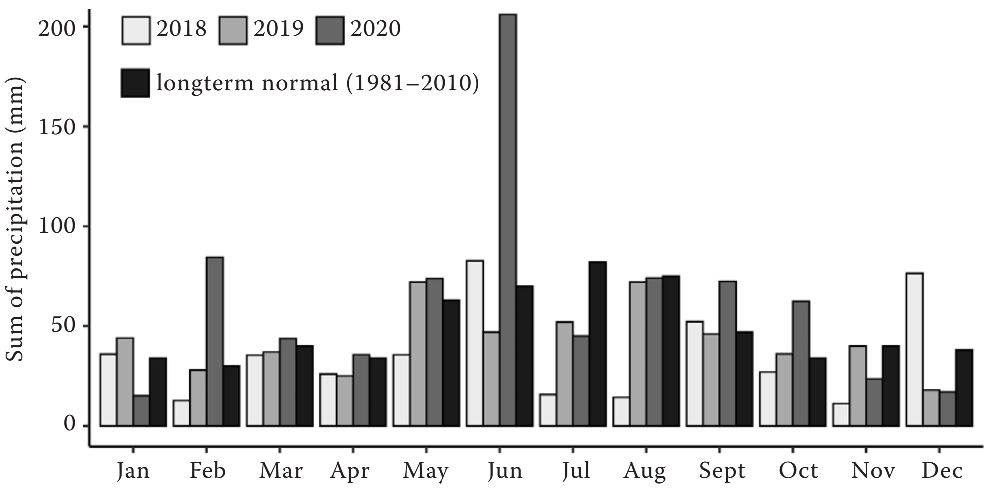

Figure 1. Rainfall conditions during investigated cropping seasons compared to a longterm normal

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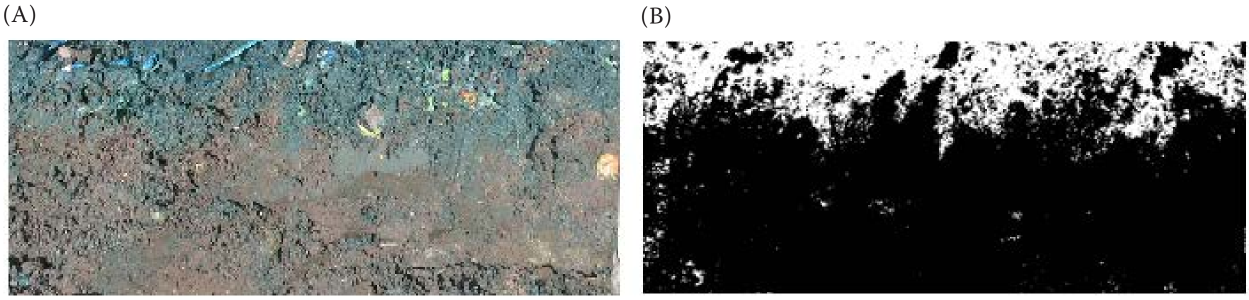

Figure 2. Water infiltration assessed by the rainfall simulator *via* (A) a digital image converted to (B) a binary image

this format, the image was also processed in ImageJ software (LOCI, Madison, USA), where the total image area was calculated together with the determination of percentages representing soil profile (black) and infiltrated part of it (white).

Energy demand for soil tillage is commonly described by the IUD. The IUD was determined using a drawbar dynamometer with strain gauge S-38/200kN (Lukas, Prague, Czech Republic) placed between the towing and the towed tractor. The IUD was measured using a tine cultivator Köckerling Vario 480 (Verl, Germany), during several passes of the machinery across each variant. The measurement was conducted under a constant speed and at a set tillage depth (2018 – 11 cm; 2019 – 17 cm; 2020 – 7 cm). The tillage depth was checked after each pass. In order to determine the potential influence of terrain slope and the rolling resistance of the towed tractor, machinery passes were repeated with the tillage implement, not in work. Data was collected using the system NI CompactRIO (National Instruments Corporation, Austin, USA), the sampling rate frequency was 0.1 s. GPS location was assigned to measured values using Trimble Business Center 2.70 (Trimble, Sunnyvale, USA).

