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Determination of the influence of biostimulants on soil properties and field crop yields**

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A b s t r a c t. There are increasing demands to increase the productivity of crops grown in unfavourable soil conditions. The objective of this study was to evaluate the potential of biostimulants to improve soil properties and crop yields. A field experiment was conducted to assess the impact of Neosol (a soil activator), biostimulant Explorer (a rhizosphere activator) and AKEO (mineral fertilizer activator, Olmix Group) on soil in terms of the yields of spring and winter wheat and winter rape. Numerous soil characteristics related to soil structure were evaluated at the 0-20 and 20-40 cm depth ranges *e.g.* bulk density, soil porosity, structural coefficient. The results show that the application of biostimulants has a positive effect on soil bulk density, porosity and the structural coefficient. The biostimulants had a positive effect on the yields of crops.

K e y w o r d s: biostimulants, soil-oxidizable carbon, soil quality, soil organic matter, drought, crop yield

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INTRODUCTION

As a result of climate change, an increase in the frequency of extreme weather fluctuations is to be expected (Renne *et al.*, 2019). These fluctuations will be manifested through the intensity of water distribution and temperature increases. In recent years, a lack of precipitation has been the restraining factor in plant growth, yields, and in the subsequent decomposition of crop residues in the soil (Katerji *et al.,* 2004; Von Lützow *et al.*, 2006; Peña-Gallardo *et al.*, 2019; Mitchell-Forsytk *et al.*, 2021; Wolny-Koładka *et al.*, 2022). Disturbances such as these cause a deterioration in the physical properties of the soil through a lack of soil organic matter and also result in the degradation of the soil structure which is induced by compaction (Nimmo, 2013; Hábová *et al.*, 2016). Damage to the soil structure leads to a decline in all of the beneficial soil characteristics which has a negative impact on agricultural machinery and crop yields (Vopravil *et al.*, 2010; Farhadi-Machekposhti *et al.*, 2020). These negative factors decrease the rate of water infiltration into the soil, and as a consequence, the management of water retention in the soil profile becomes a problem (Jaša *et al.*, 2019). A lack of precipitation and soil compaction decreases the biological activity of the soil (Farahani *et al.,* 2022). The production capability of the soil is reduced

(Nimmo, 2013) since optimal physical soil properties are associated with intensive soil biological activity (Jakšík *et al.*, 2015; Kubaczyński *et al.*, 2020). Regeneration of the soil structure in terms of improved soil porosity and retention capacity ensures the infiltration of larger amounts of water (Bartlová *et al.,* 2015; Makó *et al.*, 2020; Luan *et al.,* 2021). Biostimulants have been developed in an attempt to ameliorate this problem (Caradonia *et al.*, 2019). They are defined as products consisting of one or more active natural substances, and are still acquiring an increasing degree of attention in the scientific community (Calvo *et al.*, 2014; Caradonia *et al.*, 2019; EBIC, 2020). Thanks to soil biostimulation, the contribution of soil organic matter positively influences the biological and, as a consequence, the physical properties of the soil and the utilization of nutrients (Gobin, 2012). Biostimulants stimulate the activity of rhizosphere microorganisms and soil enzymes as well as enhancing photosynthesis (Vandenkoornhuyse *et al.*, 2005; Kałużewicz *et al.*, 2017; Hellequin *et al.*, 2018). Biostimulants improve nutrient uptake and tolerance to abiotic and biotic stress, as a consequence yield quality is increased (Calvo *et al.*, 2014; Kapela *et al.*, 2020). The aim of the study is to evaluate the potential of biostimulants to improve soil properties and increase crop yields. The absence of animal production and barnyard manure necessitated the use of auxiliary soil biostimulants, which have the potential to eliminate the adverse implications of a lack of soil organic matter, as confirmed by other studies (Calvo *et al.*, 2014; Du Jardin, 2015).

MATERIALS AND METHODS

The effect of biostimulant application was assessed to form part of the study of certain products as follows: the granulate products Neosol, Explorer, and Akeo contain calcium and magnesium carbonates, macroelements (Ca, Mg, N, P, K, S, Na), and microelements (Fe, Zn, Mn, B, Cu, I) specified by the MIP (Mineral Inducer Process) system (patent by Olmix, France).

