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Application of Multi-Component Conditioner with Clinoptilolite and *Ascophyllum nodosum* Extract for Improving Soil Properties and *Zea mays* L. Growth and Yield

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Abstract: The application of various conditioners in agriculture is one of the management practices used to improve soil quality and plant growth and development. The aim of this study was to assess the effect of a multi-component conditioner on the selected soil properties and maize (*Zea mays* L.) growth and yield. The effect of a conditioner on a set of soil properties and maize growth and yield was studied in one-year experiments carried out at three study sites, which were under a conventional tillage system. All of the study sites were located on farms in three geographic mezoregions in the Kuyavian-Pomeranian Region (Midwestern Poland). The studied soils were Haplic Luvisol (Janocin and Kobylnica) and Albic Luvisols (Krukówko) that were composed of sandy loam. A one-way analysis of variance (ANOVA) was used to determine the effect of a conditioner Solactiv on the soil and plant properties. The conditioner significantly affected the soil enzyme activities such as dehydrogenase (DHA), fluorescein sodium salt hydrolysis level (FDAH) and carboxymethylcellulose cellulase (CMC—cellulase); wherein the last one increased by about 16–20%. The application of Solactiv also increased the available K content (about 11%) but not the content of the microbial biomass C and N. Total porosity (TP), which was significantly higher in the soil treated with conditioner than in the control soils, increased the available water capacity (AWC) (about 2.2%). The higher AWC in the treated soil indicated the greater contribution of the mesopores in the TP (about 4%). A significantly higher readily available water capacity (RAWC) and small pores available water capacity (SAWC) was determined in the treated soils compared to the controls. Of the plant properties, only plant height, fresh cob biomass (BBCH 87–89) and fresh plant biomass (BBCH 84–85) were significantly increased by the conditioner. The application of Solactiv is considered to be a promising approach for developing sustainable agriculture by improving the soil's biological activity and water-related properties.

Keywords: maize; organic-mineral conditioner; soil; physico-chemical properties; water properties; enzymes

1. Introduction

The dynamic progress in maize breeding introduced the wide selection of varieties with different growing seasons and possible directions of use, as well as with resistance to cultivation in monoculture.

Moreover, the relatively simple production technology and very high yield potential mean that maize, in addition to rice and wheat, is one of the crops that are most often cultivated in the world. It has been shown that by 2070, the total land area suitable to cultivate maize in Central Europe will increase threefold [1]. Such increasing of maize cultivation areas is related to the increase of air temperature and changes in the total and annual cycles of precipitation. The maize is cultivated in place of cereal and root crops areas, as well as, to a lesser extent, forage and grasslands [1]. The different possible uses of its grain yield or biomass (consumptive, fodder, renewable energy sources–RES) means that maize is very flexible for meeting specific requirements and changing market needs [2–4]. That is why each sustainable management practice that improves maize productivity should be considered.

Farming productivity and crop yield greatly depend on healthy and fertile soil. However, the soil resources in many parts of the world are being over-exploited, degraded, and irreversibly lost because of inappropriate land management practices, industrial activities, and land-use changes that lead to the loss of organic carbon, disturb the soil physicochemical and biological processes, and cause contamination and erosion [5]. The agriculture practices that are based on intensive tillage and applying large amounts of mineral fertilizers and pesticides, with simultaneous limited use of farmyard manure and catch crops, have a significant contribution in the continuous degradation of soil resources [6]. Moreover, in Poland, more than 40% of agricultural soils are classified as poor, sandy soils of low quality and agricultural suitability [7]. This is caused by a low organic carbon and clay content, which determines the low CEC (cation exchange capacity) [7], which in turn makes the soils very sensitive to rainfall shortages and nutrient leaching. Moreover, about 80% of the arable soils is acidulated to different degrees, and 4 million hectares require liming [8]. That is why maintaining and/or improving soil quality is among the greatest challenges we are facing today. In order to counteract the unfavorable phenomena that occur in soils, a number of amendments /conditioners for improving structure and fertility of soils have been developed, e.g., for decreasing soil acidity (liming preparations) [9], for increasing root respiration, and growth, as well as plant yield (preparations with salts of humic acid) [10], for increasing the soil water capacity (preparations with hydrogels and/or zeolites) [11], and finally, for increasing the soil microbial activity (preparations with microbial consortia or specialized strains of bacteria and/or fungi) [12,13]. The commercially available "Solactiv" that was used in this study is an innovative, multiple mineral-organic conditioner that consists of four balanced components: (1) zeolite-clinoptilolite to increase the sorption and water capacity of soil, (2) calcium carbonate to stabilize the soil reaction, (3) potassium humate that contains humic acids and (4) an *Ascophyllum nodosum* extract to stimulate the multiplication and growth of soil microorganisms.

There is some information about the potential effects of these components when used separately [14–17] but there is no information about their simultaneous effect with other components in composite preparations. Generally, zeolites have a great sorption capacity and ion exchange selectivity, which are of significant importance in sorption and exchanging soil nutrients. Soil nutrients that are bound by zeolites, e.g., potassium cations, can be released and taken up by plant roots, which has a direct impact on yield quantity and quality [14,16]. This not only increases the use of nutrients by plants, but also decreases their transfer into the groundwater [11,16]. When using zeolites, it is possible to use lower doses of fertilizers, which consequently reduces the costs of cultivation, while maintaining the quantity and quality of the yield [16]. Additionally, zeolites are also able to store water, which is especially important for plants during periods of drought [11].

The second component in the studied conditioner is an extract from *Ascophyllum nodosum*, which is one of the most frequently used seaweeds in agriculture in the world. To date, this extract has been used for foliar application in Poland, while the effects of its application into the soil are not yet fully understood. The extract contains many available organic compounds such as fucoidan, mannitol, alginic acids and various amino acids, which are the sources of carbon and nitrogen for soil microorganisms [15]. Moreover, seaweed is extremely rich in nutrients, including mineral elements, trace elements, auxin, polyamines and other active substances [18]. It was found that the extract from *Ascophyllum nodosum* when applied in the form of a granulate increased the growth of the shoots and

roots of plants and activated the soil microorganisms [19]. Another component of the tested conditioner is the potassium salts of the humic acids, which affect the formation of the soil aggregate structure and thereby improve its air conditions [17]. They are beneficial to both sandy soils (increasing of compactness) and heavy (clayey) soils (loosening and airing). The salts also have a high water-holding capacity, and therefore, they are able to hold more water than their weight [20]. Humic acids with clay minerals also create organic-mineral complexes that improve the soil sorption properties. In sandy soils, humic acids limit nitrogen, potassium, magnesium and calcium leaching and can significantly improve the phosphorus uptake, thus reducing its binding to the soil particles [21]. Moreover, humic acids stimulate the growth and proliferation of beneficial soil microorganisms (e.g., bacteria of the genera *Azotobacter* and *Nitrosomonas)* and increase the production of plant enzymes as well as contribute to the formation of chlorophyll, sugars, and amino acids in plants [22].

Most of the studies concerning the application of different conditioners or their components that show their benefits as regards the plant and soil properties are usually conducted under controlled conditions. However, the effect of their application in the field has been studied less. That is why we studied the effectiveness of the selected conditioner in field conditions and assumed that the conditioner can effectively counteract the deterioration of the properties of soil that were subjected to intensive agricultural use by affecting some of the soil properties due to its composition. We also hypothesized that the conditioner would positively affect the growth and yield of maize. The aim of the study was, therefore, to determine the effect of Solactiv on selected physico-chemical and biochemical soil properties, as well as the biometric features and yield of maize in field experiments that were conducted at three selected study sites.

2. Materials and Methods

2.1. Study Site and Experimental Design

The effect of a conditioner on some of the soil properties and maize growth and yield were studied under a conventional tillage system at three sites that were different in terms of soil conditions. Study site I was located on a Cooperative Farm in Janocin (52°36′24.6″ N 18°25′11.9″ E), study site II on a farm in Kobylnica (52°35′10.4″ N 18°26′46.3″ E), and study site III on a farm in Krukówko (52°12′36.4″ N 17°40′57.9″ E). All of the experimental fields were located in three geographic mezoregions in the Kuyavian-Pomeranian Voivodeship: Inowrocław Plain (Janocin), Kuyavian Lake District (Kobylnica) and South Krajna Lake District (Krukówko/Samsieczynek). The experimental areas are located in a temperate region with a changeable climate where the marine air from the North Atlantic and the continental air from the east converge. That makes frequent day-to-day and year-to-year variabilities in the weather patterns. The parameters of the weather conditions during the sampling periods were obtained from local weather stations that are located not far from study sites (details in Table 1). According to IUSS Working Group WRB [23] the studied soils were Haplic Luvisol (Arenic District) (Janocin), Haplic Luvisols (Siltic District,) (Kobylnica) and Albic Luvisols (Aric, Cutanic) (Krukówko). The soils at each site were formed of a glacial till. The surface horizons of all of the studied soils were composed of sandy loam. The clay content ranged from 3.8 to 5.1%, and did not differ markedly between the study sites or the study fields.

