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Enzymatic Activity of Loess Soil in Organic and Conventional Farming Systems

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Abstract: This study was conducted over the period 2017–2019 in Czesławice (central Lublin region, Poland). The aim of the present study was to compare chemical soil quality parameters (soil pH, available P and K, organic carbon, and total nitrogen content) and soil enzymatic activity (dehydrogenase, acid phosphatase, alkaline phosphatase, urease, protease) in organic and conventional farming systems. The experimental design included two crop rotations (organic and conventional) in which identical plant species were grown: sugar beet-spring barley-red clover-winter wheat-oats. The loess soil on which the experiment was conducted was characterized by the grain size distribution of silt loam, and this soil was categorized as good wheat soil complex (soil class II). The experiment was set up as a split-plot design in triplicate in plots with an area of 40 m². Soil sampling was carried out using a soil auger within an area of 0.20 m² (from the 0 to 20 cm layer) in each plot during the autumn period. Over the 3-year study period, it was found that the organic system contributed to an increased soil content of organic carbon and total nitrogen. Moreover, a significantly higher soil pH value and a favorable narrow C/N ratio were found under the organic system (regardless of the crop species). Under the conventional system, in turn, a higher soil phosphorus and potassium content was observed. Enzymatic tests of the soil in the five-field crop rotation proved significantly higher activity of all the enzymes studied (in particular that of dehydrogenase, protease, and urease) in the organic system relative to the conventional one, regardless of the crop plant. Among the plants grown in crop rotation, sugar beet, and red clover had the most beneficial effect on the activity of the soil enzymes, followed by oats (especially under the organic system). The activity of the studied enzymes in the organic system was positively correlated (statistically significantly) with favorable soil pH, a higher content of organic C, and total N, and C/N ratio.

Keywords: crop rotation; organic system; conventional system; soil chemical properties; soil enzymatic activity

1. Introduction

Organic agriculture has been and is a response to the intensification of agricultural production—excessive use of mineral fertilizers and pesticides as well as related environmental pollution. Agriculture intensification is thought to be a cause of soil degradation [1]. This paper presents the effect of organic and conventional agriculture on the chemical properties and enzymatic activity of loess soil. Organic matter (which is the basis for fertilization under the organic system) has an important influence on

soil quality, improvement of its structure, and increased water capacity. Many studies indicate that practices used in organic agriculture generally increase soil biological and enzymatic activity through greater accumulation of organic matter. This is achieved by using catch crops, farmyard manure, and reduced tillage practices [2,3].

Soil enzymes are natural mediators and catalysts of many important soil processes, such as: decomposition of organic matter released into soil during plant growth, processes of soil humus formation and decomposition, the release of mineral nutrients and their supply to plants, fixation of molecular nitrogen, and the flow of carbon, nitrogen and other major elements of the biochemical cycle [4,5]. It is necessary to determine enzymatic activity and to understand factors regulating it in order to characterize soil metabolic potential and fertility. This can be used to study biochemical processes occurring in soil and to evaluate soil quality [6–9]. Information regarding enzymatic activity, coupled with information on other soil properties, facilitate the selection of soil use [10,11].

Enzymatic activity is a sensitive indicator of changes in soil environment, and it changes depending on the farming system. Dehydrogenase and protease activity, as well as organic carbon and total nitrogen content, are higher in the soil in which crop rotation is used than in soil where crops are grown in monoculture [4]. Gianfreda et al. [12] have similar observations. Saviozzi et al. [13] recorded higher values for soil metabolic potential and the biological index of fertility (BIF) in a meadow than in a cereal field. According to Dahm [14] and Burns [15], the effects of higher plants on soil enzymes depend on the plant chemical composition, which, even in the case of root exudates alone, can exhibit significant differences between various genera, species, and also varieties. Krämer et al. [16] think that plants stimulate soil enzymatic activity due to increased biomass of enzyme-producing microbes. Woźniak [17] demonstrated that legumes (pea) had a more beneficial effect on soil enzymes than cereal crops.

