Residual Effects of Different Cropping Systems on Physicochemical Properties and the Activity of Phosphatases of Soil

Sylwia Wesołowska 1, Barbara Futa 1,*, Magdalena Myszura 1 and Agata Kobyłka 2

1 Institute of Soil Science, Environment Engineering and Management, University of Life Sciences in Lublin, Leszczyńskiego St. 7, 20-069 Lublin, Poland; sylwia.wesolowska@up.lublin.pl (S.W.); magdalena.myszura@up.lublin.pl (M.M.)
2 Department of Tourism and Recreation, University of Life Sciences in Lublin, 20-950 Lublin, Poland; agata.kobyłka@up.lublin.pl

* Correspondence: barbara.futa@up.lublin.pl

Abstract: Soil plays a key role in sustainable land management and food production. The objective of the field experiment was to evaluate the subsequent effect of 10-year winter wheat and sugar beet cultivation under conventional and organic systems on selected physicochemical and biochemical properties and enzymatic pH index of lessive soil developed from loess under climatic conditions of Southeastern Poland. The experiment was set up by using the split-plot design, with three replications, on plots of 30 m². In order to evaluate the soil value of sites cultivated in 2010–2019 in two systems—conventional agriculture and organic agriculture—spring wheat was sown as a test crop in 2020. Fertilization and pesticide applications (herbicides, fungicides and insecticides) were foregone in the cultivation of this crop due to the desire to capture the subsequent impact of 2010–2019. This resulted in soil properties shaped solely by the previous 10 years of cultivation. The obtained results indicate that the organic farming system contributed to the improvement of soil pH KCl compared to the conventional system, with statistically significant differences recorded only for winter wheat cultivation. Compared to the conventional system, in the organic farming system, improvements were recorded in the chemical indicators of loess soil quality (TOC, TN and TOC/TN) and P content, as well as acid phosphatase and alkaline phosphatase activities. However, statistically significant differences were found only for winter wheat cultivation. Research on the impact of an organic system of growing different species in rotation should be continued, and the results should be implemented.

Keywords: organic system farming; conventional system farming; soil; acid and alkaline phosphatase activity; enzymatic pH index

1. Introduction

The United Nations [1] predicts that the world population will reach 9.7 billion by 2050; therefore, meeting future food demand is considered a huge global challenge [2]. Consequently, modern agriculture requires major changes to meet this dual global challenge. On the one hand, it must provide enough food to feed an ever-growing population and, on the other, minimize its environmental impact [3]. The world’s agriculture is largely based on a conventional system, where the main objective is higher productivity and economic profit. The intensive use of mineral fertilizers and pesticides remains an important tool in agricultural production, aimed at increasing yields [4–6]. Unfortunately, this has a negative impact on the environment and society, causing degradation of the soil environment, soil acidification, water and soil pollution, loss of biodiversity, eutrophication of water bodies, increased greenhouse gas emissions, climate change and contamination of agricultural crops [6–8]. Ecosystems around the world are under pressure in a way that threatens the
planet’s productive potential [9]. To address these issues, the 2030 Agenda for Sustainable Development was enacted in 2015. It is an action plan based on the 17 Sustainable Development Goals (SDGs). All the SDGs are directly or indirectly related to healthy and sustainable food [10]. In the search for more sustainable agricultural practices, organic farming is often proposed [3,11], as it makes a particular contribution to the achievement of these SDGs.

Organic farming enables yields of the highest quality, simultaneously ensuring maximum protection of the natural environment. This is in contrast to conventional systems, which are based on maximum economic efficiency, where profit overshadows the problems of protecting the immediate environment [12,13]. Organic agriculture meets the demand for high-quality food of local, national and global markets. The World Health Organization [14] defines organic farming as a holistic management system which takes into account regional circumstances and supports biodiversity, ecological cycles and soil fertility. The WHO stresses that organic farming guarantees that no agrochemical treatments have been used in production, but it cannot guarantee the complete absence of chemical residues, due to global environmental pollution [14]. Many studies show that organic farming practices generally increase soil biological and enzymatic activity through a greater accumulation of organic matter [13,15]. As a result, soil productivity and environmental quality are improved. This is achieved by using catch crops, farmyard manure and reduced tillage practices [13,15].