Table 1. Mean air temperature and amount of precipitation at the study sites.

Month	* Chrząstowo		** Głębokie	
	Temperature (°C)	Precipitation (mm)	Temperature (°C)	Precipitation (mm)
January	0.7	56.8	0.7	37.5
February	−1.0	2.3	−3.1	4.9
March	−0.2	31.8	0.4	24.6
Aril	11.8	48.8	12.8	22.4
May	17.1	5.1	16.6	29.6
June	18.2	44.5	18.4	42.8
July	20.5	120.0	20.8	122.0
August	20.1	14.3	21.1	23.0
September	15.5	31.9	16.2	24.6
October	9.7	24.8	10.6	26.7
November	4.2	8.7	4.8	17.5
December	2.0	52.2	2.2	39.3

Notes: * A local weather station located nearest to the Krukówko study site, ** a local weather station located nearest to the Janocin and Kobylnica study sites.

Maize was cultivated for grain on all of the study sites. Winter wheat was the fore crop for the maize, and pre-winter plowing was done after the winter wheat was cultivated. The maize was sown between May 2 and 10, 2018 (variety "Figaro" (FAO 240), 95,000 seeds per hectare) and harvested between September 22 and 26, 2018. The mineral fertilizers were (1) polifoska 6 (NPK(S) *6*-20-30-(7)) 300 kg ha^{-1} + urea 100 kg ha^{-1} before cultivation with a tilling set, (2) amofoska (NPK 4-12-20) 100 kg ha^{-1} while the maize was being sown and (3) urea 100 kg ha^{-1} on 1st of June 2018 after of the maize were sown.

An experimental area was designated at each site and divided into two equal parts (fields). The experimental parts were situated in the middle of the larger fields to avoid the edge influence. The areas were also flat to avoid possible surface runoff. One field was treated with Solactiv at a dose of 300 kg ha^{-1} in accordance with the manufacturer's recommended rate (there was no further benefit at rates above this), while the second field was a control (without the conditioner). The conditioner was applied before the maize was sown, and was mixed with the soil to a depth of 12 cm using the tilling set. The Solactiv used in this study consists of four components (1) zeolite-clinoptilolite (50%), (2) calcium carbonate (47.5%), (3) leonardite extract (2%), and (4) *Ascophyllum nodosum* extract (0.5%). The zeolite used to produce the conditioner came from Western Slovakia and is distributed by the Zeocem a.s. company. While the main mineral in this zeolite is clinoptilolite (84%), cristobalite (8%), illite (4%) and feldspars (3.5%) are also used. The specific surface area of this zeolite, which was determined using the BET method, was 31.4–35.4 m^{-2} g^{-1} [24]. The *Ascophyllum nodosum* algae that were used to prepare the extract was harvested from the Atlantic Ocean off the coast of Ireland by the Irish company BioAtlantis. The extract contains 8–12% w/w of organic matter, which consists of fucoidan (11%), mannitol (1%), phlorotannin (1%), and alginate (27%), among others. Potassium humate powder (95% potassium humate containing 60–65% humic acid), which was purchased from Humic Growth Solution, Inc., was also used as a raw material to produce the conditioner. This material is derived from the richest and purest sources of humic acid in North America. This humic acid is a weathered type of oxidized sub-bituminous coal that is rich in humic substances.

Changes in the soil properties (beside of bulk density and water retention properties) were determined in samples collected twice, before the maize was sown (before conditioner application) and shortly after it was harvested. At each site, twenty soil samples were collected from the field with the conditioner and twenty from the control field. The soil samples were collected using a hand auger from the Ap horizon (up to the depth of 30 cm), at regular intervals from the selected area within the studied fields (every 30 m along the longer side and every 10 m along the shorter side of the field). Each sample consisted of ten individual sub-samples taken randomly from a circular area with a radius of 2 m from the node point at each location (from which a composite sample was prepared).

2.2. Analysis of Soil Properties

The physico-chemical properties were determined according to the standard methods that are used in the soil science [25] and each sample was analyzed in triplicate. The content of total organic carbon (C_{ORG}) and total nitrogen (N_{TOT}) was determined using a dry combustion CN analyzer (Vario Max CN). The extraction of the dissolved organic carbon and nitrogen (DOC; DNt) was performed using 0.004 M $CaCl_2$ for one hour at a soil to extraction solvent ratio of 1:10 (*w/v*). The content of DOC and DNt was assayed using a Multi N/C 3100 Analityk Jena analyzer (Germany). The DOC (DNt) content was expressed in mg C(N) kg^{-1} of the dry weight of a soil sample and as a percentage share in the TOC/C_{ORG} (N_{TOT}) pool. The available Mg and K concentrations were determined by atomic absorption spectrometry (AAS) (Philips PU 9100X) after they were extracted with 0.0125 M $CaCl_2$ (available Mg) and using the Egner-Riehm DL method [26] (available K as well as P). The exchangeable forms of the nutrients (Mg, Ca, K, Na) were determined in 0.1 M $BaCl_2$ [27]. The pH in a solution of 1 M KCl was measured using the potentiometric method in 1:2.5 soil: solution suspensions [28], while the hydrolytic acidity was measured in 1M CH_3COONa. The soil gravimetric moisture content was determined after oven-drying the samples for 24 h at 105 °C. The cation exchange capacity (CEC) was calculated as the sum of the basic saturation and hydrolytic acidity. Particle size fractions were determined using a laser diffraction particle size analyzer (Mastersizer 2000 analyzer, Malvern).

Soil samples in cylinders were used to determine the bulk density (BD) and water retention properties in four replications. Total porosity (TP) was calculated according to the equation: $TP = (Sw - So) \cdot Sw^{-1} \cdot 100$ (%). The soil water retention properties were determined using low-pressure (pF range 0–2.7) and high-pressure (in pF range 3.0–4.2) chambers. Water capacities ($W_{vol.}$) were determined as the value of the soil water potential at 98.1 hPa (pF 2.0), 490.5 hPa (pF 2.7), 981.0 hPa (pF 3.0) and 15,547.9 hPa (pF 4.2) [29]. The volume of the following soil pores and the specified water capacities were calculated: macropores (total porosity-$W_{vol.}$ at pF 2.0), micropores ($W_{vol.}$ at pF 4.2) and mesopores that corresponded to the potential useful water retention (AWC–available water capacity) ($W_{vol.}$ at pF 2.0–$W_{vol.}$ at pF 4.2). For the AWC, the readily available water capacity (RAWC), ($W_{vol.}$ at pF 2.0–$W_{vol.}$ at pF 3.0) and small pores available water capacity SAWC), ($W_{vol.}$ at pF 3.0–$W_{vol.}$ at pF 4.2) were calculated.

Dehydrogenase activity (DHA) was determined according to Thalmann [30]. The soil (1 g) was mixed with a TTC solution (triphenyltetrazolium chloride 1%) and a Tris-HCl buffer (100 mM, pH 7.4–7.8, depending on the soil pH) and incubated for 24 h at 30 °C. The control contained only the buffer. After the incubation, acetone was added to each sample, mixed thoroughly and the samples were further incubated at room temperature for 2 h in the dark. The soil suspension was then filtered, and the optical density of the supernatant was measured against the blank at 546 nm. One unit of DHA was defined as the amount of mg of TPF (triphenyl formazan) that was released by 1 kg of dried soil (mg TPF kg^{-1} 24 h^{-1}) at 30 °C per 24 h.

The hydrolysis activity was determined by measuring the activity of the fluorescein sodium salt hydrolysis as described by Adam and Duncan [31]. Field-moist soil samples were treated with a phosphate buffer (60 mM, pH 7.6) with fluorescein diacetate as the substrate. After 1 h of incubation (37 °C), the reaction was stopped by adding a mixture of methyl alcohol and chloroform. Then, the soil suspension was centrifuged, and the optical density of the clear supernatant was measured at 490 nm. One unit of FDAH activity was expressed as the mg of fluorescein that was produced by 1 kg of soil at 37 °C per one hour (mg F kg^{-1} h^{-1}).

Cellulase (CEL) activities were determined as was reported by Schinner and von Mersi [32]. Field-moist soil was treated with an acetate buffer (pH 5.5) and a carboxymethylcellulose solution and incubated for 24 at 50 °C. Reducing the sugar that was released during the incubation decreased the $K_3[Fe(CN)_6]$ in an alkaline solution. The decreased $K_4[Fe(CN)_6]$ reacted with $NH_4Fe(SO_4)_2 \cdot 12H_2O$ in an acid solution to form a complex of *iron* (III) *hexacyanoferrate* (II) (Prussian blue), which was determined spectrophotometrically at 690 nm. The control was prepared by adding the substrate after the incubation but immediately before filtration. One unit of CEL activity was defined as the

milligrams of glucose that were released by 1 kg of dried soil at 50 °C per 1 h (mg Glu kg^{-1} h^{-1}). The enzymatic activity was expressed on a moisture-free basis. The moisture content was determined by drying the soil samples at 105 °C for 24 h.