Soil enzymatic activity is considered to be an essential parameter that reveals the status of the natural environment and shows the biochemical process that occurs in the environment. This parameter reflects the level and extent of pollution found in the environment [8]. Soil enzymatic activity can be influenced through agronomic practices (fertilization) [9]. Farming system (organic or conventional) and catch crops (in particular under the organic system) also have a significant impact on the activity of soil enzymes [18,19]. Catch crops are used to improve soil organic matter content, prevent the leaching of nutrients (predominantly nitrogen and phosphorus), and enhance the activity of soil microbes [20,21].

The novelty of this study was to determine soil chemistry and enzymatic activity in a five-field crop rotation (sugar beet-spring barley-red clover-winter wheat-oats) in the organic system relative to an identical experimental design conducted in the conventional system. It can be hypothesized based on the literature of the subject that the organic system, in comparison with the conventional system, as well as legumes and root plants increase the soil content of organic carbon and available forms of macronutrients. Soil enzymatic activity in organically cultivated soil is also higher than that in conventionally farmed soil used for cereal cropping. The present study was designed to determine the effects of organic and conventional farming systems and the effects of previous crops on soil chemical properties and enzymatic activity.

2. Material and Methods

2.1. Experimental Setup

A field experiment in growing crops in two 5-field crop rotations under organic and conventional farming systems was conducted over the period 2017–2019 at the Czesławice Experimental Farm (51°30' N; 22°26' E; Lubelskie Voivodeship, Poland). The experiment was set up as a split-plot design in 3 replicates in plots with an area of 40 m². It was located on a loess-derived Luvisol, with the grain size distribution of silt loam (PWsp), classified as good wheat soil complex (soil class II). Before the establishment of the experiment (2016, autumn), the soil was characterized by a medium content of available macronutrients (Table 1).

Table 1. Soil characteristics before the establishment of the experiment (2016).

Farming System	Soil pH (1M KCl)	N (%)	P (mg kg ⁻¹)	K (mg kg ⁻¹)	C Organic (%)
Organic	6.5	0.08	129	209	1.16
Conventional	6.4	0.12	133	217	1.25

The experiment included 2 farming systems:

1. Conventional—the recommended rates of mineral NPK (ammonium nitrate—34% N, enriched superphosphate—40% P₂O₅, potassium chloride—60% K₂O) and organic fertilization (manure applied for sugar beet), seed dressing, fungicide and herbicide application, and mechanical weed control (harrowing before emergence and at the 3–4 leaf stage);
2. Organic—organic fertilization with the fertilizer Humac Agro *, catch crops (lacy phacelia, faba bean + field pea mixture—as “green fertilizers” plowed under in autumn), and mechanical weed control (harrowing before emergence and at the 3–4 leaf stage). (* The chemical composition of the fertilizer Humac Agro is as follows: Humic acid content—62% on a dry weight basis; macro- and micronutrient content on a dry weight basis: potassium (K) 1.18 g kg⁻¹; calcium (Ca) 16.80 g kg⁻¹; sodium (Na) 12.80 g kg⁻¹, iron (Fe) 14.50 g kg⁻¹; zinc (Zn) 64 mg kg⁻¹; bromine (Br) 77 mg kg⁻¹; copper (Cu) 19 mg kg⁻¹; selenium (Se) 6 mg kg⁻¹; and moisture content—20%.)

All the crops tested were grown in 2 crop rotations (organic and conventional): sugar beet (*Beta vulgaris* L. subsp. *vulgaris*), spring barley (*Hordeum vulgare* L.), red clover (*Trifolium pratense* L.), winter wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.). Each year, the same mineral fertilization was used for individual crops. Mineral fertilization in conventional farming treatment is shown in Table 2.

Table 2. Fertilization applied in the conventional system.

Crop Plant	Mineral Fertilization in kg ha ⁻¹			Manure Fertilization in t ha ⁻¹
	N	P	K	
Sugar beat	100 (before sowing)	100 (before sowing)	140 (before sowing)	30 (autumn; before sowing)
Spring barley	60 (split doses) *	40 (before sowing)	80 (before sowing)	-
Red clover	30 (before sowing)	20 (before sowing)	50 (before sowing)	-
Winter wheat	100 (split doses) **	80 (before sowing)	120 (before sowing)	-
Oats	40 (before sowing)	30 (before sowing)	50 (before sowing)	-

* N—60 kg (20 kg before sowing, 40 kg in spring at stem elongation (BBCH 32–34)); ** N—100 kg (40 kg before sowing, 40 kg in spring at the beginning of the growing season (BBCH 21–24), 20 kg at the turn of stem elongation and heading stages (BBCH 32–36)).