The product characteristics are as follows: dry matter 98.9%, dry matter crude ash 25.0%, pH 8.0-10.0, calcium (CaO) – 28.0%, and magnesium (MgO) – 15.9%.

Organic carbon was determined using the oxidation-titration method with the use of a mineralization block according to Nelson and Somers (1982). The Kjeldahl method was used to determine the total nitrogen content in the soil. It is based on the complete decomposition of soil organic matter with concentrated hot sulfuric acid. The symbol C/N denotes the proportion of organic carbon (C) to total nitrogen (N). This proportion is determined using standards from the humus horizons of both organic and mineral soils, as well as from the level of the bottoms of podzolic soils. A narrow C/N ratio (*e.g.* up to 12) means the rapid (efficient) decomposition of organic matter in the soil, and a broad ratio (*e.g.* over 20) means slower decomposition and the accumulation of organic matter. The lowest C/N value (below 4 on occasion) is found in the mineral horizons of soils, and the highest - in peat soils of raised bogs (over 60 on occasion). The C/N value indicates the biological activity of soils as manifested by the degree of decomposition of organic matter in the soil. Low C/N values indicate a high soil biological activity, and a high value indicates the opposite.

The field experiment was conducted in 2017-2019 in a field registered in Litobratrice village cadastre, south Moravia, in the Czech Republic. In 2016, sugar beet (*Beta vulgaris*) was grown as a forecrop. Primarily, the plots were prepared by deep chiselling up to a 30 cm depth during autumn 2016 after the sugar beet harvest. Next, spring wheat (*Triticum aestivum*) and winter wheat (*Triticum aestivum*) were grown in 2017 and 2018, respectively. In 2019, winter rape (*Brassica napus*) was cultivated. In spring 2017, soil biostimulants were applied at a dose of 150 kg ha^{-1} after spring wheat was sown. The second portion of the biostimulants was applied at a dose of 150 kg ha^{-1} after winter wheat was sown in autumn 2017. In 2017 there was a double application due to the conditions for application before seeding. During 2017 the spring crop was planted first, this was followed by the autumn crop. In the autumn of 2018, the third wide application of 150 kg ha^{-1} of soil biostimulants was performed a week after winter rape seeding. In 2019 the same application of biostimulants was performed as in the previous year. As a part of the field experiment, the physical and chemical soil properties as well as the yields of the main field crops (spring wheat, winter wheat, and winter rape) were assessed. Biostimulants were applied through the use of wide spreading and incorporated into the soil by applying a preseeding soil treatment using a seeding machine. The depth of application ranged from approximately 5 to 10 cm. Each variant was assigned an area of 3 ha. The plots were 36 m wide and 850 m long. A description of the individual variants is shown in Table 1.

The field experiment was located in a corn production area, at an altitude of 210 m above sea level and in a very hot and dry climate zone (VH – very hot).

Soil type and conditions: modal black soil on loess, mid-heavy, heavy, soil texture: loamy to clayey-loamy. The classification was carried out according to the taxonomic soil classification system of the Czech Republic (Němeček, 2011).

Table 1. Variants of the field experiment

Variant	Fertilization
1	Control
2	Neosol – soil vital function activator
3	Akeo – soil biomass activator for mixing with fertilizer
4	Explorer – stimulator of rhizosphere biological activity

The annual precipitation in the experimental location was 380 mm in 2017. There was only 66.2 mm of rainfall during the vegetation period. In 2018, the annual precipitation was 411 with 87 mm of rainfall during the vegetation period. The average annual temperature was within the range of 9-10°C, with a temperature of 15.3°C occurring during the vegetation period. The annual precipitation in 2019 was 487 with 360 mm of rainfall occurring during the vegetation period. 2017 was typical with a dry and warm spring. 2018 was atypical, as it was characterized by a very early spring and unusually high temperatures at the beginning of March with minimum rainfall. 2019 was characterized by a very dry spring with the early and rapid onset of weather normally associated with summer, unusually high temperatures occurred in March and April. The highest precipitation rates were recorded in September.

The following physical soil parameters were determined: bulk density, total soil porosity, minimum air capacity and maximum capillary water capacity.