The microbial biomass C and N were determined using the chloroform fumigation-extraction method [33,34]. Moist soil samples (50% WHC; 25 g) were fumigated with ethanol-free CHCl$_3$ at 25 °C for 24 h. After incubation, the chloroform was removed by repeated evacuations. Both the fumigated and unfumigated soils (controls) were extracted with 0.5 M of K$_2$SO$_4$ (ratio 5: 1) and analyzed for soluble C as was proposed by Vance et al. [34]. The total N was determined according to Bremner and Mulvaney [35].

2.3. Field and Laboratory Analysis of Maize

The leaf greenness index (SPAD), which is useful for determining the state of plant nutrition with nitrogen, was determined using a Hydro N-Tester Minolta-502 with a scale 0–800. Thirty plants from each experiment object (field) were measured in the middle of the youngest, unfolded leaf three times: (a) in the five-to-six leaf phase (BBCH 15–16), (b) in the three-node phase (BBCH 32–34), and (c) in the panicle blooming phase (BBCH 64–65). Additionally, the mean value of SPAD for the growing season was also determined (as the mean of three terms given above). Right before the maize was harvested (BBCH 87–89), for the number of plants in 2 m long sections that were located in rows in individual experimental objects, five measuring sections in each field was determined. The density of the maize plants before the harvest was calculated by multiplying the number of plants on 1 linear meter and the row spacing of the maize (0.75). In the same phase (BBCH 87–89), in each of the five replications from the individual experimental objects, 15 plants were harvested by cutting them directly at the soil surface and were then used to determine their fresh biomass, plant height, and grain yield. The fresh biomass was assessed by weighing the plants in the field immediately after they were cut. The height of the plants was measured from their roots (place of the cut) to the end of the inflorescence (panicle). The cobs on the individual plants were also calculated, and then they were broken off, the cover leaves were stripped, and the cobs were dried. The mass of the grain from an individual plant was determined in the laboratory based on the weight of the grains that were hulled from all of the cobs on one plant. The grain that was hulled from the cobs of the plants from the individual experimental objects was used to determine the weight of 1000 seeds. The maize yield was calculated based on the plant density, which was determined before the harvest and the average grain weight of the plants from each experimental object.

2.4. Statistical Analysis

The data of the studied properties did not show a normal distribution according to the Shapiro-Wilk test (Statistica v. 9.0), and therefore they were log-transformed. Since the transformation improved the normality of data distribution, the further analyses were performed with the corrected data. A one-way analysis of variance (ANOVA) was used to determine the effect of the application of conditioner (compared to the control–without the conditioner) on the soil and maize-related properties. Based on these analyses, an ANOVA synthesis was performed for the three sites of the research. In the synthesis, the study site was a random effect, while the application of the conditioner was the constant (mixed model). When significant treatment effects were found, a post-hoc Tukey's HDS test was used to compare the treatment means. The means were considered to be significantly different at $p < 0.05$.

3. Results

3.1. Soil Biochemical Properties

Generally, the application of the conditioner significantly affected the enzymes but not the content of the microbial biomass C and N. The DHA in the study ranged between 5.11 and 16.85 mg TPF kg^{-1} 24 h^{-1} (Figure 1). Although there were no significant changes in this activity in the soil samples

that have been taken from all of the studied fields before the Solactiv was applied, the activity was higher in the area that had been dedicated for conditioner application on two sites than in the field that was planned to be left without the conditioner, while in the third location, the trend was the opposite. There was a low but significant increase of DHA by the soil conditioner on only one site, while at the two other locations, the DHA was significantly lower after the Solactiv was applied compared to the activity in the control soils. When the study sites were considered together, there was a significant decrease of DHA after the conditioner was applied. At all of the experimental sites, there were no significant differences in FDAH activity in soil samples collected in the fields where Solactiv was to be applied compared to the areas that were planned as the controls before the maize was sown (Figure 2).
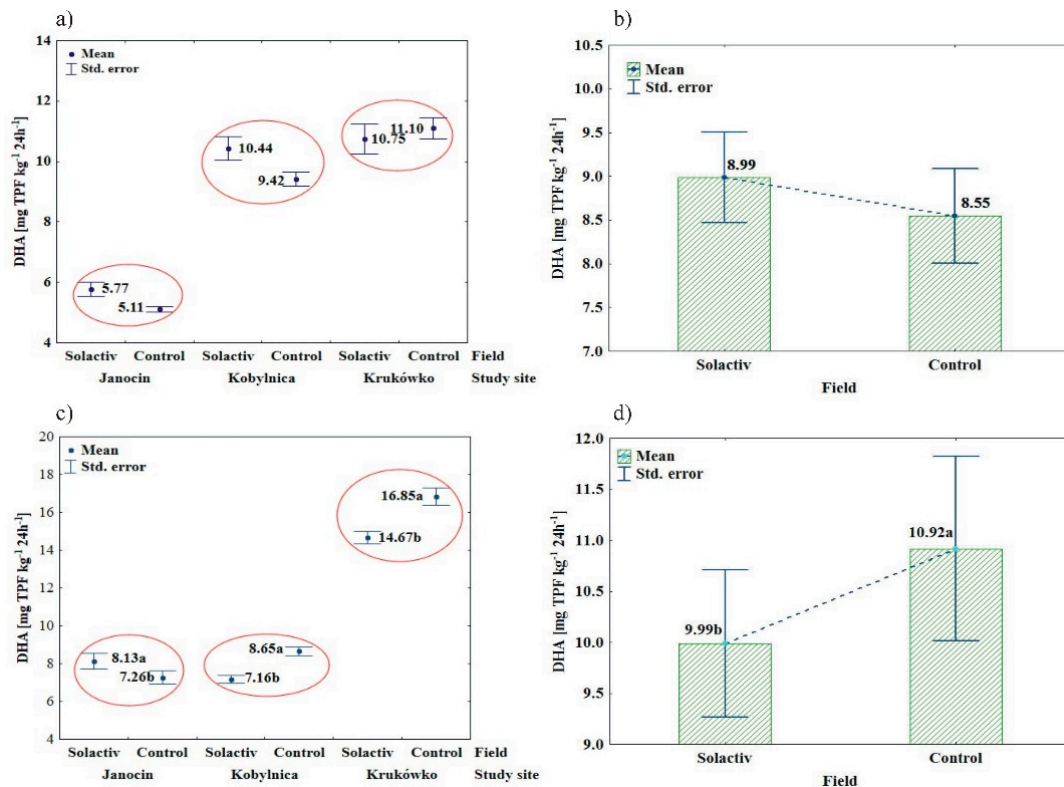

Figure 1. Dehydrogenase activity as affected by the tested conditioner. (**a**,**b**) I sampling (sampling before the maize was sown, *n* = 10); (**c**,**d**) II sampling (after the maize was harvested, *n* = 10); (**b**,**d**) the mean for all study sites (*n* = 30). Data were analyzed using one-way ANOVA. Mean values for conditioner and control followed by different letters are significantly different at $p \leq 0.05$ according to the Tukey HSD Test. The lack of letters indicates the lack of significance between means.
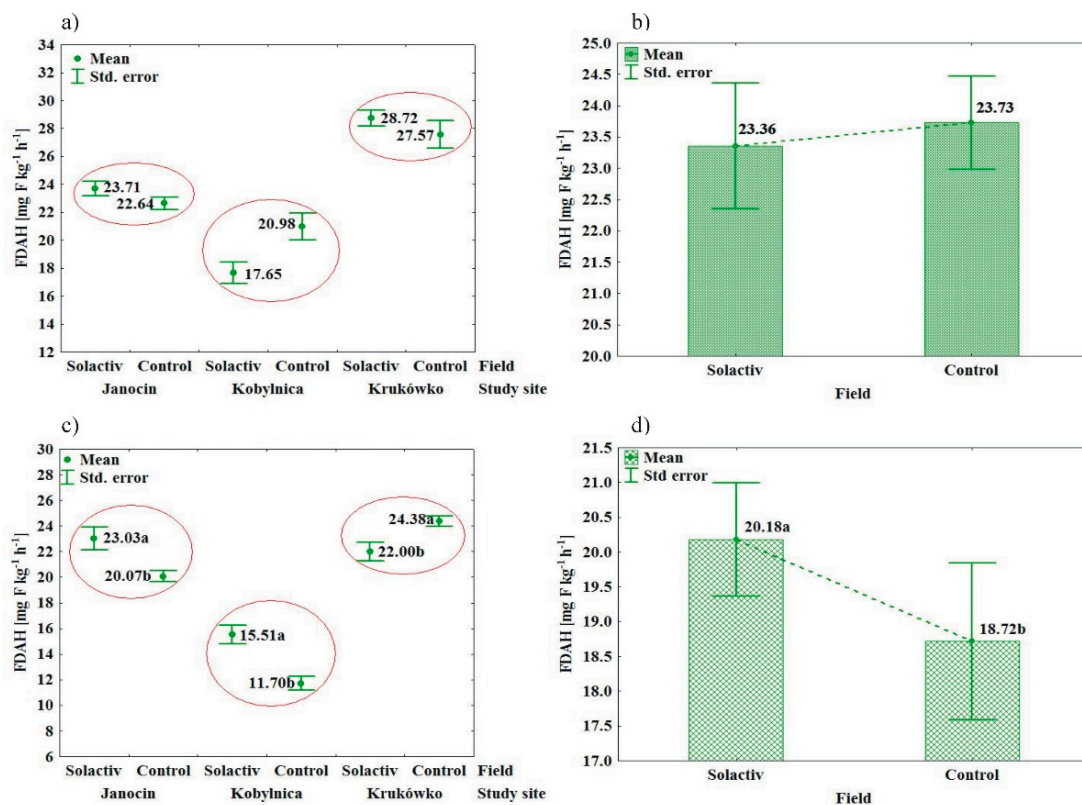
Figure 2. The FDAH level as affected by the tested conditioner. (**a**,**b**) I sampling (before the maize was sown, *n* = 10); (**c**,**d**) II sampling (after the maize was harvested, *n* = 10); (**b**,**d**) the mean for all study sites (*n* = 30). Data were analyzed using one-way ANOVA. Mean values for the conditioner and control followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's HSD Test. The lack of letters indicates the lack of significance between means.