Crop yields were measured using three separate passes of a harvester per each variant. The yield was weighed after each pass. When relevant, samples were taken to ascertain representative characteristics of the harvested product.

Since the set of soil properties has a direct impact on cropped vegetation, crop status within investigated variants was also evaluated. In the presented study, freely available Sentinel-2 satellite images (European Space Agency) with atmospheric correction and 10 m spatial resolution were collected and processed to obtain the normalised difference vegetation index (NDVI). NDVI is considered as a common indirect indicator of vegetation greenness and health (Rouse et al. 1974) and is often used to describe actual crop status. Each variant was then described by the mean value of NDVI of all pixels within its boundary.

Statistics. The acquired dataset of all investigated soil and crop properties was eventually statistically analysed with the aim to describe potential differences between investigated variants. The required homogeneity of variances for ANOVA utilisation was not met in the case of soil physical properties; therefore, a non-parametric Kruskal-Wallis test of variance was applied. Nevertheless, remotely sensed data met the ANOVA requirements, and so NDVI variance was evaluated using a standard parametric test (ANOVA with random effect of the term) followed by Tukey *HSD* (honestly significant difference) test for multiple comparisons. For all the computations, the R version 4.0.4 (R Core Team 2021) with packages *readexcel*, *tidyverse*, and *reshape2* was utilised. Plots were further generated using the *ggplot* package (Vienna, Austria).

RESULTS AND DISCUSSION

Table 3 provides the results of the Kruskal-Wallis variance test for all investigated soil properties. CI was monitored in soil profile depths of 4, 8, 12, 16, and 20 cm. Although there was no statistically significant difference between variants, the trend depicted in Figure 3 shows the lowest values within FYM_ZF compared to the other two variants almost at all depth levels. In terms of WI, FYM_ZF performed the best since the analysis showed a significant difference compared to C in 2018 and 2020, i.e., in the years straight after the manure application. The situation in particular soil profile levels is presented in Figure 4, where FYM_ZF shows the best infiltration characteristics at all depths and years. Eventually, IUD results indicated significant differences in FYM and FYM_ZF compared to C in seasons 2018 and 2020, i.e., again instantly after the manure application. Figure 5 provides the overview

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Table 3. Descriptive statistics of investigated physical soil properties within variants C (control), FYM (farmyard manure), and FYM_ZF (farmyard manure with Z'Fix)