Soil density was determined in terms of the ratio of the volume of the void mass of the soil sample to the volume of the soil sample. The total soil porosity, which is the ratio of the voids volume to the total soil volume, was determined (Osman, 2013). These properties are described in works by Flint and Flint (2002a, b). The maximum capillary water capacity was obtained after a 2 h period of suction (on filter paper) of the fully saturated soil samples. The minimum air capacity is the air content of the soil when it is wetted to its maximum capillary water capacity and this was calculated from the total porosity and maximum capillary water capacity (Vopravil *et al*., 2017). The water retention capacity was determined after 24 h of suction (on filter paper) of the fully saturated soil samples (Šimečková *et al*., 2016). The saturated water content was obtained after the soil samples were fully soaked with capillary water. Samples for the assessment of physical soil properties were collected using Kopecky sampling cylinders at the end of the growing season at two depths 0-0.20 and 0.20-0.40 m, and the same sampling site was always used (Folegatti *et al.,* 2001). Six samples were taken at each sampling depth and for each variant per year (research from 2017 to 2019).

Aggregate size distribution was determined by sieving dry soil through a 0.25, 0.5, 2.0, 5.0, 10.0, and 20.0 mm mesh. The samples were collected at the end of the growing season from two depths, 0-20 cm, and 20-40 cm, in three repetitions, totalling up to 6 averaged samples annually. Furthermore, every structural fraction was weighed separately in the laboratory and calculated as a percentage. The structure coefficient (SC) was calculated as an evaluation variable. The soil SC is the ratio between agronomically valuable (0.25-10.00 mm) and less valuable structural elements (> 10.00 and < 0.25 mm) according to Tamari (2001) and Jandák *et al.* (2015).

Soil samples were taken from two depths: 0-20 and 20-40 cm for the purposes of performing a chemical analysis in order to estimate the basic nutrient content of the soil. Soil pH in KCl was determined from 1 M KCl leaching and measured using a potentiometric pH-meter (Zbíral and Honsa, 2010). Oxidizable carbon (C_{ox}) and humus content were also analysed. A common principle of the methods used for soil humus estimation is based on the carbon oxidation of organic substances. The total oxidizable carbon content was determined using the oxidimetric titration method according to (Nelson and Sommers, 1982). The fractional composition of humic substances (HS) was determined using the short fractionation method described by Kononova *et al*. (1963).

The spring wheat (*Triticum aestivum*), winter wheat (*Triticum aestivum*), and winter rape (*Brassica napus*) crops were harvested on 10 July 2017, 3 July 2018, and 8 July 2019, respectively. The yields were obtained by combining the harvests from each variant in three replications. During the biological inventory, the number of spikes per 1 m^2 was counted and the grain harvest moisture level was measured. Next, the yield figures were recalculated based on a standard 14% moisture content of the yield, and the thousand seed weight was estimated. The term grain unit, which forms a part of the manually measured biological parameters of crop yield was introduced by Woermann (1944) and allows for mutual comparisons to be made using a single indicator of the yield of various crops differing in nutrition and energy values.

The results obtained were evaluated by means of Statistica software (version 12.0, StatSoft Inc., Tulsa, OK, USA). A multi-factor analysis of variance and Tukey test were also carried out. Statistical calculations were performed on the basis of a specific algorithm written in Excel (Tretowski and Wójcik, 1991).

RESULTS AND DISCUSSION

In the first year (2017) of observation (Table 2), there were no significant differences in bulk density and total porosity between all of the soil biostimulant variants and the control described in Table 1.

The physical property values of the soil (Table 3) exhibited noteworthy differences in 2018. In the second year of observation, it was evident that the biostimulant-treated variants represented a lower soil compaction level that was indicated by the bulk density (BD) values. Variant 1 had the highest value of BD and the lowest value of total porosity, which was in agreement with the other observed parameters. More acceptable physical properties were obtained in variant 2 which was treated with an activator of mineralization and humification, therefore higher yields were observed. As reported by Lhotsky (2000), the limit of the value of heavy compaction in loamy soils is 1.45 g cm^{-3}. This was exceeded in 2018 for variant 1 in the topsoil

Table 2. Results of the determination of soil physical properties – Litobratrice 2017