In the case of the organic cropping system, the fertilizer Humac Agro was applied at the following rates (Table 3):

Table 3. Fertilization applied in the organic system.

Crop plant	Mineral Fertilization (Humac Agro) in kg ha ⁻¹	Manure Fertilization (Originating from Organic Livestock Production) in t ha ⁻¹
Sugar beat	500 (before sowing)	20 (autumn; before sowing)
Spring barley	350 (before sowing)	-
Red clover	50 (as top dressing)	-

Table 3. Cont.

Crop plant	Mineral Fertilization (Humac Agro) in kg ha ⁻¹	Manure Fertilization (Originating from Organic Livestock Production) in t ha ⁻¹
Winter wheat	400 (before sowing)	-
Oats	300 (before sowing)	-

Crop management operations in individual organically grown crops involved mechanical inter-row cultivation (sugar beet) and triple harrowing (cereal crops). Under the conventional system, crop management operations included the use of chemical crop protection products (seed dressing, herbicides, fungicides, insecticides, and retardants) from the product assortment and at times and rates compliant with the Crop Protection Calendar of the Institute of Plant Protection—State Research Institute in Poznań [22], as well as the use of mechanical weed control identical to that used in the organic treatment (but harrowing operations in cereal crops were carried out twice, not three times as in the organic treatment). Tillage was typical for each plant species. The individual plant species were harvested following the agronomic recommendations at optimal crop maturity dates.

Sowing and harvest dates for the individual crop species grown in a crop rotation under the organic and conventional systems were identical in each year of the study and were within the following time range (Table 4):

Table 4. Sowing and harvest dates of the crop plants included in the experiment.

Crop Plant	Sowing Date	Harvest Date
Sugar beat	20–25.04	16–19.10
Spring wheat	18–21.04	10–12.08
Red clover	18–21.04	20–22.08
Winter wheat *	20–22.09	8–10.08
Oats **	10–12.04	17–19.08

* In the organic system, after harvest of the winter wheat, a catch crop (faba bean + field pea mixture) was sown on August 15–18, whereas the catch crop biomass was plowed under on October 16–20. ** In the conventional system, after harvest of the oats, a catch crop (lacy phacelia) was sown on August 21–22, whereas the catch crop biomass was plowed under on October 25–28.

The results presented in this paper (2017–2019) are a part (continuation) of an organic cropping experiment conducted continuously since 2009 (it is now the 11th year of organic farming). Furthermore, during the period 2007–2008, phytosanitary crops (oats, white mustard) were grown in this field. Throughout this entire period (2007–2020), this field has been under the supervision of a certification body (Polish Society of Organic Farming "Eco-guarantee"), and it has an Organic Farming Certificate. The distance between the organic and conventional plots was 100 m (a buffer zone sown with the following organically grown crops: white mustard, oats, and red clover). The distance of the fields from a traffic artery was 500 m.

To determine the comprehensive effect of the farming systems and the individual plant species in the crop rotation on soil chemistry, soil samples were taken from the 0 to 20 cm layer (using a soil sampling tube). Soil samples were collected at the end of the growing season of the specific crops grown. The sampling tube (Figure 1) allowed soil structure samples to be taken precisely from a depth of 20 cm.

Five soil samples were taken randomly from each plot, following the sampling scheme shown in Figure 2. Taking into account that each experimental treatment was carried out in triplicate, 15 soil samples were collected for a particular treatment combination. The samples were sieved through a 2 mm-mesh sieve and stored in a refrigerator at + 4 °C.



Figure 1. Soil sampling tube.

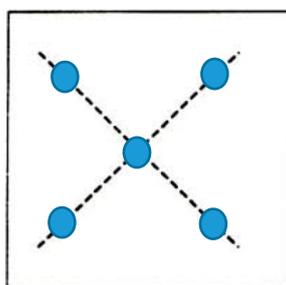


Figure 2. Soil sampling scheme.