	Variant	2018			2019			2020		
		mean ± SD	C	FYM	mean ± SD	C	FYM	mean ± SD	C	FYM
CI (MPa)										
4 cm	C	0.35 ± 0.334	–	–	0.43 ± 0.134	–	–	0.55 ± 0.127	–	–
	FYM	0.422 ± 0.406	0.8	–	0.4 ± 0.125	0.97	–	0.55 ± 0.085	0.91	–
	FYM_ZF	0.39 ± 0.281	0.8	0.84	0.42 ± 0.123	0.97	0.97	0.58 ± 0.199	0.91	0.91
8 cm	C	1.17 ± 0.587	–	–	0.83 ± 0.125	–	–	0.99 ± 0.247	–	–
	FYM	1 ± 0.568	0.68	–	0.83 ± 0.2	0.72	–	0.89 ± 0.233	0.45	–
	FYM_ZF	0.94 ± 0.712	0.59	0.68	0.77 ± 0.067	0.72	0.72	0.8 ± 0.125	0.13	0.48
12 cm	C	2.04 ± 0.532	–	–	1.07 ± 0.267	–	–	1.33 ± 0.424	–	–
	FYM	1.289 ± 0.528	0.4	–	0.94 ± 0.158	0.53	–	1.12 ± 0.355	0.36	–
	FYM_ZF	1.2 ± 0.506	0.4	0.54	0.9 ± 0.141	0.32	0.53	1.07 ± 0.350	0.2	0.62
16 cm	C	2.04 ± 0.532	–	–	1.45 ± 0.493	–	–	1.62 ± 0.450	–	–
	FYM	1.744 ± 0.332	0.45	–	1.09 ± 0.238	0.092	–	1.53 ± 0.291	0.91	–
	FYM_ZF	1.75 ± 0.453	0.45	1	1.01 ± 0.166	0.058	0.509	1.45 ± 0.328	0.91	0.91
20 cm	C	2.36 ± 0.497	–	–	1.71 ± 0.547	–	–	1.99 ± 0.482	–	–
	FYM	2.011 ± 0.289	0.42	–	1.25 ± 0.242	0.054	–	2.03 ± 0.416	0.62	–
	FYM_ZF	2.25 ± 0.54	0.73	0.45	1.24 ± 0.299	0.054	0.787	1.8 ± 0.422	0.57	0.57
UID (kN/m^2)	C	105.11 ± 4.131	–	–	170.8 ± 5.376	–	–	246.571 ± 14.095	–	–
	FYM	104.62 ± 5.833	0.82	–	172.77 ± 4.973	0.29	–	243.47 ± 14.340	0.26	–
	FYM_ZF	97.86 ± 6.713	**< 0.001**	**< 0.001**	168.82 ± 6.766	0.29	0.1	233.43 ± 15.319	**< 0.001**	**< 0.001**
WI (%)	C	22.724 ± 8.566	–	–	22.34 ± 3.195	–	–	12.76 ± 3.163	–	–
	FYM	30.243 ± 13.447	0.325	–	36.827 ± 4.853	0.0591	–	22.253 ± 5.003	0.198	–
	FYM_ZF	48.975 ± 18.093	**0.034**	0.146	53.02 ± 5.256	0.0097	0.0591	34.82 ± 5.391	**0.013**	0.198

Results of Kruskal-Wallis variance test (significance level $P < 0.05$ in bold). SD – standard deviation; CI – Cone index; IUD – implement unit draft; WI – water infiltration

for all three seasons. Furthermore, vegetation status expressed by means of NDVI was evaluated, and results are presented in Table 4. Even though three different crops were evaluated, statistically significant differences were indicated by ANOVA in all levels ($P < 0.01$). The secondary impact of a particular treatment on crop status is also demonstrated by yield information provided in Table 5. The best yields were consistently attained by FYM_ZF, followed by FYM throughout all three seasons. As demonstrated

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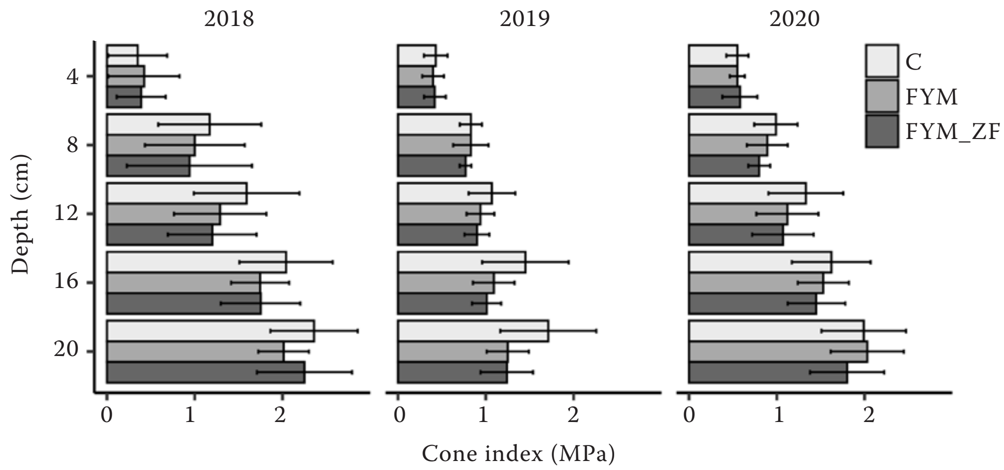

Figure 3. Cone index acquired by the penetrometer PN70, error bars representing standard deviation. C – control; FYM – farmyard manure; FYM_ZF – farmyard manure with Z'Fix

in Table 5, the differences in yields were significant between FYM_ZF and C in the case of sugar beet and winter wheat. Also, the sugar content reached by FYM and FYM_ZF was significantly higher than the one attained by C.