The ecosystem services of soil depend on its natural resources (i.e., clay and soil organic matter contents, diversity and activity of soil organisms, soil depth and water retention capacity) and how it is managed. Soil management in different agroecosystems to increase food production involves some trade-offs or adverse services (e.g., decline in biodiversity, non-point source pollution and accelerated water and wind erosion) [16], which can be minimized by organic farming [3].

Soil is a natural habitat for a variety of living organisms. They constitute extremely metabolically active mechanisms that, by transforming vast quantities of mineral and organic substances, enrich soils with biogenic elements or other biologically active substances. Through these transformations, they co-create the soil and shape its fertility, transforming it into one suitable for plant life and development [17]. Fertility and its yield-forming potential are related to physicochemical properties and biological activity, i.e., the intensity of microbially catalyzed processes of transformation of organic and mineral substances [17]. To assess soil quality, its physicochemical properties, i.e., organic carbon (TOC) and total nitrogen (TN) contents; nutrients (P, K and Mg); and pH and sorption capacity of the soil complex, i.e., the capacity to retain and absorb various particles and ions, are widely used [18]. The content of TOC, TN and TOC/TN in soil is considered one of the most important indicators describing soil quality [19]. Due to its sorption properties, soil can accumulate nutrients and protect them against leaching or the formation of compounds that are difficult for plants to access [18]. Changes in soil physicochemical parameters under the influence of stress factors occur extremely slowly, so that significant differences in their values can be observed only after many years [20,21]. In contrast, soil biological and biochemical properties, such as soil microbial activity and/or enzyme activity, are sensitive to sudden environmental changes and provide sensitive information about changes in soil quality [22–24].

Enzymatic tests allow us to assess both the influence of natural factors and anthropopresses on ecosystem functioning [25]. Among many soil enzymes, phosphatases play an important role in the environment, as they stimulate the conversion of organic phosphorus compounds into inorganic phosphates available to plants and soil organisms [26]. Thus, taking into account the complex nature of the soil and the diverse properties that may affect its fertility, it is important to select appropriate soil quality indicators [27]. According to many authors [28,29], a reliable assessment of soil quality can be given by simultaneous studies of soil physicochemical properties and soil enzymes’ activity.
In the present study, a research hypothesis was made that, under the conditions of organic cultivation of winter wheat and sugar beet in 2010–2019, compared with conventional cultivation, there would be an improvement of physicochemical (soil reaction, the content of organic carbon, total nitrogen and available phosphorus, and the sorption properties) and biochemical (acid phosphatase and alkaline phosphatase activities) parameters of lessive soil developed from loess under the climatic conditions of Southeastern Poland. The aim of the field experiment—was to evaluate the following effect of 10-year winter wheat and sugar beet cultivation under conventional and organic systems on selected physicochemical and biochemical properties and enzymatic pH index of loess soil.

2. Materials and Methods

2.1. Study Area and Field Experiment

The field experiment was conducted at the Czesławice Experimental Farm, which belongs to the University of Life Sciences in Lublin, Poland (51°18’23” N; 22°16’02” E). The experiment was set up by using the split-plot method, in 3 repetitions, on plots with an area of 30 m². The field study was established on a Haplic Luvisol (LVha) soil made of silt loam (PWsp) and categorized as good wheat soil complex (soil class II) [30]. The particle size distribution in the 0–30 cm layer (arable layer) of this soil was as follows: 2.0–0.5 mm fraction (sand fraction)—16.4%; 0.5–0.25 mm fraction (silt fraction)—41.6%; and <0.002 mm fraction (clay fraction)—42.0% [31]. The soil was characterized by an acidic to slightly acidic reaction, a very high content of available phosphorus forms, a medium content of available magnesium and potassium forms, and manganese, as well as a low content of zinc, copper and boron. The properties of the initial soil of the experiment site at Czeslawice are presented in Table 1.

| Initial Soil Properties | Unit | Value |
|-------------------------|------|-------|
| pH_KCl                  |      | 5.46–5.65 |
| Total organic carbon (TOC) | g·kg⁻¹ | 15.15–16.81 |
| Total nitrogen (TN)    |      | 1.29–1.73 |
| Available P            | mg·kg⁻¹ | 138.7–156.5 |
| Available K            |      | 226.8–237.9 |
| Available Mg           |      | 65.9–68.0 |
| B                       |      | 2.16–2.38 |
| Cu                      |      | 6.9–7.3 |
| Mn                      |      | 181.0–198.2 |
| Zn                      |      | 8.9–9.1 |