However, there was a statistically significant response of the FDAH activity to the tested conditioner at two study sites, while its application at the third site caused a significant decrease in the FDAH level. When the experimental locations were considered together, there was a significant increase in the FDAH level after the Solactiv was applied.

Independent of the experimental locations and fields (conditioner, control), the CMC-cellulase activity was significantly lower in the soil that was collected before the maize was sown (9.81 mg Glu kg^{-1} h^{-1}) than after it was harvested (16.8 mg Glu kg^{-1} h^{-1}) (Figure 3). The differences between this property in the soil that were collected from both fields (destined for the conditioner or the control) before the Solactiv was applied was not significant at any of the experimental sites. After the maize was harvested, there was only a statistical significance for two of the three sites, where the increase in the CMC activity was about 16% and 20%.
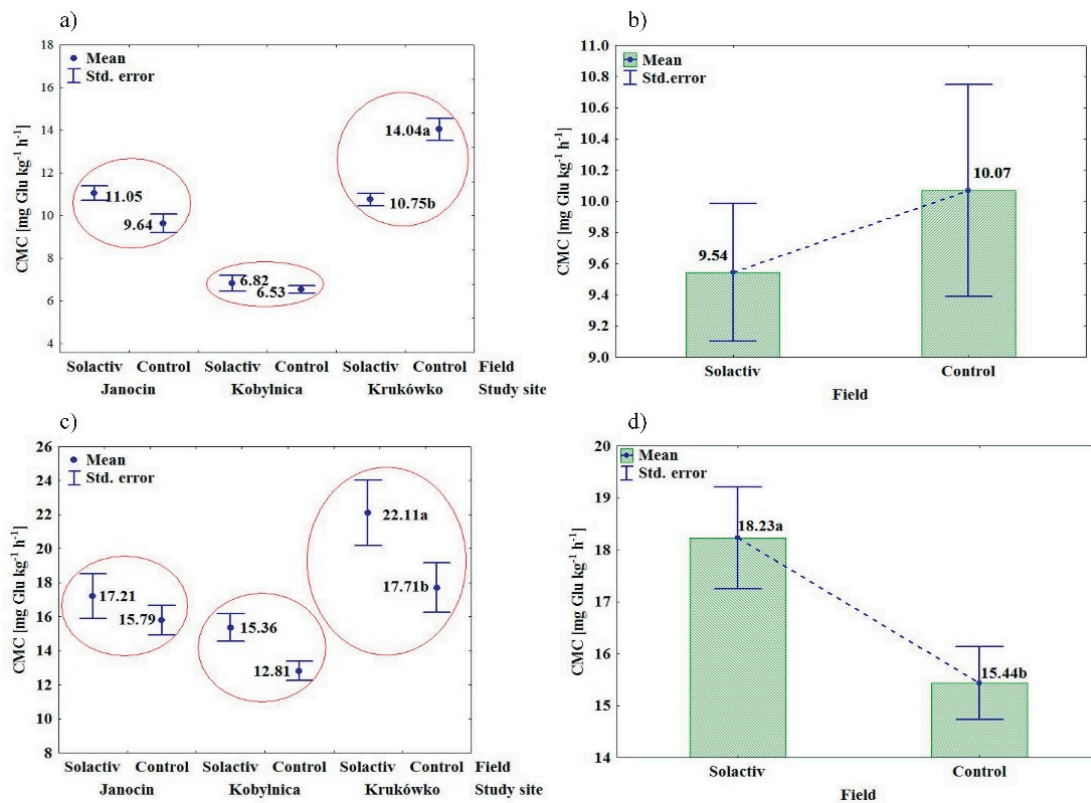
Figure 3. CMC-celulase activity as affected by the tested conditioner. (**a**,**b**) I sampling (sampling before the maize was sown, *n* = 10); (**c**,**d**) II sampling (after the maize was harvested, *n* = 10); (**b**,**d**) the mean for all study sites (*n* = 30). Data were analyzed using one-way ANOVA. Mean values for the conditioner and control followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's HSD Test. The lack of letters indicates the lack of significance between means.

There were no clear differences in the MBC and MBN content due to the application of the conditioner at the individual study sites (Table 2). Independent of the study sites, the application of the conditioner did not affect none of these properties. Although the differences between these properties in the soil collected from both fields (conditioner and control) before and after the Solactiv was applied were significant, they were similar (about 14.9 and 11.5 mg kg^{-1} in the case of MBC and 1.4 and 1.5 mg kg^{-1} for MBN), which suggests that the conditioner had no effect on these microbial properties.

Table 2. Soil carbon- and nitrogen-related properties as affected by the applied conditioner, mean (±SE) for the study sites.

Property	Sampling Time	Solactive		Control	
		Mean (±SE)	Range	Mean (±SE)	Range
C_{ORG} (g·kg^{-1})	I *	8.08 (±0.39)	5.99–11.4	9.07 (±0.33)	7.04–11.9
	II **	7.94 (±0.39)	5.47–11.4	8.54 (±0.37)	6.67–11.2
N_{TOT} (g·kg^{-1})	I *	1.08 (±0.05)	0.81–1.46	1.19 (±0.04)	0.95–1.58
	II **	0.98 (±0.04)	0.68–1.25	1.05 (±0.04)	0.84–1.34
DOC (mg·kg^{-1})	I *	92.1 (±2.53)	71.8–110.3	96.6 (±2.63)	79.1–131.7
	II **	76.0 (±2.81)	55.2–97.2	80.8 (±2.09)	65.0–93.0
DNt (mg·kg^{-1})	I *	27.4 (±1.56)	18.6–42.0	31.4 (±1.56)	20.6–44.3
	II **	20.7 (±1.45)	12.8–36.8	25.7 (±2.66)	14.4–48.8
DOC (%)	I *	1.17 (±0.03)	0.94–1.37	1.08 (±0.03)	0.80–1.29
	II **	0.97 (±0.02)	0.77–1.13	0.97 (±0.04)	0.74–2.34
DNt (%)	I *	2.54 (±0.08)	1.98–3.09	2.65 (±0.10)	1.89–3.51
	II **	2.07 (±0.07)	1.56–2.94	2.33 (±0.16)	1.48–3.76
MBC (mg·kg^{-1})	I *	118.6 (±4.27)	104.5–128.9	103.7 (±5.07)	78.4–135.7
	II **	104.7 (±5.25)	78.9–139.7	93.2 (±4.66)	65.5–132.2
MBN (mg·kg^{-1})	I *	18.9 (±1.17)	16.1–20.6	17.5 (±2.25)	13.4–22.2
	II **	16.8 (±2.55)	12.9–22.3	15.3 (±1.88)	11.2–21.7

Notes: SE—standard error, C_{ORG}—organic carbon, N_{TOT}—total nitrogen, DOC—dissolved organic carbon, DNt—dissolved total nitrogen, I—before maize was sown (* conditioner was to be applied), II—after maize was harvested (** conditioner was applied). Data were analyzed using one-way ANOVA. Mean values for the conditioner and control (in the same sampling time) are not significantly different at $p \leq 0.05$ according to Tukey HSD Test.

3.2. Soil Chemical and Physical Properties

The content of C_{ORG} and N_{TOT} was in the range of 5.47 and 11.9 mg kg^{-1} and 0.68 and 0.95 mg·kg^{-1}, respectively, and was not significantly affected by the conditioner (Table 2). Independent of the study sites, the differences in the DOC and DNt (mg kg^{-1}) between the fields with the conditioner and the control were similar on both sampling dates (about 4.4 and 4.8 mg kg^{-1} for the DOC and 4.0 and 5.1 mg kg^{-1} for DNt) (Table 2). The observation suggested that the studied conditioner had no effect on these properties. Considering the contribution of the DOC and DNt in the C_{ORG} and $N_{TOT,}$ respectively, there was a larger decrease in their contribution in the soil that was collected from the field with the conditioner compared to the control (DNt–0.47% in the field with the conditioner, and 0.2% in the control; DOC–0.2% in the field with the conditioner, and 0.11% in the control).