The following parameters were determined: soil pH was determined electrometrically using a 1 M KCl solution and water (by using pH-Meter CP-511). A carbon analyzer (SDCHN435) was used to determine C organic content, total nitrogen was analyzed by the Kjeldahl method, whereas the Egner-Riehm method was employed to find the content of available forms of phosphorus and potassium. The following 5 soil enzymes: dehydrogenase [23], acid phosphatase, and alkaline phosphatase [24], urease [25], and protease [26], were also assayed in order to determine their activity. Dehydrogenase activity was determined in 5 g soil samples using 2,3,5-triphenyl tetrazolium chloride as substrate, incubating in 0.2 M trishydroxymethyl-aminomethane-HCl buffer (Tris-HCl pH 7.4) for 48 h, at 30 °C. Enzyme activity was expressed as mg TPF kg⁻¹ d.m. of soil d⁻¹. Acid phosphatase and alkaline phosphatase activity were determined in 1 g soil samples using p-nitrophenyl phosphate disodium as substrate, incubating in a modified universal buffer (acid phosphatase: pH 6.5; alkaline phosphatase: pH 11) for 1 h, at 37 °C. Enzyme activity was expressed as mg PNP kg⁻¹ d.m. of soil h⁻¹. Urease activity was determined in 10 g soil samples using urea solution as substrate, incubating for 18 h, at 37 °C. Enzyme activity was expressed as a unit: mg N-NH₄ kg⁻¹ d.m. of soil 18 h⁻¹. Protease activity was determined in 2 g soil samples using casein as substrate, incubating in 0.2 M Tris-HCl buffer (pH 8.0) for 1 h, at 50 °C. Enzyme activity was expressed as mg tyrosine kg⁻¹ d.m. of soil h⁻¹.

2.2. Statistical Analysis

The obtained results were analyzed by analysis of variance, while the significance of differences evaluated by Tukey's test was applied to determine HSD (Honest Significant Difference) values at $p < 0.05$. Moreover, to determine dependencies and relationships between the studied characteristics, correlation analysis was applied. An Excel 9.0 spreadsheet and the statistical package Statistica for Windows StatSoft. Inc. was used to collate and statistically analyze the results. For the resulting data presented in Tables 5 and 6, the following was calculated: SD—standard deviation. The mean for the study period was given in the results tables because the year-to-year differences between the

characteristics analyzed were statistically insignificant. No significant 3-factor ($A \times B \times C$) interaction was found between the main experimental factors: A (farming system) and B (crop plant), and C (years).

3. Results

The statistical analysis of the obtained study results confirmed a significantly higher soil pH values under the organic system compared to the conventional one (on average by 0.3–0.4, regardless of the crop grown in this system). When we consider the effect of the individual plant species used in the crop rotations on soil pH, we noticed that the lowest soil pH was found in the soil under oat crops (pH = 6.2), whereas it was significantly higher in the soil under sugar beet crops (pH = 6.5). Organic cropping contributed to a significant increase in organic C and total N content in the topsoil layer (on average, by about 35% and 44%, respectively) in comparison to conventional farming. Regardless of the farming system, significantly, the highest soil organic C content was found in the plots with sugar beet (1.24%) and red clover (1.06%) crops, compared to the plots where spring barley (0.75%) and winter wheat (0.79%) were grown. The highest total N content was recorded in the soil under sugar beet (0.12%) and red clover (0.11%) crops relative to the soil under the other crops (0.07–0.09%). Significantly, the highest soil content of organic C (1.50%) and total N (0.16%) was found in the plots with the organically grown sugar beet (Table 5). As far as soil C/N ratio is concerned, we note that it was dependent on the farming system and that the organic system was characterized by a narrower C/N ratio. The individual plant species in the crop rotations did not significantly affect the C/N ratio. As regards all the plant species used in crop rotation, the conventional system resulted in a significant rise in the soil content of available phosphorus (averaging about 15%–24%) and potassium (averaging about 10%–13%). Regardless of the farming system, a significantly lower (by 10%) soil content of available phosphorus was found in the plots after the red clover crop (on average 158 mg kg⁻¹) compared to the soil after the sugar beet crop (on average 176.1 mg kg⁻¹). The soil content of available potassium was significantly higher (by 11%) after the sugar beet crop (on average 257.1 mg kg⁻¹) compared to the plots where red clover (on average 231.5 mg kg⁻¹) and oats (on average 231.0 mg kg⁻¹) were grown (Table 5).