Variant	Soil depth (cm)	Bulk density (g cm^{-3})	Total porosity (%)	Actual content of		Max. capillary capacity	Min. air capacity
				water	air		
				% volume			
1	0-20	1.13	57.99	20.42	37.57	39.61	18.38
	20-40	1.39	47.09	13.95	33.14	37.31	9.78
	Average	1.27^{a}	51.50^{a}	17.20^{a}	35.40^{b}	38.50^{b}	14.10^{b}
2	0-20	1.12	57.70	19.30	38.40	40.60	17.10
	20-40	1.44	45.00	16.40	28.70	34.40	10.60
	Average	1.28^{a}	51.40^{a}	17.90^{a}	33.60^{a}	37.50^{a}	13.90^{b}
3	0-20	1.12	57.36	20.50	36.86	37.79	19.57
	20-40	1.43	45.25	16.10	29.15	34.54	10.71
	Average	1.28^{a}	51.30^{a}	18.30^{a}	33.00^{a}	36.20^{a}	15.40^{c}
4	0-20	1.17	55.31	21.04	34.27	39.76	15.54
	20-40	1.39	47.07	14.06	33.01	39.10	7.97
	Average	1.28^{a}	51.20^{a}	17.60^{a}	33.60^{a}	39.40^{c}	11.80^{a}

Variant numbers: 1 – Control, 2 – Neosol – soil vital function activator, 3 – Akeo – soil biomass activator for mixing with fertilizer, 4 – Explorer – stimulator of rhizosphere biological activity. The same letters indicate no significant differences between the results obtained. Different letters (a, b, c) indicate the occurrence of significant differences between the obtained results.

Table 3. Results of the determination of soil physical properties – Litobratrice 2018

Variant	Soil depth (cm)	Bulk density (g cm^{-3})	Total porosity (%)	Actual content of		Max. capillary capacity	Min. air capacity
				water	air		
				% volume			
1	0-20	1.49	42.9	27.3	15.6	36.2	6.7
	20-40	1.53	40.9	14.8	26.1	33.6	8.0
	Average	1.51^{a}	41.9^{a}	21.1^{a}	20.9^{a}	34.9^{a}	7.4^{a}
2	0-20	1.31	49.9	29.9	20.0	39.6	10.3
	20-40	1.26	51.9	14.5	37.4	35.8	16.1
	Average	1.29^{b}	50.9^{b}	22.2^{a}	28.7^{b}	37.7^{b}	13.2^{b}
3	0-20	1.30	50.5	24.3	26.2	37.2	13.3
	20-40	1.39	46.9	14.9	31.9	39.0	9.9
	Average	1.35^{c}	48.1^{b}	19.6^{a}	29.1^{b}	38.1^{b}	11.6^{b}
4	0-20	1.34	48.1	25.1	23.0	36.3	11.9
	20-40	1.36	47.4	17.4	30.0	38.9	8.5
	Average	1.35^{c}	47.8^{b}	21.3^{a}	26.5^{b}	37.6^{b}	10.2^{b}

Explanations as in Table 2.

layer as well as in the subsoil layer. The BD value in the biostimulation variants remained at the 2017 level. This corresponded with a marked decrease in total porosity in control variant 1. Both of these soil physical parameters have a substantial impact on soil water management.

In the third year (2019), the application of soil biostimulants induced differences in comparison with the control variant (Table 4). As shown by the measurement results, the biostimulation variants were characterized by markedly decreased BD values (lower soil compaction) and increased total porosity, in contrast to the control. There was also a negative correlation of the soil physical properties with the other analysed parameters in the case of variant 1 (control). Improvement in the physical conditions of the soil were obtained for variant 2 and variant 4 (treatment with a stimulator of rhizosphere biological activity). Both BD and total porosity influence the soil air regime to a considerable extent, which is primarily related to the intensity of soil biological activity. As indicated by the resulting BD values, the soil biostimulant had a positive impact on soil aeration and decreased the degree of compaction of the topsoil layer. Miller (2000) reported the conformable results, *i.e.* the improvement in soil properties through the application of soil conditioners and other additives.

Table 4. Results of the determination of soil physical properties – Loitobratrice 2019