In order to evaluate the soil of the sites cultivated between 2010 and 2019 in 2 farming systems—conventional agriculture and organic agriculture—spring wheat was sown in 2020 as a test crop. The tillage for spring wheat in 2020 was typical. Fertilization and pesticide applications (herbicides, fungicides and insecticides) were omitted from the cultivation of this crop due to the desire to register the subsequent impact of the 2010–2019 cultivation. This resulted in soil properties shaped solely by the previous 10 years of cultivation.

The experiment included 2 farming systems:

1. Conventional system—recommended mineral NPK doses (the doses of mineral fertilizer are presented in Table 2) and organic doses (pig manure at a rate of 30 t·ha⁻¹ under sugar beet), seed dressing, fungicide, insecticide, herbicide, retardant and one-time mechanical weed control;
2. Organic system—no chemical plant protection and mineral fertilization; application of pig manure at a dose of 40 t·ha⁻¹ under sugar beet; ploughing in autumn of stubble crops (phacelia, faba bean and field pea) three times under oats and under sugar beet; 3-fold mechanical weeding of crops.
Table 2. Fertilization used in the conventional system.

| Crop Plant          | Mineral Fertilization in kg·ha⁻¹ | Manure Fertilization in t·ha⁻¹ |
|---------------------|----------------------------------|-------------------------------|
|                     | N  | P  | K  |                                 |
| Sugar beet          | 100 (prior to sowing) | 100 (prior to sowing) | 140 (prior to sowing) | 30 (in autumn) |
| Spring barley       | 90 (split dose *)    | 70 (prior to sowing)     | 90 (prior to sowing) |
| Red clover          | -   | 80 (prior to sowing) | 100 (in spring) |
| Winter wheat        | 140 (split dose **)  | 60 (prior to sowing)     | 80 (prior to sowing) |
| Oats                | 70 (prior to sowing) | 70 (prior to sowing)     | 110 (prior to sowing) |

Explanations: * N-90 kg (30 kg prior to sowing, 60 kg in phase BBCH 32–34); ** N-140 kg (50 kg prior to sowing, 50 kg in spring in phase BBCH 21–24, 40 kg in phase BBCH 32–36).

In each farming system, identical five-field crop rotations with the following crop sequence were carried out in the years 2009 (winter wheat sowing date) to 2019: sugar beet (*Beta vulgaris* L. subsp. *vulgaris*)—spring barley (*Hordeum vulgare* L.) with red clover undersown—red clover (*Trifolium pratense* L.)—winter wheat (*Triticum aestivum* L.)—oats (*Avena sativa* L.). Tillage for all crops was typical. The dates of sowing and harvesting of individual plant species in both cropping systems were identical in each year of the study and fell within the following time frame (Table 3).

Table 3. Dates for sowing and harvesting crops in the crop rotation.

| Crop Plant         | Date of Sowing    | Date of Harvest          |
|--------------------|-------------------|--------------------------|
| Sugar beet         | 20–25 April       | 16–19 October            |
| Spring barley      | 18–21 April       | 10–12 August             |
| Red clover         | 18–21 April       | Blooming phase           |
| Winter wheat *     | 20–22 September   | 8–10 August next year    |
| Oats **            | 10–12 April       | 17–19 August             |

Explanations: * In the organic system, after the winter wheat harvest, the catch crop (faba bean + field pear) was sown on 15–18 August, while the catch crop biomass was ploughed on 16–20 October. ** After the oat harvest, the catch crop (blue phacelia) was sown on 21–22 August, while the biomass was ploughed on 25–28 October.

2.2. Weather Conditions

The weather conditions during the spring wheat vegetation period in 2020 at the experimental site in Czesławice are presented in Table 4. The total precipitation during the spring wheat vegetation period in 2020 was 453.8 mm and was higher than the multi-year total by 94.4 mm. The year in question was warmer than in the multi-year period by 0.9 °C. The warmest months were August, July and June. The highest precipitation was recorded in June and May, and less in April.