As for the available forms of the macronutrients, only K increased significantly (more than 11%) after the conditioner was applied compared to the control (Table 3). The available form of Mg had the opposite trend and was significantly lower in the field with the conditioner than in the control (second sampling time), while before the conditioner was applied, there were no significant differences between the two fields (Table 3). In turn, the differences in the available P in the soil collected in both fields (conditioner and control) before and after the Solactiv was applied were significant (for the conditioner), although they were similar (about 18.5% in the soil samples that were collected before the conditioner was applied and 21.3% at the second sampling time), which actually indicated that the conditioner had little effect on this variable (2.8%) (Table 3).

Table 3. Available and exchangeable forms of the macronutrients and some sorption soil properties as affected by the conditioner application, mean (±SE) for the studied sites.

Property	Sampling Time	Solactiv		Control	
		Mean (±SE)	Range	Mean (±SE)	Range
Mg-$_{AVAIL}$ ($mg·kg^{-1}$)	I *	74.6 (±4.61)	40.6–98.7	70.7 (±4.66)	38.3–96.0
	II **	88.2 (±5.75)b	45.4–132.7	93.6 (±6.78)a	44.1–145.6
P-$_{AVAIL}$ ($mg·kg^{-1}$)	I *	79.1 (±2.11)a	63.0–97.0	64.5 (±1.70)b	51.4–78.6
	II **	65.7 (±3.48)a	34.4–96.5	51.7 (±2.82)b	29.3–70.6
K-$_{AVAIL}$ ($mg·kg^{-1}$)	I *	129.5 (±5.03)	92.7–175.0	127.8 (±6.34)	91.2–184.3
	II **	189.4 (±5.87)a	145.7–256.6	167.7 (±12.4)b	88.6–288.4
Mg-$_{EXCHAN}$ ($cmol·kg^{-1}$)	I *	4.28 (±0.22)	2.67–5.97	3.57 (±0.33)	1.23–5.41
	II **	7.33 (±0.50)	3.78–10.5	7.80 (±0.58)	3.88–12.5
Ca-$_{EXCHAN}$ ($cmol·kg^{-1}$)	I *	5.14 (±1.03)a	4.23–5.99	4.51 (±2.40)b	2.69–6.66
	II **	5.50 (±1.68)a	3.98–6.91	5.10 (±1.84)b	3.75–7.13
K-$_{EXCHAN}$ ($cmol·kg^{-1}$)	I *	3.95 (±0.18)	2.64–5.87	4.14 (±0.20)	2.61–5.88
	II **	2.38 (±0.18)	1.47–4.30	2.83 (±0.25)	1.12–4.95
Na-$_{EXCHAN}$ ($cmol·kg^{-1}$)	I *	2.89 (±0.16)	1.73–3.79	2.71 (±0.17)	1.45–3.98
	II **	1.94 (±0.19)b	0.94–3.83	2.31 (±0.23)a	0.72–3.83
pH$_{KCl}$	I *	6.04 (±0.14)a	4.82–7.25	5.71 (±0.16)b	4.14–6.78
	II **	6.03 (±0.12)a	4.67–7.06	5.59 (±0.14)b	4.32–6.92
Hh ($cmol·kg^{-1}$)	I *	1.38 (±0.11)b	0.37–2.30	1.83 (±0.15)a	0.80–3.66
	II **	1.59 (±0.10)b	0.66–2.62	2.13 (±0.15)a	0.94–3.75
S ($cmol·kg^{-1}$)	I *	6.25 (±0.11)a	5.26–7.38	5.55 (±0.29)b	3.33–7.68
	II **	6.66 (±0.18)	5.18–8.03	6.39 (±0.27)	4.40–9.19
CEC ($cmol·kg^{-1}$)	I *	7.64 (±0.14)	5.73–8.88	7.38 (±0.33)	5.01–10.0
	II **	8.25 (±0.19)	6.82–10.0	8.53 (±0.32)	6.24–11.2
Basic saturation (%)	I *	82.2 (±1.26)a	71.9–94.8	75.0 (±1.78)b	62.2–87.4
	II **	80.8 (±1.16)a	67.5–91.6	75.1 (±1.41)b	62.2–85.7

Notes: SE—standard error, I—before maize was sown (* conditioner was to be applied), II—after maize was harvested (** conditioner was applied), AVAIL—available forms, EXCHAN—exchangeable forms, pH$_{KCl}$—exchangeable acidity, Hh—hydrolytic acidity, S—basic saturation, CEC—cation exchange capacity. Data were analyzed using one-way ANOVA. Mean values for conditioner and control (in the same sampling time) followed by different letters are significantly different at $p ≤ 0.05$ according to Tukey HSD Test. The lack of letters indicates the lack of significance between means.

When the experimental locations and sampling times were considered together, the exchangeable forms of Mg and K were not significantly affected by the conditioner, while the exchangeable Ca was significantly higher in the field with the conditioner at both sampling times, although the increase for the conditioner was only 12.3% (I sampling) and 7.3% (II sampling), thus indicating the lack of any real impact of the Solactiv. In turn, the exchangeable Na decreased significantly in soils on which the conditioner was applied compared to the controls (Table 3).

The differences in the pH in KCl between the fields with and without the conditioner at both sampling times was similar, which suggests that the conditioner had little effect on this property (Table 3). The control soil before the maize was sown and after it was harvested had a significantly higher hydrolytic acidity (Hh) compared to the soil from the field with the conditioner (0.45 and 0.54 cmol·kg^{-1}, respectively). Independent of the study sites and sampling times, the CEC (cmol·kg^{-1}) was not affected by the conditioner, while the S (cmol·kg^{-1}) was not significantly affected by the Solactiv in the soil that was collected after the maize was harvested (Table 3).

Independent of the study sites, the soil total porosity (TP) was significantly higher in the soil that was sampled from the field with the conditioner (37.6%) than in the control soil samples (36.3%) (Figure 4). This tendency was true for two of the three study sites. The higher total porosity in the field

with Solactiv was closely related to the lower bulk density in this field (1.54 g cm^{-3}) compared to the control (1.57 g cm^{-3}) (Figure 5) and to the greater participation of the macropores (10.7%) in the TP compared to the control field (9.3%) (Figure 6).
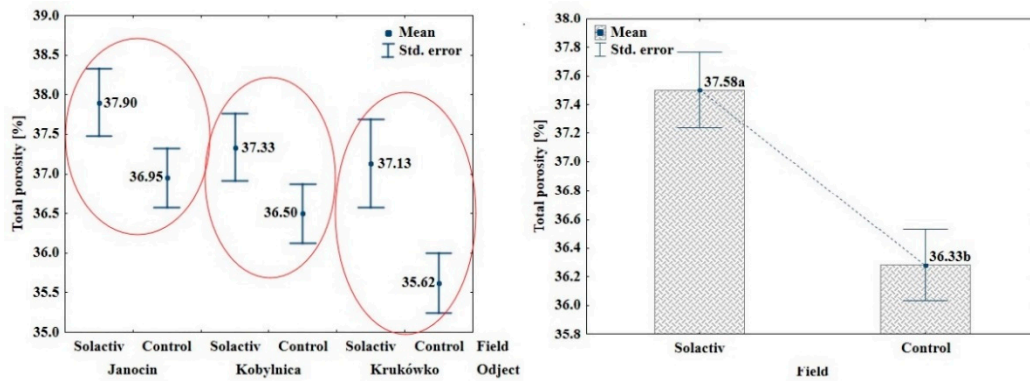