Variant	Soil depth (cm)	Bulk density (g cm^{-3})	Total porosity (%)	Actual content of		Max. capillary capacity	Min. air capacity
				water	air		
				% volume			
1	0-20	1.55	44.9	25.4	15.0	34.1	5.9
	20-40	1.58	38.8	13.6	25.2	29.1	6.0
	Average	1.57^{a}	41.9^{a}	19.5^{a}	19.39^{a}	31.6^{a}	6.0^{a}
2	0-20	1.29	52.1	31.2	24.8	41.3	12.1
	20-40	1.23	53.5	18.5	41.3	37.4	17.8
	Average	1.26^{c}	52.8^{b}	24.9^{b}	33.0^{c}	39.4^{b}	15.0^{b}
3	0-20	1.28	51.7	25.1	27.7	38.9	14.5
	20-40	1.34	49.4	16.2	33.2	39.0	10.1
	Average	1.31^{c}	50.6^{b}	20.7^{a}	30.1^{a}	39.0^{b}	12.3^{b}
4	0-20	1.32	52.8	28.4	25.1	40.6	16.9
	20-40	1.34	49.3	19.8	33.6	38.2	10.2
	Average	1.32^{c}	51.1^{b}	24.1^{b}	29.4^{b}	38.9^{b}	13.6^{b}

Explanations as in Table 2.

SC was measured in the individual variants (Table 5) and expresses the quality of the soil structure. It captures a representation of the structural elements in five size categories based on a percentage representation of the total sample weight. SC measures the degree of violation of the soil structure. At values higher than 1.0, the soil has a better structure and, therefore, the risk of undesirable compaction is lessened, while values of less than 1.0 are below structural stability levels (Hůla *et al.*, 2010). This relates to the qualitative composition of soil humus forming an agronomically valuable structure. Lower SC values were reached in variant 1, this means that the values at a depth from 0 to 20 cm were around 1.0, which is not a satisfactory situation. In 2017, the SC values in the control were over the limit value of 1. This is just above the limit of structural stability. Variant 2 also presents a lower value of SC due to the more intense mineralization processes occurring in the soil after the application of the mineralization activator (Du Jardin, 2015). Variant 3 was treated with the rhizosphere biostimulant and showed very significant differences as compared to the control. In 2018, the value of SC in variants 2, 3, and 4 was higher to a statistically significant extent versus variant 1. This may be associated with a reduction in the quality of the soil environment in terms of other physical properties and, as a consequence, may exert a negative influence over the chemical properties of the soil (Arshad and Coen, 1992; Legros *et al.*, 1998). The results recorded in 2019 confirmed this influence as reflected by the markedly decreased differences in SC in variants 2, 4, and 3, in contrast to the control (variant 1). The soil structure deteriorated in comparison with the first year (2017) of the measurements. This was caused by direct intensive mechanical cultivation using agricultural tools. Nevertheless, the application of soil biostimulants induced a positive effect on soil structure and also on the creation of soil aggregates.

An analysis of variance of 72 mean sample values of percentage representation in 5 categories of structural elements produced an F-ratio of 0.0002 with a resulting p-value greater than 0.05 and there were no statistically significant differences in the mean values of the dependent variable soil structure in the different experimental variants.

The content of soil organic matter is one of the most important indicators of soil quality (Kosolapova *et al.,* 2016). The soil acid-base reaction (pH) is a very important indicator of soil environment status. The results show statistically significant differences between the biostimulant application variants (2, 3, 4) and the control.

The content of C_{ox} was considerably higher in variants 2 and 3 (Table 6). The positive influence of soil biostimulant application into the soil was confirmed in 2019.

The mean value of the C/N ratio indicating nitrogen reserves in the entire locality was slightly below the optimal value of 10/1 (Fig. 1). In the evaluation of the C/N ratio, a clear difference was evident between the initial values in 2017 and the values measured in 2018 and 2019. The decrease in these values in variants 3 and 4 may have been related to the relative lack of carbon due to the more rapid mineralization rate recorded in 2017. The greatest differences were found in variant 2, as the C/N ratio increased in 2018 and 2019. The maximum value was 9.11. The optimal average C/N ratio was achieved in variant 2 in 2018 and 2019. The C/N ratio dynamic is fundamental, as it is a characteristic of soil biological activity (Bhandari *et al.*, 2018). The C/N ratio in organic matter affects the movement of nitrogen. Organic matter with a reduced C/N