CI represents a staple soil property since it is closely related to root architecture and thus also a water uptake (Colombi et al. 2018). CI around 2.5 MPa is considered the threshold where higher values directly restrict the plant growth (Whalley et al. 2007). In the case of this study, this threshold was not reached within any variant, nor depth. However, positive effects of Z'Fix treatment may be observed through the reduced CI values in comparison with control and pure manure. The study of Celik et al. (2010) confirms that the application of organic fertilisers leads to a reduction in CI. In our study, FYM_ZF performs even better than FYM in most of the cases, and this beneficial effect, even though not significant, is likely to be supported by Z'Fix addition. The reduction of CI in upper layers of the soil profile is in line with findings of the study of Čermáková et al. (2019). When CI was lower when using Z'Fix.

The results of WI using a rain simulator showed a trend that was maintained during all monitored seasons. These results seem to be very interesting, as they do not provide a simple point information since the area under investigation involves approx. 4 square meters of the soil profile. The highest WI was always achieved by the FYM_ZF variant. In addition, there were statistically significant differences between C and FYM_ZF each season following manure application. The results clearly show an improvement of infiltration conditions for the FYM_ZF variant,

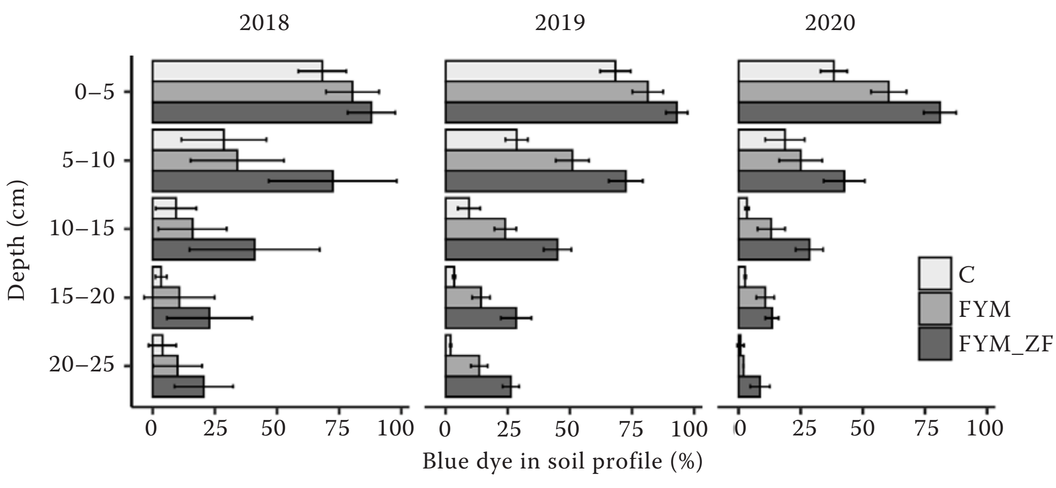

Figure 4. Percentage of infiltrated area (WI) using rainfall simulator in specific levels error bars representing the standard deviation. C – control; FYM – farmyard manure; FYM_ZF – farmyard manure with Z'Fix

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Table 4. Descriptive statistics of normalised difference vegetation index (NDVI) (best performing variant in bold) and results of ANOVA with random effect (term) through Tukey *HSD* (honestly significant difference) test (*sowing date; $^{\times}$harvest date)