Table 4. Mean air temperature (in °C) and mean precipitation (in mm) during spring wheat-growing season in 2020, including multiyear period 1963–2010.

| Month     | March | April | May | June | July | August | March–August |
|-----------|-------|-------|-----|------|------|--------|--------------|
| Rainfall (in mm) | 26.0  | 19.0  | 111.4 | 170.3 | 67.8  | 59.3    | 453.8        |
| 1963–2010 | 31.3  | 42.4  | 63.5 | 72.7 | 80.0 | 69.5    | 359.4        |
| Air temperature (in °C) | 4.6   | 8.6   | 11.2 | 17.4 | 18.8 | 20.4    | 13.5         |
| 1963–2010 | 1.8   | 7.7   | 13.6 | 16.5 | 18.3 | 17.7    | 12.6         |

2.3. Sampling and Analyses

Soil material for physicochemical and biochemical analyses was collected in August 2020. Soil samples were taken at 10 randomly selected sites from each experimental plot,
at a soil depth of 0–30 cm (arable layer) and 30–50 cm. Soil samples were taken by using a special cane with a diameter of 4 cm. A total of 40 soil samples were taken, 20 in each system. The collected soil samples were combined into one aggregate sample from each plot and layer. In addition, soil samples from layers 0–30 cm and 30–50 cm were taken from the control object, which was an arable field. Each sample was assayed in three replications. Soil samples for the biochemical analyses were collected, sieved through a 2 mm sieve and stored at 4 °C, according to the principles specified in ISO 18400 [32]. Soil samples for physicochemical analyses were dried at room temperature. Then they were ground in a soil mill.

The physicochemical analyses consisted of the determination of the following parameters: pH\textsubscript{KCl}, content of total organic carbon (TOC), total nitrogen (TN), available phosphorus (P) and soil sorption properties. The pH\textsubscript{KCl} was determined by the potentiometric method in a 1 mol·dm\textsuperscript{-3} KCl (1:2.5) solution [33]. The content of total organic carbon (TOC) by the Tiurin method [34] was determined by combustion soil samples, using a TOC-VCSH apparatus with an SSM-5000A module (Shimadzu Corp.; Kyoto, Japan). The content of total nitrogen (TN) was determined by the modified Kjeldahl method, using a Kjeltech TM 8100 distillation unit (Foss; Hillerød, Denmark) [35]. The content of available phosphorus (P) was determined by the Egner–Riehm method [36]. The hydrolytic acidity (HA) and exchangeable base cations (BC) were determined with Kappen’s method [37]. The cation exchange capacity of the soil (CEC) was calculated according to the following formula:

$$\text{CEC} = \text{HA} + \text{BC},$$

(1)

The activity of alkaline and acid phosphatase was determined, as these enzymes are directly involved in the biogeochemical cycle of phosphorus in the environment. The alkaline phosphatase activity (AlPh) and acid phosphatase activity (AcPh) were determined according to Tabatabai and Bremner [38], using a 0.8% disodium p-nitrophenyl phosphate solution (pNPP) as a substrate in buffer pH 8.5 and pH 5.4, respectively, with 1 h–long incubation at temperature of 37 °C. The activities of the enzymes were determined by the colorimetric method measuring the extinction of p-nitrophenol (PNP) obtained from the hydrolysis of PNP\textsubscript{Na} with a CECIL CE 2011 spectrophotometer (Cecil Instruments) at the following wavelength: \(\lambda = 410\) nm. The ratio of alkaline phosphatase to acid phosphatase activity (AlPh/ACPh) was also calculated. The value of this ratio is considered an indicator for assessing soil pH suitable for crop growth and development and for determining the need for a soil liming treatment. If the value of the alkaline/acid phosphatase activity ratio (AlPh/ACPh) is higher than or equal to 0.5, the soil has a normal reaction and shows normal reactions. On the other hand, if the index is lower than 0.5, the soil has an unfavorable reaction and requires liming treatment.

2.4. Statistical Analysis

Basic descriptive statistics (the mean and the standard deviation), which determine the degree of variation of the results, were specified. One-way ANOVA was used to test the significance of differences in soil physicochemical and biochemical properties between cultivation variants. In the case of statistically significant differences between the means of soil properties tested, Tukey’s post hoc (multiple comparisons) tests (HSD) were performed. Pearson’s linear correlation coefficient was used to examine the strength of the correlation between the variables, i.e., physicochemical and biochemical properties of the studied soils.