Table 5. Soil structural elements in 2017-2019, mean values of SC

Year	Variant	Soil structure elements (% weight)						Structural coefficient
		over 10 mm	5-10 mm	2-5 mm	0.5-2 mm	0.25-0.5 mm	below 0.25 mm	
2017	1	39.45	26.82	18.96	13.57	0.33	0.87	
	sd	0.42	0.33	0.28	0.15	0.03	0.04	1.48
	2	34.36	28.50	22.12	13.90	0.31	0.82	
	sd	0.41	0.35	0.29	0.16	0.03	0.04	1.84
	3	29.48	27.96	25.27	16.16	0.38	0.75	
	sd	0.38	0.34	0.30	0.17	0.03	0.04	2.31
	4	23.72	24.43	31.19	19.76	0.36	0.55	
	sd	0.36	0.32	0.32	0.20	0.03	0.03	3.12
2018	1	40.06	22.62	18.23	13.68	1.48	3.92	
	sd	0.42	0.32	0.29	0.16	0.08	0.12	1.28
	2	28.21	22.56	23.70	19.38	2.26	3.90	
	sd	0.38	0.33	0.31	0.28	0.09	0.13	2.97
	3	26.02	25.88	24.63	17.47	2.06	3.94	
	sd	0.36	0.35	0.31	0.27	0.09	0.14	2.85
	4	27.56	32.63	18.41	17.66	1.21	2.53	
	sd	0.35	0.41	0.28	0.26	0.07	0.13	2.92
2019	1	62.84	15.63	14.62	6.42	0.16	0.32	
	sd	0.95	0.18	0.17	0.17	0.01	0.03	0.58
	2	43.15	24.99	21.40	9.79	0.22	0.45	
	sd	0.48	0.35	0.33	0.21	0.02	0.03	1.29
	3	48.88	20.44	21.48	8.64	0.18	0.37	
	sd	0.49	0.32	0.33	0.20	0.02	0.03	1.03
	4	39.79	22.47	26.35	10.41	0.33	0.36	
	sd	0.43	0.33	0.36	0.22	0.03	0.03	1.47

Variant numbers: 1 – Control, 2 – Neosol – soil vital function activator, 3 – Akeo – soil biomass activator for mixing with fertilizer, 4 – Explorer – stimulator of rhizosphere biological activity; sd – standard deviation.

Table 6. Results of the Tukey HSD test of selected statistically significant parameters

Variant	Year	pH	Sg.	C_{ox} (%)	Content of humus (%)	Sg.
1	2017	6.3	a	1.23	2.13	a
2	2017	5.8	b	1.50	2.59	b
3	2017	5.9	b	1.42	2.46	b
4	2017	6.8	c	1.25	2.16	a
1	2018	6.0	a	1.39	2.40	a
2	2018	6.1	a	1.58	2.72	b
3	2018	6.5	b	1.57	2.71	b
4	2018	6.6	c	1.39	2.40	a
1	2019	6.0	a	1.30	2.24	a
2	2019	6.7	b	1.69	2.91	c
3	2019	6.8	c	1.54	2.70	b
4	2019	6.7	b	1.62	2.79	b

Sg. – signification, C_{ox} – oxidizable carbon. Other explanations as in Table 2.

ratio is more easily mineralized by microorganisms, which subsequently leads to a substantial decrease in the overall content of organic substances in the soil (Bhandari *et al.,* 2020). Mineralization is influenced to a considerable extent by water content and soil temperature. By knowing the soil C/N ratio, farmers can avoid applying excessive or insufficient amounts of nitrogen, both of which would have a beneficial economic and environmental impact.

The crop yields are presented in Fig. 2. These data show that, in comparison with the control yields (1), the effects in the biostimulant-treated variants (2, 3, 4) were significantly higher in 2018 despite the lack of precipitation during the vegetation period. The results obtained in 2019 show an increase in the yield due to improved soil physical properties thereby ensuring higher winter moisture efficacy; hence, higher yield coefficients were obtained. Enhanced root functioning, soil moisture utilization, and nutrient uptake are among the potential contributing factors increasing crop yields. Such impacts of biostimulants on yields were also reported by Calvo *et al*. (2014), Šindelková *et al*. (2019) and Fei *et al.* (2020).