The enzymatic tests clearly showed differences between the organic and conventional treatments (in favor of the organic ones), regardless of the crop plant. Organic cropping promoted in particular the activity of dehydrogenase, urease, and protease because their activity was nearly twice higher than in the conventional system. Particularly large differences in the activity of the above-mentioned enzymes under the organic system (compared to the conventional system) were found in the treatments with sugar beet (on average by 5.6 mg TPF kg⁻¹) and red clover (on average by 4.7 mg TPF kg⁻¹) crops. Regardless of the farming system, statistically proven significantly higher activity of all the soil enzymes studied was determined in the plots with the sugar beet and red clover crops compared to the plots where spring barley, winter wheat, and oats were grown. Significantly the highest activity of dehydrogenase, alkaline phosphatase, urease, and protease was found in the soil under sugar beet in the organic system. Generally, organic cropping stimulated the activity of the enzymes analyzed (dehydrogenase, acid and alkaline phosphatase, urease, and protease) in the soil under all the crop plants included in this experiment (Table 6).

Moreover, the activities of the enzymes studied were accompanied by favorable changes in soil chemical properties (pH, organic C, total N), as evidenced by the high significant positive correlation coefficients between enzyme activity and soil pH, organic C content, total N content, and C/N ratio. A higher soil potassium and phosphorus available content was found in the conventional system relative to the organic one, whereas the positive correlation of soil P and K content with the activity of the individual enzymes was not statistically significant (Table 7).

A significantly positive correlation was noted between organic cropping of sugar beet, red clover, and oats and the activity of all the enzymes studied as well as between organic cropping of winter wheat and the activity of alkaline phosphatase, urease, and protease. In the conventional system, on the other hand, significantly positive correlation coefficients were found between sugar beet and oat cultivation and dehydrogenase activity (Table 8).

Table 5. Selected soil chemical components (0–20 cm profile)—mean for 2017–2019.

Crop Plant	Farming System	pH 1M KCl	Organic C %	Total N %	C/N	P mg kg ⁻¹	K mg kg ⁻¹
Sugar beet	Organic	6.7 ± 0.1 **	1.50 ± 0.11	0.16 ± 0.03	9.3 ± 0.1	159.8 ± 2.2	240.1 ± 2.5
	Conventional	6.4 ± 0.1	0.98 ± 0.08	0.09 ± 0.02	10.8 ± 0.2	192.5 ± 1.9	274.2 ± 3.1
	Mean	6.5	1.24	0.12	10.0	176.1	257.15
Spring barley	Organic	6.5 ± 0.2	0.81 ± 0.03	0.09 ± 0.02	9.0 ± 0.2	139.6 ± 2.0	226.0 ± 1.7
	Conventional	6.1 ± 0.1	0.70 ± 0.04	0.06 ± 0.01	10.0 ± 0.2	180.7 ± 1.6	251.9 ± 1.9
	Mean	6.3	0.75	0.07	9.5	160.1	238.9
Red clover	Organic	6.6 ± 0.2	1.19 ± 0.05	0.13 ± 0.04	9.1 ± 0.1	146.8 ± 2.0	219.8 ± 2.5
	Conventional	6.3 ± 0.1	0.93 ± 0.03	0.09 ± 0.03	10.3 ± 0.1	170.2 ± 1.8	243.3 ± 2.6
	Mean	6.4	1.06	0.11	9.7	158.5	231.5
Winter wheat	Organic	6.4 ± 0.1	0.86 ± 0.04	0.09 ± 0.02	9.5 ± 0.3	141.0 ± 0.8	231.6 ± 1.8
	Conventional	6.0 ± 0.2	0.72 ± 0.01	0.07 ± 0.02	10.2 ± 0.2	186.7 ± 1.4	260.4 ± 2.6
	Mean	6.2	0.79	0.08	9.8	163.8	246.0
Oats	Organic	6.4 ± 0.1	1.03 ± 0.05	0.10 ± 0.03	10.3 ± 0.2	150.2 ± 2.4	219.7 ± 2.2
	Conventional	6.0 ± 0.2	0.96 ± 0.04	0.09 ± 0.03	10.6 ± 0.2	178.8 ± 2.7	242.4 ± 2.4
	Mean	6.2	0.99	0.09	10.4	164.5	231.0
HSD _(0.05) for farming system (A)		0.29	0.112	0.022	0.72	44.62	33.23
HSD _(0.05) for crop plant (B)		0.28	0.178	0.015	n.s.	19.4	24.92
HSD _(0.05) for interaction (A × B)		n.s. *	0.214	0.029	n.s.	n.s.	n.s.