Two methods of numerical taxonomy (cluster analysis) were used to identify groups of crop variants that have similarity in activity/content (acid and alkaline phosphatase) and indicator values (TOC, TN and TOC/TN) [39]: Ward’s method and the k-means method. Ward’s method was to determine the number of clusters based on visual analysis of the graph of distance changes in successive agglomeration stages and the connection tree (as Ward’s dendrogram). The k-means method was used to determine the composition of clusters. The analysis of variance was also performed to determine the significance
of cluster differentiation. Principal component analysis (PCA) was used to interpret the relationships between the cropping system, plant species and the soil properties studied.

Statistical analyses were performed by using the Statistica 13.1 program (TIBCO Software Inc.; Palo Alto, CA, USA).

3. Results
3.1. Soil Physicochemical Properties

The study showed that the physicochemical and biochemical properties and enzymatic pH index of loess soil of the studied objects varied depending on the cultivation system, crop species and soil layer (Tables 5–7). During the study period, the monitored soils were characterized by a slightly acid reaction, with mean pH$_{KCl}$ values ranging from 5.85 to 6.33 (Table 5). The study showed higher pH$_{KCl}$ values for soil cultivated in the organic system compared to the conventional system, with statistically significant differences recorded only for winter wheat cultivation. The analysis of the effect of particular plant species used in crop rotation on the reaction of soil environment showed that the soils under winter wheat cultivation were characterized by lower pH$_{KCl}$ than the soils of the sites with sugar beet cultivation (Table 5). Irrespective of the farming system and the crop grown, the topsoil layers (0–30 cm) were characterized by higher values of parameters describing sorption properties in comparison with the 30–50 cm layer.

![Table 5. Effect of the interaction of the experimental factors on the pH$_{KCl}$ and sorption properties of soil.](image)

The sorption properties of the soil environment are shaped by the following parameters: hydrolytic acidity (HA), exchangeable base cations (BC) and cation exchange capacity (CEC) (Table 5). The lowest mean HA value was recorded in the soil of the object with sugar beet grown in the organic system and the highest in the soil of the plot with the same crop grown in the conventional system. The highest mean BC and CEC values were found in the soil of the plot with winter wheat cultivation in the conventional system, and the lowest were found in the soil of the object with sugar beet cultivation in the organic system. In general, soils cultivated in the conventional system were characterized by significantly higher BC and CEC values than soils in the organic system. Soils under sugar beet cultivation had lower mean BC and CEC values than soils under winter wheat cultivation, but statistically significant differences in BC were recorded only for conventional grain cultivation. However, in the case of CEC, significant differences were found among all objects. Irrespective of the farming system and the crop grown, the topsoil layers (0–30 cm) were characterized by higher values of parameters describing sorption properties in comparison with the 30–50 cm layer, while statistically significant differences concerned only HA.
The highest average contents of organic carbon (TOC) and available phosphorus (P) were recorded in the soil of the plot with sugar beet cultivation in the conventional system (respectively 9.81 g·kg\(^{-1}\) and 71.19 mg·kg\(^{-1}\)), and the highest content of total nitrogen (TN) was recorded in the soil of the plot with winter wheat cultivation in the organic system (0.90 g·kg\(^{-1}\)). The lowest average TOC, TN and P contents were found in soil under conventional winter wheat cultivation (5.90 g·kg\(^{-1}\), 0.56 g·kg\(^{-1}\) and 56.20 mg·kg\(^{-1}\), respectively). The obtained results indicate that the content of TOC, TN and P in soil depended on the crop species (Table 6). Within the plots with winter wheat cultivation, a statistically significantly higher mean content of TOC, TN and P was recorded in soil under conventional winter wheat cultivation (5.90 g·kg\(^{-1}\)) compared to plots with sugar beet cultivation. Within the plots with sugar beet cultivation, significantly higher mean content of TOC, TN and P as compared to the 30–50 cm layer. As far as soil C/N ratio is concerned, it was found to depend mainly on the crop species. The soils of plots with winter wheat cultivation were characterized by a significantly narrower TOC/TN ratio compared to plots with sugar beet cultivation. The farming system had no significant effect on the average values of the TOC/TN ratio in soils from winter wheat cultivation. Within the plots with sugar beet cultivation, significantly higher mean TOC/TN values were found in soil under conventional tillage compared to organic tillage. In the 0–30 cm layer, in general, significantly higher TOC/TN values were found compared to the 30–50 cm layer.