Figure 4. Soil total porosity as affected by the tested conditioner. On the left: means for individual study sites (n = 10); on the right: means for all study sites (n = 30). Data were analyzed using one-way ANOVA. The mean values for the conditioner and control followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's HSD Test. The lack of letters indicates the lack of significance between means.
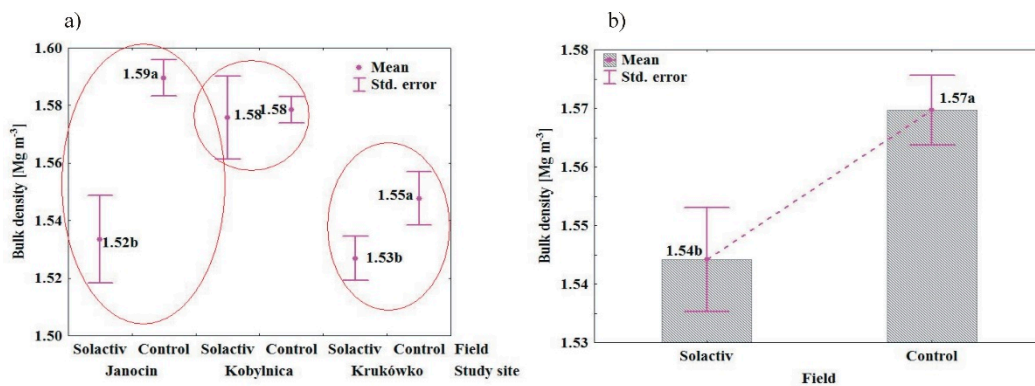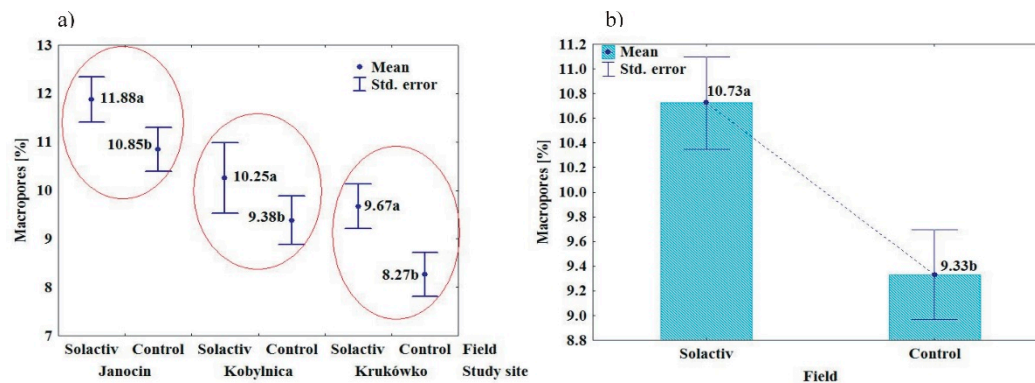

Figure 5. Soil bulk density as affected by the tested conditioner. (**a**) means for individual study sites (n = 10); (**b**) means for all study sites (n = 30). Data were analyzed using one-way ANOVA. Mean values for conditioner and control followed by different letters are significantly different at $p \leq 0.05$ according to Tukey HSD Test. The lack of letters indicates a lack of significance between means.

Figure 6. Soil macropores as affected by the tested conditioner. (**a**) means for individual study sites (n = 10); (**b**) means for all study sites (n = 30). Different small letters indicated significant differences between mean values. Data were analyzed using one-way ANOVA. Mean values for conditioner and control followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's HSD Test.

The higher TP in the field with the conditioner likely increased the available water capacity (AWC), which was 18.8% in this field but was lower in the control field (16.6%) (Figure 7). The greatest difference in the AWC between both of the fields was observed at the Krukówko study site. The AWC is usually affected by the content of mesopores, and the higher AWC in the field with the conditioner indicated a greater contribution of the mesopores in the TP. The opposite effect was observed in the case of the micropores, and thus, their content was significantly higher in the control soils than in the field with the conditioner, which was true for all of the study sites (Figure 8).
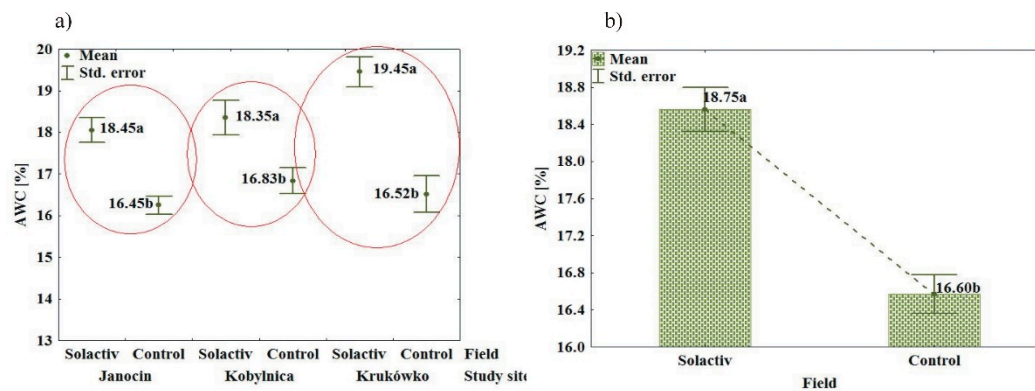

Figure 7. Soil AWC as affected by the tested conditioner. (**a**) The means for individual study sites (*n* = 10); (**b**) the means for all study sites (*n* = 30). Data were analyzed using one-way ANOVA. Mean values for the conditioner and control followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's HSD Test.
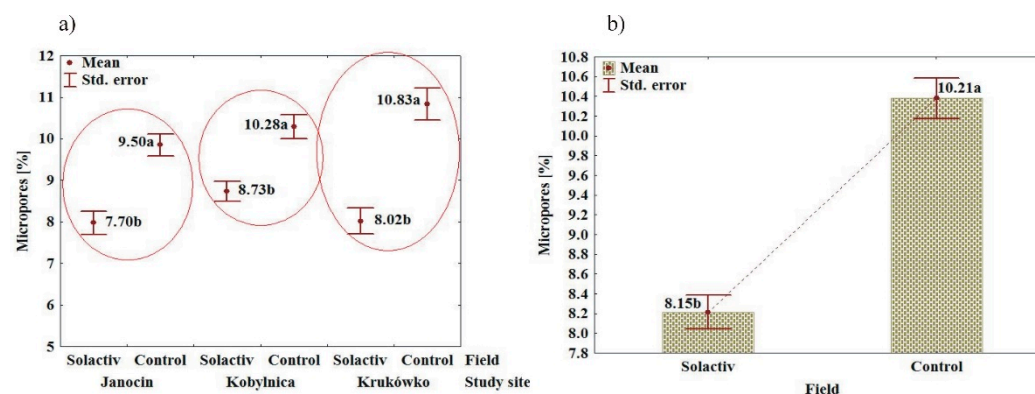

Figure 8. Soil micropores as affected by the tested conditioner. (**a**) The means for individual study sites (*n* = 10); (**b**) the means for all study sites (*n* = 30). Data were analyzed using one-way ANOVA. Mean values for conditioner and control followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's HSD Test.

The AWC consists of the readily available water capacity (RAWC) and small pores available water capacity (SAWC). The values of these retentions were significantly higher in the soil with the Solactiv than in the control soil (Figures 9 and 10). There were also significant differences in the RAWC and SAWC between the field with the conditioner and the control in two of the three studied sites.
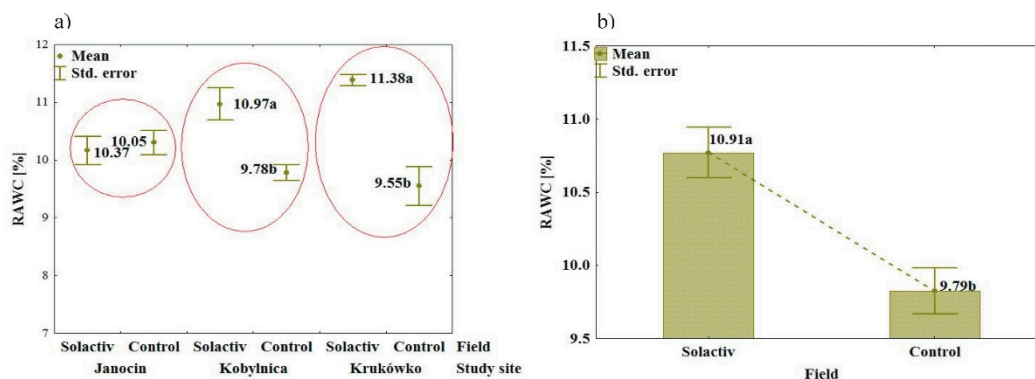
Figure 9. Soil RAWC as affected by the tested conditioner. (**a**) means for individual study sites (*n* = 10); (**b**) means for all study sites (*n* = 30). Data were analyzed using one-way ANOVA. Mean values for conditioner and control followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's HSD Test. The lack of letters indicates the lack of significance between means.

Figure 10. Soil SAWC as affected by the tested conditioner. (**a**) means for individual study sites (*n* = 10); (**b**) means for all study sites (*n* = 30). Data were analyzed using one-way ANOVA. Mean values for conditioner and control followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's HSD Test. The lack of letters indicates the lack of significance between means.
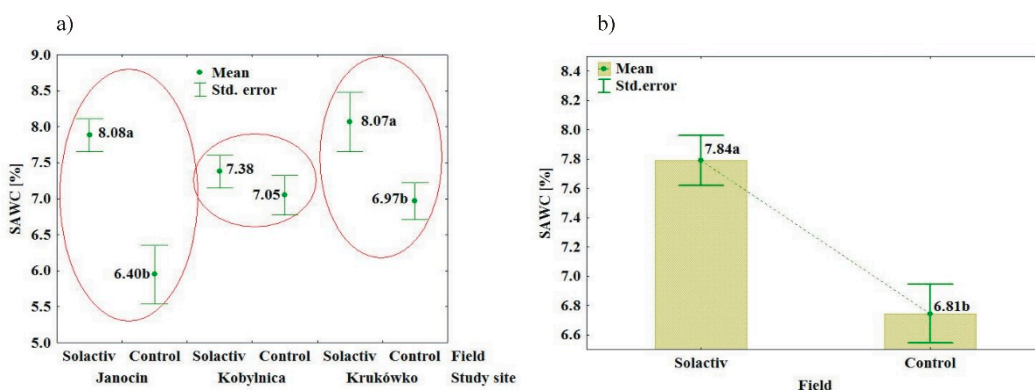
3.3. Properties Related to the Growth and Yield of Maize

Independent of the application of the conditioner and the study sites, the average value of the SPAD was 464 units and was the highest in the panicle blooming phase (619 units) (Table 4). The application of the conditioner to the soil significantly increased the nutrition of the maize with nitrogen, which was confirmed by the higher values of the SPAD in the BBHC 33–34 and BBCH 64–65, and the higher values of this index (19, 28 and 16 units–for three measurements, respectively) in the soil that was treated with the conditioner compared to the control. The effect of the conditioner on the SPAD was associated with the site conditions (Janocin and Kobylnica) and was not observed in Krukówko.