Sugar beet 31. 3. 2018* 23. 10. 2018$^{\times}$	Tukey *HSD*	19. 4.	21. 4.	29. 4.	4. 5.	21. 5.	26. 5.	3. 7.	5. 7.	22. 8.	27. 8.	29. 8.	18. 9.	28. 9.	11. 10.
FYM	b	0.231 ± 0.010	0.225 ± 0.008	0.219 ± 0.009	0.276 ± 0.010	0.635 ± 0.052	0.742 ± 0.034	0.883 ± 0.006	0.823 ± 0.007	0.577 ± 0.026	0.593 ± 0.026	0.602 ± 0.025	0.640 ± 0.031	**0.663** ± 0.035	**0.672** ± 0.035
FYM_ZF	c	**0.234** ± 0.010	**0.231** ± 0.009	**0.226** ± 0.009	**0.286** ± 0.010	**0.705** ± 0.062	0.781 ± 0.040	**0.886** ± 0.009	**0.827** ± 0.012	**0.605** ± 0.045	**0.627** ± 0.045	**0.626** ± 0.041	**0.646** ± 0.051	0.651 ± 0.045	0.648 ± 0.038
C	a	0.227 ± 0.010	0.223 ± 0.008	0.219 ± 0.009	0.280 ± 0.008	0.700 ± 0.024	**0.781** ± 0.013	0.881 ± 0.007	0.819 ± 0.010	0.556 ± 0.022	0.569 ± 0.024	0.581 ± 0.022	0.597 ± 0.031	0.603 ± 0.030	0.610 ± 0.028
Poppy 1. 3. 2019* 26. 7. 2019$^{\times}$		1. 4.	4. 4.	21. 4.	26. 5.	3. 6.	5. 6.								
FYM	b	0.213 ± 0.014	0.181 ± 0.016	0.254 ± 0.020	**0.859** ± 0.008	**0.929** ± 0.004	**0.908** ± 0.005								
FYM_ZF	c	0.222 ± 0.011	0.195 ± 0.011	0.265 ± 0.013	0.857 ± 0.008	0.927 ± 0.004	0.904 ± 0.006								
C	a	**0.227** ± 0.009	**0.206** ± 0.011	**0.271** ± 0.009	0.857 ± 0.011	0.925 ± 0.008	0.904 ± 0.010								
Winter wheat 4. 10. 2019* 23. 7. 2020$^{\times}$		31. 10.	30. 11.	24. 3.	29. 3.	5. 4.	8. 4.	20. 4.	23. 4.	28. 4.	8. 5.	18. 5.			
FYM	b	0.395 ± 0.056	0.661 ± 0.065	0.801 ± 0.039	0.755 ± 0.038	0.723 ± 0.034	0.751 ± 0.029	0.824 ± 0.017	0.846 ± 0.015	0.835 ± 0.015	0.856 ± 0.012	0.897 ± 0.011			
FYM_ZF	c	**0.454** ± 0.025	**0.738** ± 0.030	**0.852** ± 0.022	**0.815** ± 0.022	**0.783** ± 0.023	**0.803** ± 0.022	**0.838** ± 0.016	**0.855** ± 0.015	**0.840** ± 0.015	**0.864** ± 0.011	**0.898** ± 0.008			
C	a	0.351 ± 0.030	0.584 ± 0.031	0.761 ± 0.032	0.738 ± 0.038	0.712 ± 0.035	0.746 ± 0.033	0.811 ± 0.021	0.834 ± 0.018	0.826 ± 0.018	0.853 ± 0.013	0.890 ± 0.011			

C – control; FYM – farmyard manure; FYM_ZF – farmyard manure with Z'Fix

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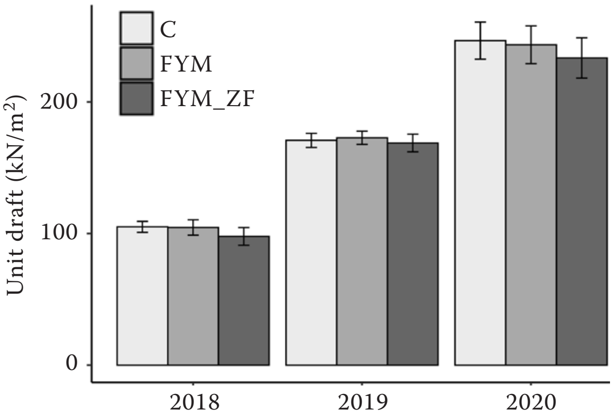

Figure 5. Implement unit draft obtained by dynamometer with strain gauge S-38/200kN, error bars representing the standard deviation. C – control; FYM – farmyard manure; FYM_ZF – farmyard manure with Z'Fix

as well as the general effect of manure and other organic matter, but to a lesser extent than when using activators. Concerning the fact that the WI is influenced by the bulk density (Chyba et al. 2017), WI results of the present study concurrently confirm the conclusions of the study of Šařec et al. (2017b), which described the favourable effect of Z'Fix on soil properties, bulk density, respectively.