Ward’s cluster analysis based on TOC, TN and TOC/TN, considered as chemical indicators of soil quality, showed that the CS and OS variants (sugar beet cultivation in conventional and organic systems) are similar to each other (Figure 1), with no variables significantly differentiating (\(p < 0.05\)) the clusters obtained by the k-means method (Table 7).
3.2. Soil Biochemical Properties

The highest average activity of acid phosphatase (AcPh) was recorded in the soil of the plot with winter wheat cultivation in the organic system (67.47 mmol PNP kg\(^{-1}\)·h\(^{-1}\)) and the highest average activity of alkaline phosphatase (AlPh) was recorded in the soil under conventional sugar beet cultivation (26.04 mmol PNP kg\(^{-1}\)·h\(^{-1}\)). The lowest average activities of the studied enzymes were found in the soil under organic sugar beet cultivation (45.22 mmol PNP kg\(^{-1}\)·h\(^{-1}\) and 20.29 mmol PNP kg\(^{-1}\)·h\(^{-1}\), respectively). Similarly, as in the case of TOC, TN and P, the obtained results indicate that the activity of the enzymes studied in the soil depend on the type of crop (Table 8). Within the winter wheat plots, higher AcPh and AlPh activities were recorded in the soil under organic farming system, with statistically significant differences found only for AcPh. However, within the sugar beet plots (Table 8), higher activity of the studied enzymes was found in the soil under conventional farming. In this case, statistically significant differences were also found only for acid phosphatase activity. Irrespective of the cultivation system and plant species, the topsoil layers (0–30 cm) were characterized by significantly higher activities of the enzymes studied compared with the layer at 30–50 cm.

The AlPh/AcPh index is used to assess the soil pH suitable for the growth and development of crops and to determine the need for liming. The present study showed that, irrespective of the farming system and crop plant, the values of the AlPh/AcPh index ranged between 0.35 and 0.49, indicating an unfavorable pH for plant growth.

Ward’s cluster analysis, which is based on the activity of the enzymes evaluated, showed that the CW and OS variants were the most similar (Figure 2). A binding distance of 1.5 in the tree diagram indicated two clusters (intersection of the dendrogram). In the k-means method, the number of clusters was assumed to be k = 2, and the maximum number of iterations was set to 10. It was shown that only one of the two variables significantly differentiates (p < 0.05) the clusters obtained by the k-means method (Table 9).
Table 8. Effect of the interaction of the experimental factors on the activity of acid and alkaline phosphatase and AlPh/AcPh ratio.

| Farming System       | Crop Plant          | Soil Layers | AcPh mmol PNP kg⁻¹ h⁻¹ | AlPh mmol PNP kg⁻¹ h⁻¹ | AlPh/AcPh |
|----------------------|---------------------|-------------|------------------------|------------------------|-----------|
| Conventional winter  | wheat               | 0–30 cm     | 69.55 ± 2.41 c         | 26.56 ± 3.74 bc        | 0.38 ± 0.15 b |
| (CW)                 |                     | 30–50 cm    | 34.66 ± 1.24 b         | 15.92 ± 0.83 a         | 0.45 ± 0.06 d |
| Organic              | winter wheat (OW)   | Mean        | 52.11 ± 1.83 cd        | 21.24 ± 2.29 b         | 0.42 ± 0.13 c |
| Conventional sugar   | beet (CS)           | 0–30 cm     | 88.54 ± 2.88 f         | 30.85 ± 3.16 b         | 0.35 ± 0.11 a |
| Organic              | sugar beet (OS)     | 30–50 cm    | 46.40 ± 2.82 c         | 19.51 ± 2.39 ab        | 0.42 ± 0.08 c |
|                      |                     | Mean        | 67.47 ± 2.85 c         | 25.18 ± 2.78 b         | 0.39 ± 0.10 b |
|                      |                      |             |                        |                        |            |

Explanation: AcPh—activity of acid phosphatase; AlPh—activity of alkaline phosphatase; AlPh/AcPh—AlPh/AcPh ratio; a–f—different letters indicate significant difference at p ≤ 0.05.