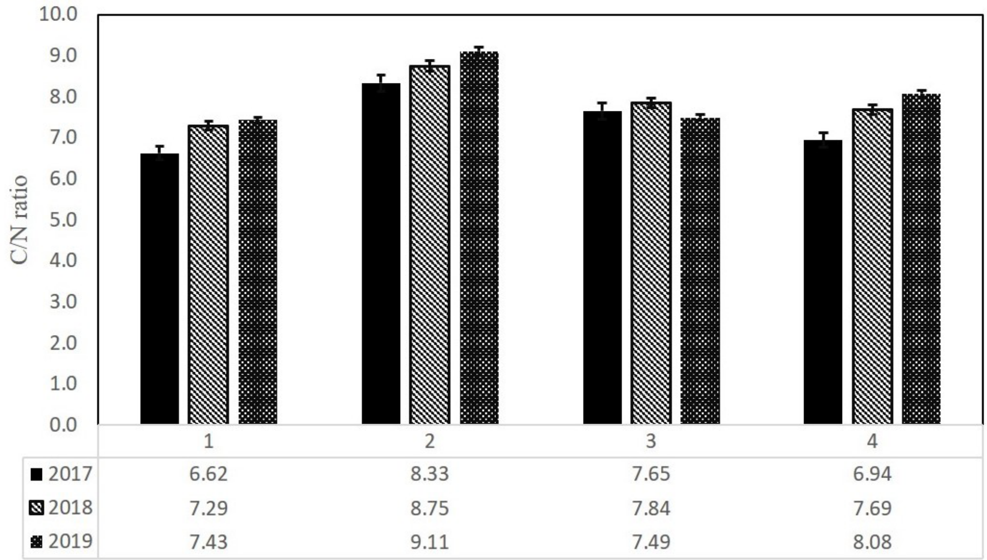

Fig. 1. Average values of the C/N ratio by observed variants. 1 – Control, 2 – Neosol – soil vital function activator, 3 – Akeo – soil biomass activator for mixing with fertilizer, 4 – Explorer – stimulator of rhizosphere biological activity. The vertical bars are standard deviations.

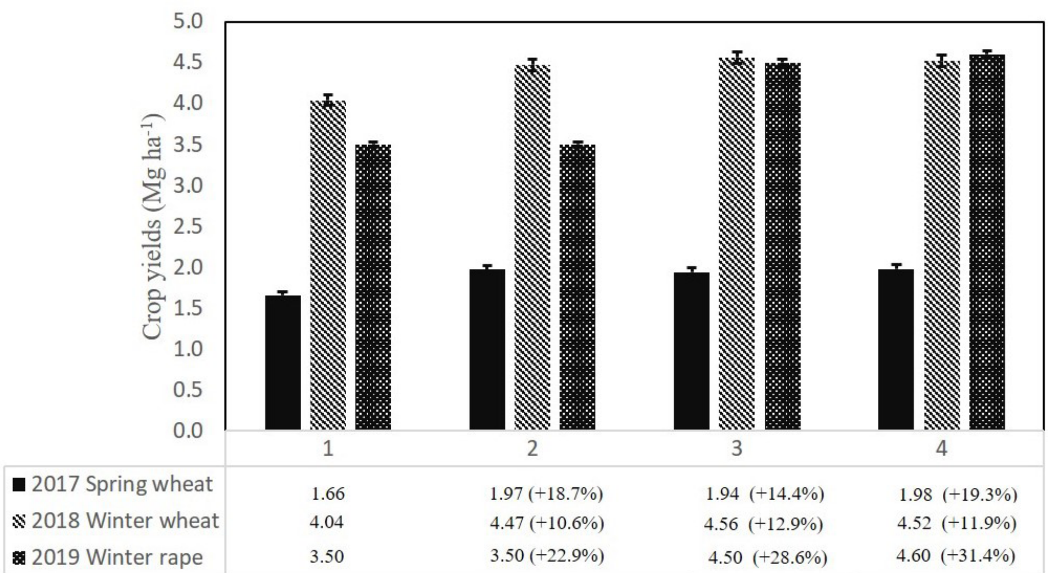

Fig. 2. Measured field crop yields from 2017-2019 in Mg ha^{-1}. 1 – Control, 2 – Neosol – soil vital function activator, 3 – Akeo – soil biomass activator for mixing with fertilizer, 4 – Explorer – stimulator of rhizosphere biological activity. The vertical bars are standard deviations.

CONCLUSIONS

1. The results showed a significant decrease in the bulk density of soil after the application of biostimulants. The effect ranged from 10.6 to 20% and increased with successive applications.

2. Following the application of biostimulants, an increase in oxidizable carbon content was noted.

3. Biostimulants increased crop yields and the effect was most pronounced for winter rape in the last year of the field experiment.

Data availability statement: The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request.

Conflicts of interest: The authors declare that there is no conflict of interest regarding the publication of this paper.

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