The reduction in IUD within FYM_ZF is in line with the results obtained in previous small-plots one-year studies on two different soil types, where cattle manure treated by Z'Fix was applied (Šařec and Žemličková 2016, Žemličková and Šařec 2016). Tillage is one of the most energy-intensive operations in agriculture. The implement draft of FYM_ZF decreased by 4.5% (three-years average) compared to FYM. This decrease might result in fuel savings of about 0.45 L/ha (assuming average power delivery efficiency of around 50% and the fuel requirements of tillage operations at the level of 20 L/ha). However, the benefit is not only linked directly to fuel consumption and costs but also to the reduced emissions produced during tillage (Lal et al. 2019). Finally, vegetation conditions were evaluated. A total of 31 satellite images between 2018–2020 were analysed to derive the NDVI index. The beneficial effect of the Z'Fix during the emergence phase could be observed by sugar beet (2018) and wheat (2020). However, the effect was uncertain in 2019 (Table 4). Z'Fix seemed to maintain beneficial even during the drought periods. Although the months of July and August were really dry in 2018 (Figure 1), FYM_ZF kept showing the highest NDVI values. This observation is in line with the statement of Šařec et al. (2017b), which declares that Z'Fix can alleviate the stress of vegetation in the dry season.

Table 5. Descriptive statistics of yield parameters during the period of field experiment and results of one-way ANOVA through Tukey *HSD* (honestly significant difference) test (statistically significant results with $P < 0.05$ marked as bold)

Year	Variable	Variant	Mean ± SD	C	FYM
2018	sugar beet yield (t/ha)	C	55.19 ± 2.38	–	–
		FYM	58.60 ± 1.84	0.150	–
		FYM_ZF	61.17 ± 1.33	**0.020**	0.295
	sugar content (%)	C	19.00 ± 0.46	–	–
		FYM	21.80 ± 0.70	**0.002**	–
		FYM_ZF	22.20 ± 0.30	**0.001**	0.629
2019	poppy yield (t/ha)	C	0.82 ± 0.10	–	–
		FYM	0.89 ± 0.06	0.555	–
		FYM_ZF	0.97 ± 0.07	0.126	0.473
	poppy seed and straw mix yield (t/ha)	C	1.41 ± 0.09	–	–
		FYM	1.49 ± 0.07	0.496	–
		FYM_ZF	1.56 ± 0.09	0.141	0.576
2020	winter wheat yield (t/ha)	C	7.60 ± 0.27	–	–
		FYM	8.13 ± 0.20	0.322	–
		FYM_ZF	8.66 ± 0.62	**0.044**	0.322

SD – standard deviation; C – control; FYM – farmyard manure; FYM_ZF – farmyard manure with Z'Fix

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Eventually, based on the above-described results, the following conclusions can be drawn. CI and IUD were mostly reduced when using agent Z'Fix for manure treatment. Concurrently, WI status was found to be superior over the other variants. All those described effects on the soil environment also positively influenced the plant status indicated by NDVI and finally resulted in higher yields during investigated cropping seasons, especially in drought periods. With respect to the sustainability of agricultural production, these findings are directly applicable to the agricultural practice; nevertheless, it is necessary to verify them further under different conditions (various soil types, manures, and climatic conditions, etc.).

REFERENCES

Bauer A., Black A.L. (1994): Quantification of the effect of soil organic matter content on soil productivity. Soil Science Society of America Journal, 58: 185–193.