HSD_(0.05) for years (C)—not significant differences. HSD_(0.05) for interaction (A × B × C)—not significant differences. * n.s.—not significant differences; ** SD—standard deviation.

Table 6. Soil enzymatic activity (0–20 cm profile)—mean for 2017–2019.

Crop Plant	Farming System	Dh *	Pal	Pac	Ur	Pr
Sugar beet	Organic	9.7 ± 0.3 ***	170.2 ± 4.3	111.4 ± 3.3	25.7 ± 1.4	20.6 ± 1.1
	Conventional	4.1 ± 0.4	125.8 ± 2.7	41.7 ± 2.7	11.0 ± 0.8	14.5 ± 0.7
	Mean	6.9	148.0	76.5	18.3	17.5
Spring barley	Organic	6.1 ± 0.4	111.3 ± 1.6	68.7 ± 2.1	16.3 ± 0.9	12.9 ± 0.9
	Conventional	2.5 ± 0.2	70.1 ± 1.2	55.2 ± 1.7	6.9 ± 0.6	7.9 ± 0.5
	Mean	4.3	90.7	61.9	11.6	10.4
Red clover	Organic	8.6 ± 0.5	126.2 ± 2.5	113.7 ± 3.1	19.8 ± 1.0	15.3 ± 0.3
	Conventional	3.9 ± 0.3	98.2 ± 2.2	66.9 ± 2.2	9.2 ± 0.7	10.3 ± 0.2
	Mean	6.2	112.2	90.3	14.5	17.3
Winter wheat	Organic	6.5 ± 0.1	102.3 ± 1.8	70.4 ± 2.6	17.6 ± 0.6	13.8 ± 0.4
	Conventional	2.8 ± 0.2	67.9 ± 0.9	56.3 ± 1.8	7.1 ± 0.3	8.2 ± 0.2
	Mean	4.6	85.1	63.3	12.3	11.0
Oats	Organic	8.1 ± 0.3	119.5 ± 3.0	111.8 ± 2.3	17.5 ± 0.5	14.9 ± 0.6
	Conventional	3.5 ± 0.3	89.4 ± 2.6	60.8 ± 1.9	7.4 ± 0.2	9.0 ± 0.3
	Mean	5.8	104.4	86.3	12.4	11.9
HSD _(0.05) for farming system (A)		0.91	25.69	16.22	2.92	3.78
HSD _(0.05) for crop plant (B)		0.95	29.61	9.23	2.08	4.13
HSD _(0.05) for interaction (A × B)		0.99	39.49	n.s. **	5.07	4.98

HSD_(0.05) for years (C)—not significant differences. HSD_(0.05) for interaction (A × B × C)—not significant differences. * Dh—dehydrogenase (in mg TPF kg⁻¹ d.m. of soil d⁻¹), Pal—alkaline phosphatase and Pac—acid phosphatase (in mg PNP kg⁻¹ d.m. of soil h⁻¹), Ur—urease (in mg N-NH₄ kg⁻¹ d.m. of soil 18 h⁻¹), Pr—protease (in mg tyrosine kg⁻¹ d.m. of soil h⁻¹); ** n.s.—not significant differences; *** SD—standard deviation.

Table 7. Correlation coefficients (r) between selected soil chemical components under organic and conventional systems and enzymatic activity.