Table 4. The leaf greenness index (SPAD) at the three study sites as affected by the applied conditioner (mean ± SE).

BBCH Growth Stage	Conditioner	Study Site			Mean **
		Janocin (I)	Kobylnica (II)	Krukówko (III)	
BBCH 15–16 *(three-leaf phase)*	Solactiv	322(±0.95)	292(±3.51)	282(±1.23)	299
	Control	323(±2.62)	291(±5.01)	279(±1.98)	298
	*Mean ***	*323*	*292*	*281*	***298***
BBCH 33–34 *(three-node phase)*	Solactiv	512(±2.20)a	501(±1.27)a	442(±2.76)	485a
	Control	491(±3.36)b	475(±3.31)b	434(±1.39)	466b
	*Mean ***	*501*	*488*	*438*	***476***
BBCH 64–65 *(panicle blooming phase)*	Solactiv	646(±2.55)a	663(±4.69)a	589(±1.97)	633a
	Control	609(±3.39)b	618(±5.23)b	588(±2.03)	605b
	*Mean ***	*627*	*641*	*588*	***619***
Mean for the three measurements	Solactiv	493(±1.18)a	485(±2.27)a	438(±1.49)	472a
	Control	474(±2.60)b	461(±4.31)b	433(±1.40)	456b
	*Mean ***	*484*	*473*	*436*	***464***

Notes: Mean * (for the conditioner). Mean ** (for the study sites). Data were analyzed using one-way ANOVA. Data within a column followed by different letters are significantly different at $p \leq 0.05$ according to Tukey's HSD Test. The lack of letters indicates the lack of significance between means.

The height of the maize plants was higher in the fields with the conditioner compared to the control soils (Table 5). With regards to the study site, the highest maize plant height was found in Kobylnica, while the lowest was found in Krukówko. Although this effect was not statistically significant depending on the study site, it proved to be strong enough in Kobylnica and Janocin, but was quite the opposite in Krukówko. The average value of the fresh biomass of the maize for the three study sites was 694.9 g and it was 24.7% higher in Janocin than in Krukówko (Table 5).

Table 5. Maize-related properties at the three study sites as affected by the applied conditioner (mean ± SE).

Property	Field	Study Site			Mean **
		Janocin (I)	Kobylnica (II)	Krukówko (III)	
Plant height (cm) before harvesting *(BBCH 87–89)*	Solactiv	265.4(±31.73)	275.4(±2.30)	252.5(±1.53)	264.4
	Control	258.0(±1.55)	267.8(±2.67)	254.4(3.86)	260.1
	*Mean ***	*261.7*	*271.6*	*253.4*	***262.2***
Fresh plant biomass (g) *(BBCH 84–85)*	Solactiv	785.5(±14.8)	745.6(±8.53)	615.4(±11.1)	715.5a
	Control	715.2(±7.52)	720.1(±21.0)	587.7(±14.9)	674.3b
	*Mean ***	*750.3*	*732.9*	*601.5*	***694.9***
Fresh cob biomass before harvesting *(BBCH 87–89)*	Solactiv	311.4(±4.88)	302.3(±2.94)	212.6(±4.41)	275.4a
	Control	292.1(±5.55)	284.2(±12.4)	202.0(±5.25)	259.4b
	*Mean ***	*301.8*	*293.2*	*207.3*	***267.4***
Grain yield (t·ha^{-1})	Solactiv	13.4(±0.51)	9.82(±0.74)	8.51(±0.34)	10.6
	Control	11.9(±0.76)	9.62(±0.60)	9.00(±0.41)	10.2
	*Mean ***	*12.6*	*9.7*	*8.7*	***10.4***
Weight of 1000 seeds (g)	Solactiv	308.4(±3.64)a	211.4(±8.05)	232.8(±6.43)	250.8
	Control	275.7(±12.9)b	216.8(±5.45)	243.5(±3.96)	245.3
	*Mean ***	*292.0*	*214.1*	*238.1*	***248.1***

Notes: Mean * (for the conditioner). Mean ** (for the study sites). Data within a column followed by different letters are significantly different at $p \leq 0.05$ according to Tukey HSD Test. The lack of letters indicates the lack of significance between means.

The application of the conditioner significantly affected the fresh plant biomass compared to the control, and the increase was about 41.2 g, i.e., 6.1%. The mean value of the maize grain yield was 10.4 t·ha^{-1} and ranged from 8.51 t·ha^{-1} in Krukówko to 13.4 t·ha^{-1} in Janocin (both fields with the conditioner) (Table 5). The difference of 0.4 t·ha^{-1} between the control fields and those with the conditioner was too small to be confirmed statistically. The weight of 1000 seeds was confirmed to be statistically significant for the field with the conditioner (Table 5). However, this was only true for one study site (Janocin). In the other two locations, the tendency was the opposite, and the weight of 1000 seeds was significantly higher in the control fields than in the field on which the Solactiv was applied. The average fresh cobs biomass in three experiments was 267.4 g, which was 38.5% of total fresh plant biomass. The maize cultivated in Janocin and Kobylnica had the heaviest cobs, while the maize from Krukówko was lightest (by about one third–1/3) (Table 5). The application of the conditioner to the soil generally increased the fresh cob biomass significantly (about + 16 g–6%). The largest but statistically insignificant increase of the cob biomass was found in the object located in Janocin (+19.3 g), while the lowest was found in the object located in Krukówko (+10.6 g).

4. Discussion

According to the producer, Solactiv significantly improves the soil sorption capacity, increases the effectiveness of fertilization, improves the soil structure and water retention and stimulates the development of plant roots (Manufacturer's leaflet), despite the low dose that is applied per 1 hectare. In this study, we found that the applied conditioner significantly improved some of the maize-related properties as well as selected soil properties (Figures 1–10, Tables 2–5).

4.1. Soil Biochemical Properties

The applied conditioner significantly affected the activity of the studied enzymes but not the content of microbial biomass, expressed as the C and N content. All of the components of the conditioner might indirectly contribute to the positive response of the enzymatic activity to its application, and also directly by improving some of the physico-chemical soil properties. Literature data claims that microbial populations can respond to a zeolite amendment in different ways. Most of the data on the relationship between zeolites and the soil microflora indicate a positive effect of these minerals on the quantitative composition and activity of soil microorganisms [36,37]. Treatments with zeolite-clinoptilolite had a significantly higher DHA compared to the control in the study of Karličić et al. [38]; however, a significantly higher DHA was observed in the same study after treatment with mineral fertilizer (calcium ammonium nitrate) than in the zeolite-clinoptilolite, ammonia-loaded zeolite-clinoptilolite and control. Mühlbachová and Šimon [39] observed that zeolite-amended soil decreased its microbial biomass slightly, however, not significantly. By contrast, several authors have claimed that the quantity of microorganisms might be increased in organic-zeolitic-amended soils [37,40].

It is commonly known that when used as biofertilizer, seaweeds affect the soil biochemical properties, which has been reported by numerous studies, e.g., References [41,42]. Because of the composition of the seaweeds (several organic contents, particularly carbohydrates, proteins and fatty acids), they are considered to have a significant effect on the soil enzymes. It was found earlier that seaweed contains more than 5000 different enzymes [43], primarily oxidoreductases and hydrolases, which catalyze the redox and hydrolysis reactions, respectively. Oxidoreductases provide an overall picture of the soil microbial processes, whereas hydrolases provide specific information about the biogeochemical cycles of C, N, S, and P [44]. Recently, Wang et al. [42] found that at different dilutions, seaweed fertilizers affected the microbial and soil enzymatic activities such as dehydrogenases and proteases. They stated that the application of seaweed fertilizer after biological fermentation may generate more bioavailable substrates such as non-structural proteins and abundant peptides in soil. The presence of a large amount of bioavailable N can induce protease secretion. Additionally, Chen et al. [45] found that the enzymatic activities of dehydrogenase, nitrite reductase, urease, and cellulase in the soil increased significantly shortly after the application of seaweed fertilizer

to the maize rhizosphere soil. In this study, *Ascophyllum nodosum* extract could induce the activity of hydrolytic enzymes determined by the level of the hydrolysis of fluorescein diacetate (FDAH). The activity of bacteria in the soil is known to increase when seaweed extract is applied to the soil. Seaweed fertilizers help soil to create an environment that is suitable for root growth by increasing the microbial diversity and improving biological properties like respiration and nitrogen mobilization, as well as the mineralization of mineral nutrients [46]. However, our data did not confirm these findings because both the microbial biomass C and N content and the DHA (on two of the three study sites), as well the maize root system, were not significantly affected by the tested conditioner. The lack of differences in MBC and MBN between treated and untreated soils could be explained by the short duration of the study, as well as by the complexity of interaction between the components of the conditioner. A water deficit during the growing season might also affect such relationship.