Berzsenyi Z., Győrffy B., Lap D.Q. (2000): Effect of crop rotation and fertilisation on maize and wheat yields and yield stability in a long-term experiment. European Journal of Agronomy, 13: 225–244.

Cai A.D., Xu M.G., Wang B.R., Zhang W.J., Liang G., Hou E., Luo Y. (2019): Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility. Soil and Tillage Research, 189: 168–175.

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: 236–243.

Čermáková N., Šařec P., Látal O. (2019): Impact of manure and selected conditionners on physical properties of clay soil. In: TAE 2019 – Proceeding of 7th International Conference on Trends in Agricultural Engineering. Prague, Czech University of Life Sciences Prague, 93–98. ISBN 978-80-213-2953-9

Chyba J., Kroulik M., Krištof K., Misiewicz P.A. (2017): The influence of agricultural traffic on soil infiltration rates. Agronomy Research, 15: 664–673.

Cluett J., VanderZaag A.C., Baldé H., McGinn S., Jenson E., Hayes A.C., Ekwe S. (2020): Effects of two manure additives on methane emissions from dairy manure. Animals, 10: 807.

Colombi T., Torres L.C., Walter A., Keller T. (2018): Feedbacks between soil penetration resistance, root architecture and water uptake limit water accessibility and crop growth – a vicious circle. Science of The Total Environment, 626: 1026–1035.

Czech Statistical Office (2021): Czech Statistical Office. Prague, Czech Statistical Office.

Gerber P.J., Steinfeld H., Henderson B., Mottet A., Opio C., Dijkman J., Falcucci A., Tempio G. (2013): Tackling Climate Change Through Livestock – A Global Assessment of Emissions and Mitigation Opportunities. Rome, Food and Agriculture Organisation of the United Nations.

Lal B., Gautam P., Nayak A.K., Panda B.B., Bihari P., Tripathi R., Shahid M., Guru P.K., Chatterjee D., Kumar U., Meena B.P. (2019): Energy and carbon budgeting of tillage for environmentally clean and resilient soil health of rice-maize cropping system. Journal of Cleaner Production, 226: 815–830.

Lal R. (2020): Soil organic matter and water retention. Agronomy Journal, 112: 3265–3277.

Matula S. (2003): The influence of tillage treatments on water infiltration into soil profile. Plant, Soil and Environment, 49: 298–306.

Mozdzer E., Chudecka J. (2017): Impact of natural fertilization using PRP fix on some soil fertility indicators. Journal of Ecological Engineering, 18: 137–144.

Önemli F. (2011): The effects of soil organic matter on seedling emergence in sunflower (*Helianthus annuus* L.). Plant, Soil and Environment, 50: 494–499.

R Core Team (2021): R: A Language and Environment for Statistical Computing. Vienna, R Foundation for Statistical Computing.

Rouse R.W.H., Haas J.A.W., Deering D.W. (1974): Monitoring Vegetation Systems in the Great Plains with ERTS. In: Proceedings of a Symposium Held – Third Earth Resources Technology Satellite-1 Symposium. Washington, NASA SP-351, 309–317.

Šařec P., Látal O., Novák P. (2017a): Technological and economic evaluation of manure production using an activator of biological transformation. Research in Agricultural Engineering, 63: S59–S65.

Šařec P., Novák P., Kumhálová J. (2017b): Impact of activators of organic matter on soil and crop stand properties in conditions of very heavy soils. In: Proceedings of the 16th International Scientific Conference Engineering for Rural Development, Jelgava.

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.

Voltr V., Menšík L., Hlisnikovský L., Hruška M., Pokorný E., Pospíšilová L. (2021): The soil organic matter in connection with soil properties and soil inputs. Agronomy, 11: 779.

Whalley W.R., To J., Kay B.D., Whitmore A.P. (2007): Prediction of the penetrometer resistance of soils with models with few parameters. Geoderma, 137: 370–377.

Žemličková N., Šařec P. (2016): Influence of application of organic matter and its activators on soil-tillage implement draft on Modal Luvisol. In: Proceedings of the 6th International Conference on Trends in Agricultural Engineering. Prague, 736–742.

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