Parameter	Farming System	Dh **	Pal	Pac	Ur	Pr
pH	Organic	0.61 *	0.59 *	0.56 *	0.72 *	0.78 *
	Conventional	0.45	0.34	0.30	0.36	0.38
Organic C	Organic	0.85 *	0.57 *	0.55 *	0.80 *	0.77 *
	Conventional	0.40	0.29	0.26	0.37	0.35
Total N	Organic	0.56 *	0.49	0.46	0.53 *	0.54 *
	Conventional	0.32	0.30	0.25	0.35	0.37
C/N	Organic	0.81 *	0.59 *	0.63 *	0.77 *	0.79 *
	Conventional	0.44	0.32	0.36	0.39	0.41
P	Organic	0.22	0.21	0.20	0.17	0.21
	Conventional	0.28	0.32	0.31	0.26	0.28
K	Organic	0.18	0.11	0.14	0.23	0.16
	Conventional	0.35	0.19	0.22	0.28	0.21

* significant correlation coefficient (0.05); ** Dh—dehydrogenase, Pal—alkaline phosphatase, Pac—acid phosphatase, Ur—urease, Pr—protease.

Table 8. Correlation coefficients (r) between the plant species grown under organic and conventional systems and enzymatic activity.

Parameter	Farming System	Dh **	Pal	Pac	Ur	Pr
Sugar beet	Organic	0.77 *	0.62 *	0.59 *	0.69 *	0.73 *
	Conventional	0.53 *	0.41	0.33	0.44	0.49
Spring barley	Organic	0.38	0.32	0.25	0.28	0.30
	Conventional	0.25	0.30	0.17	0.22	0.19
Red clover	Organic	0.71 *	0.57 *	0.55 *	0.62 *	0.68 *
	Conventional	0.52 *	0.41	0.22	0.31	0.29
Winter wheat	Organic	0.42	0.38	0.55 *	0.53 *	0.59 *
	Conventional	0.40	0.28	0.42	0.35	0.51 *
Oats	Organic	0.64 *	0.57 *	0.53 *	0.52 *	0.58 *
	Conventional	0.54 *	0.40	0.31	0.30	0.36

* significant correlation coefficient (0.05); ** Dh—dehydrogenase, Pal—alkaline phosphatase, Pac—acid phosphatase, Ur—urease, Pr—protease.

4. Discussion

Farming system (organic, conventional), soil use (intensive, extensive), and crop species composition (monoculture, crop rotation) have an impact on soil microorganisms and chemical processes through a change in the quantity and quality of plant residues entering the soil. They become the main source of soil organic matter [4,12]. This study found variations in soil chemical properties, in particular in enzymatic activity, which results, among others, from the different farming systems (organic, conventional). The study results prove that the organic cropping system contributed to a significantly higher organic C and total N content as well as a more favorable soil pH compared to the conventional (traditional) system. Soil pH is quite a stable characteristic that changes over a time horizon of many years [27]. In the present experiment, agricultural practices characteristic of organic farming, such as natural/organic fertilization and catch crops that are plowed under and were used in the field in the organic treatment over a period of 10 years. During a dozen or so years of conversion to organic farming, these practices had an impact on the pH value (the soil pH increased). In the conventional system, in turn, mineral fertilizers, including acidifying nitrogen ones (greater yields and removal of macronutrients from the soil) were used over this period. Therefore, the soil pH in the conventional system was lower than in the organic one. Other authors also report similar findings [1].

Bai et al. [27] also drew attention to a more favorable soil pH in the organic system relative to the conventional one. Similarly to the present study, Drinkwater et al. [28] and Wang et al. [3] also recorded a higher organic C and N total content as well as a higher nitrogen mineralization rate in fields with organically grown crops compared to conventional cropping. Comparing different soil activity parameters, Fließbach et al. [29], Birkhofer et al. [30], and Joergensen et al. [31] found the soil quality indicators to be more favorable under the organic system in comparison with conventional cultivation. In the present study, a lower phosphorus and potassium content was determined in the soil under organic crops than for conventional ones. Other authors [32,33] also observed a decrease in phosphorus and potassium content in the soil of organically cultivated fields. Gosling and Shepherd [34] proved that potassium and phosphorus concentrations were much lower in organically cultivated soil than in conventionally farmed soil, as well.

The positions regarding the issue of improvement of soil fertility as influenced by organic farming are diverse. Improvement of soil fertility and productivity in organic agriculture is a long-lasting process and requires an integrated approach to this problem, not strictly oriented measures, which is the case in conventional agriculture [34,35].