4.2. Soil Chemical and Physical Properties

A significant increase in the available K can mainly be attributed to the presence of zeolite-clinoptilolite in the conditioner. It is commonly known that zeolites are one of the most efficient cationic exchangers. In fact, clinoptilolite, which is the most abundant zeolite in nature [47], is often used as a source of potassium and ions and can control the release of K from fertilizers for their optimum use by plants [48]. Their cationic exchange capacity is two to three times greater than other types of minerals that are found in soils. That is why zeolites are widely used as slow-release fertilizers that increase nutrient retention capacity. Józefaciuk et al. [49] used clinoptilolite in their field experiment and found that the surface area of zeolite-enriched soil was significantly larger than the sum of the surface areas of the initial soil and the added zeolite. This was also confirmed by Filcheva and Tsadilas [50], who found that while the addition of clinoptilolite significantly increased soil pH and exchangeable K, it did not affect the soil humus content or the soil chemical composition.

An effect on total C and N is commonly observed after the continuous application of conditioners for at least several years [51]. Thus, the limited timeframe of our study (one season) may be the reason why the C_{ORG} and N_{TOT} only changed slightly between the fields with and without the conditioner.

In our study, water-related properties could also have been affected by the zeolite from the tested conditioner. It was previously found that the application of zeolites (7.5 t ha^{-1}) increased the soil pH, water-holding capacity (from 33% in the control to 48% in the pots with 7.5 t ha^{-1} of zeolite) and CEC [52]. Zeolites can hold water within its pores, which can form a layer around the surface by desorption, thus generating a friendly environment for microorganisms. Zeolites form a permanent water reservoir and provide prolonged moisture in dry periods, which helps plants to withstand drought. An amendment of sand with zeolite increased the available water to plants by 50% (16). The property of zeolites that significantly increases the available water capacity (AWC) and especially the RAWC as was found in this study.

Decreasing the bulk density (BD) in the fields with the conditioner could be explained by the presence of zeolite-clinoptilolite in the conditioner. This was confirmed by Abdel-Hassan and Radi [53] in a study that was carried out on two different soils (sandy loam and silty loam) under wheat cultivation. They showed that, depending on the dose, zeolite led to a decrease in BD in the sandy loam (1.28 to 1.15, 1.08, 0.84 and 0.75 Mgm^{-3}) and in the silty loam (1.12, 0.92, 0.87, 0.70 and 0.66 Mg m^{-3}). The same effect was found in the study of Hassan and Mahmoud [54]; after a mixture of zeolite with bentonite was applied to sandy soil, the DB decreased from 0.05 to 0.12 Mg m^{-3}. The same authors [53,54] also found an increase in the total porosity in the same soils, which was associated with the dose of the zeolite and soil texture. Moreover, in the pot culture study of Ravali et al. [52], the application of zeolite significantly reduced the bulk density of soil (7.5 t ha^{-1} of zeolite resulted in the lowest bulk density 0.97 Mg m^{-3}). The zeolite in the tested conditioner also probably affected the increase of the macropores and the decrease of the micropores in the total porosity, which was confirmed by the data of Githinji et al. [55], who observed an increase of the macro-porosity from 15 m^3 m^{-3} to 25 m^3 m^{-3} after adding clinoptilolite to the sandy soil. The significant increase of AWC,

RAWC, and SAWC in the fields with the conditioner could also be associated with the presence of zeolite, which was confirmed by the study of de Campos Bernardi et al. [47] carried out on Entisols in which the addition of the zeolites increased the AWC by about 10–67% and RAWC by about 15–111%, depending on the dose. Such high values of AWC and RAWC in this study were possible because their values in the studied Entisols were low and the zeolite doses were high (even up to 100 g kg^{-1}). A similar increase in the AWC, RAWC, and SAWC was previously observed in sandy soil and silty loam [47,54,55]. The application of a preparation with zeolite by Hassan and Mahmoud [54] in loamy sand and sand that was under maize cultivation resulted in an increase in the maize yield from 5.2 to 19.5 t ha^{-1}. Very high rates of zeolites mixed with sand (44.8 t ha^{-1}) improved the soil moisture content by only 1.3%, which simultaneously resulted in a lower maize yield because Na had been added with the zeolite, which should be leached before crops are grown [56]. In the same study, the water retention at matric potentials of −100 and −300 kPa (plant available water) was greatest for a mixed zeolite rate of 44.8 Mg ha^{-1} compared to a lower zeolite rate and the control.

4.3. Plant Properties

The leaf greenness index (SPAD) is one of the maize-related properties that was significantly improved by the tested conditioner. The level of nitrogen nutrition, which determines the yield, is one of the parameters that determine the condition of maize during the vegetation period. A test that was based on determining the chlorophyll in leaves by assessing their greenness index (SPAD) is a popular and frequently used method in agriculture practice to determine the level of plant nutrition with nitrogen [57]. A close relationship was found between the nitrogen content and the amount of chlorophyll in leaves [58]. Some authors have indicated that seaweed extract might be a potential factor that affects the chlorophyll in plants [59]. In fact, an increase in the chlorophyll content was achieved in different crops (tomato, wheat, barley and maize) that had been treated with liquid *Ascophyllum nodosum* alkaline extracts. It was explained earlier that this increase in the chlorophyll content was due to the presence of betaines in the seaweed extracts [60].

The effect of *Ascophyllum nodosum* extract on the growth and yield of various cultivated plants is commonly known [45,61,62]. Alam et al. [61,62] reported the effects of this extract on strawberries and carrots and found that its application could also increase the root-zone soil microbial activity, in addition to its effect on plant growth and production. In the study of Chen et al. [45], the growth of maize seedlings was confirmed to be greatly promoted by using seaweed fertilizer and that the seedling height and above-ground seedling fresh mass increased significantly ($p < 0.01$). The above-mentioned effect could be due to the content of biostimulants (2% of abscisic acid, 3% adenine and 5% indoleacetic acid) [18].

The content of zeolite in the tested conditioner could have a positive effect on the fresh maize plant biomass and fresh cob biomass, which was confirmed by other authors. Aainaa et al. [63] recommended adding clinoptilolite with a 25% reduction of mineral fertilization compared to 100% of the recommended rate of fertilization in maize cultivation cycles because of the similar cob yield in both cases. After six weeks of corn growth in an amended sandy soil, the application of zeolite at 22 Mg ha^{-1} seemed to increase the corn weight compared to the controls [56]. By using clinoptilolite-rich tuff as a soil conditioner, significant increases in the yields of wheat (13–15%), eggplant (19–55%), apples (13–38%), and carrots (63%) were reported when 1.6–3.2 t zeolite ha^{-1} were used [64].

An experiment that was conducted in Venezuela under maize cultivation revealed that applying potassium humate to loamy sand soil resulted in an increase in the SPAD (27–59%), while the plant height of 56–151% was dependent of the dose used [65]. The application of potassium humate also positively affected the weight of 1000 seeds, which was also found in carbonate soils [66]. Many studies, however, have shown little or no benefit when humates are applied to a field at the recommended doses (for K humate commonly 5–10 kg/ha), which are therefore likely to be too low to be effective [67,68]. The amount of potassium humate in the conditioner used in this study (6 kg/ha) seemed to be too low

to produce the claimed benefits because it is unlikely that, at these doses, there are sufficient quantities of the active components.

5. Conclusions

The application of the tested conditioner was found to be beneficial for selected maize- and soil-related properties despite the low dose (300 kg ha^{-1}) that was used. The conditioner was effective in improving the soil water storage and soil K plant availability and helped improve the soil biological activity by increasing its enzymatic activity. Its lack of effectiveness toward some properties such as the maize yield or most of the studied soil physico-chemical properties compared to the other studies may have resulted from the differences in the number of components used to produce the fertilizer. In turn, the observed effect may have arisen from the interactions of the conditioner components.

It can be concluded that the amended conditioner is a promising approach for developing more sustainable agriculture, which will also be beneficial for plant development and soil status; however, several more cycles of maize cultivation at different locations and at a larger scale will be needed to test the effectiveness of this conditioner. Since the studied Luvisols are moderately fertile soils, the relatively high nutrient abundance could weaken the visibility of the conditioner impact. That is why the effectiveness of the Solactiv should be tested also in poor, sandy soils, with low nutrients abundance and low yielding. Climatic factors such as temperature and rainfall distribution between the study sites should also be taken into consideration in order to confirm the findings of the study.

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