Marinari et al. [36] are of the opinion that a minimum organic farming period after which the soils achieved better physico-chemical and biological parameters was 7 years. After this period, these authors noted an increase in total nitrogen and available phosphorus content as well as higher activity of soil enzymes (acid phosphatase, proteases, and dehydrogenase).

The present study demonstrates that the highest activity of the enzymes, especially dehydrogenase, urease, and protease, was found in the organically farmed soil, which was characterized by higher accumulation of soil organic matter. Dehydrogenases are commonly found in organic matter-rich soils and they are regarded as good indicators of the respiratory metabolism of microbes [37,38]. Nannipieri et al. [39] report that phosphatases stimulate the conversion of organic phosphorus compounds into inorganic phosphates, while ureases participate in ammonification, during which ammonia is released from urea, amino acids, and purine bases. Soil fertility and productivity depend on soil organic matter, which is a reserve of nutrients and is very important in nutrient cycling [27] as well as improves soil physical, chemical, and biological properties [40]. Processes associated with organic matter transformations in soil occur with the participation of soil microorganisms and their enzymes [41].

The significant correlation between enzymatic activity and C/N ratio found in this study confirms how important the quality of organic matter, supplied among others by plants, is. The high soil enzymatic activity in the organic system was related to a quite high content of organic matter with a good decomposition rate (among others, catch crop biomass was ploughed under), which is confirmed by the low value C/N ratio [42]. Catch crops having a narrow C/N ratio cause abrupt changes in soil physical, chemical, and biological properties [43] and accelerated soil mineralization. The C/N ratio also determines the rate of organic matter transformation and its direction [44,45]. A high soil content of organic matter (its layer and the degree of decomposition) determine the temperature and moisture content of topsoil layers, which in turn has a significant effect on the level of activity of enzymes, especially dehydrogenases [5,10,46,47]. The pH value also has a significant impact on soil microbial activity and enzymes exhibit high sensitivity to soil pH [48], which is also evidenced by the results of this study.

The present study proved a strong relationship between the activity of the studied enzymes and the quantity and quality of soil organic matter. The soils in the organic system showed the highest dehydrogenase and urease activity, whereas the lowest activity of the enzymes was found in the crop soils, which contained significantly less organic matter. The plants producing a lot of biomass (sugar beet, red clover) provided more favorable organic matter compared to the cereals. Woźniak [17] also found the effect of cereal crops (on the example of winter wheat) on soil enzymatic activity to be smaller compared to pea, which contributed to the formation of a greater amount of organic matter in the soil. The present study demonstrated that regardless of the farming system, sugar beet had the

most favorable effect on improvement of the soil quality indicators analyzed. Other authors [29,49] also indicate the positive role of root crops in determining soil chemistry.

The C/N ratio decreases in the presence of legume crop residues relative to its value in the presence of cereal crop residues [50]. The high soil enzymatic activity under the organic system was also due to the effect of plant biomass in the crops where no pesticides had been used. This is confirmed by reports of other authors [18,19,51–53]. Furthermore, cover crops were additionally grown under the organic system, which contributed to the higher activity of the enzymes in the soil environment [54].

5. Conclusions

The results of the 3-year study reveal that the organic farming system promoted a more favorable chemical composition and enzyme activity of loess soil relative to the conventional system. A significantly higher soil pH as well as a higher organic C and total N content were found in the organic system. However, the soil phosphorus and potassium content was lower than that under the conventional system. The positive effect of the organic system was manifested in the higher activity of all the soil enzymes under consideration (in particular dehydrogenase, urease, and protease). Soil enzyme activity under the organic system was positively correlated with soil pH, a high organic C and total N content, and a favorable narrow C/N ratio.

The individual plant species grown in crop rotations affected differently enzyme activity and soil chemistry properties. Organic cropping of sugar beet and red clover had the most beneficial effect on the activity of the studied enzymes (especially dehydrogenases and urease) and the soil chemical composition, while the effect of oat cultivation was smaller. The other cereal plants grown in the crop rotation (spring barley, winter wheat) had a lower impact on the activity of the soil enzymes.

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