Figure 2. Tree diagram—Ward’s dendogram for AcPh and AlPh.

Explanation: CW, OW, CS and OS—farming system and crop plant, as in Table 5.

Table 9. Analysis of variance (k-means method) for AcPh and AlPh.

| Variable | Between SS | df | Within SS | df | F     | p    |
|----------|------------|----|-----------|----|-------|------|
| AcPh     | 2.004      | 1  | 0.996     | 2  | 4.024 | 0.183|
| AlPh     | 2.898      | 1  | 0.102     | 2  | 57.078| 0.017*|

Explanation: AcPh—activity of acid phosphatase; AlPh—activity of alkaline phosphatase; SS—sum of squares; df—degrees of freedom; * statistically significant differences (p < 0.05).

In order to assess the distance between the resulting clusters, the distances between the centers of gravity of the groups were determined (Euclidean distances based on standard-
ized data). Clusters 1 and 2 were quite distant and, therefore, dissimilar (distance = 1.57; see Table 10).

**Table 10.** Euclidean distance between clusters obtained by the k-means method for AcPh and AlPh.

| Clusters | 1  | 2  |
|----------|----|----|
| 1        | 0.00 | 1.57 |
| 2        | 0.00 | 0.00 |

On the basis of the cluster profiles, it can be observed that Cluster 1 (OW and CS) was characterized by a high mean value of the analyzed indicator, and Cluster 2 (CW and OS) by a low one (Table 11).

**Table 11.** Mean values of the output variables in the clusters.

| Variable | Clusters 1 (OW and CS) | Clusters 2 (CW and OS) |
|----------|------------------------|------------------------|
| AcPh     | 61.87                  | 48.67                  |
| AlPh     | 25.61                  | 20.76                  |

Explanation: AcPh—activity of acid phosphatase; AlPh—activity of alkaline phosphatase; CW, OW, CS and OS—farming system and crop plant, as in Table 5.

The principal component analysis (PCA) is widely used to identify the most sensitive factor explaining significant differences between different cropping or cover systems [40]. The figure shows the results of the principal component analysis (PCA). Factors 1 and 2, which were extracted in the course of the analysis, explain a total of 82.80% of the variance in the analyzed properties of the studied soils. Factor 1 explains 53.15% of variation of the analyzed properties (total variance) and is strongly correlated with soil parameters: TOC, TN and AcPh. Factor 2 explains 29.65% of variation of the analyzed properties and is strongly correlated with P and AcPh. In contrast, TOC/TN and $\text{pH}_{\text{KCl}}$ are correlated mainly with Factors 2 and 3, which explain 17.20% of the total variance. The low correlation of TOC/TN and $\text{pH}_{\text{KCl}}$ with Factor 1 can be seen in Figure 3, because the points indicating them lie much closer to the center of the circle than the points of the other indicators. However, the farther a point (load) is from the center of the circle, the higher the correlation of the corresponding variable with the factor axis (Figure 3).

The principal component analysis (PCA) showed that AcPh and AlPh enzyme activities are positively correlated. TOC and TN, and P and TOC/TN are also positively correlated, while $\text{pH}_{\text{KCl}}$ and AcPh are negatively correlated; that is, as one parameter increases, the value of the other decreases. When considering the first dimension (factor), it can be seen that the CS and OW variants had high values of TOC, TN and AlPh indices, while the CW and OS variants had low values (Figure 3).
4. Discussion

Soil is increasingly recognized as a non-renewable resource on a human-life scale because, once it is degraded, its regeneration is an extremely slow process [41]. Given the importance of soils for crop and livestock production, as well as for the provision of wider ecosystem services to local and global communities, maintaining soils in good condition is of paramount importance [42]. Soil fertility and quality play a key role in agricultural systems, as they underpin food production [43].

The results of a follow-up study on the effect of 10 years of winter wheat and sugar beet cultivation in two farming systems (conventional and organic) show that the organic farming system contributed to an improvement in soil pH\textsubscript{KCl} compared to the conventional system. In the present experiment, farming practices specific to organic farming, such as organic fertilization and catch crops that were ploughed and left in the field, were applied for 10 years; this influenced the increase in pH\textsubscript{KCl} value, with significant differences recorded only for winter wheat cultivation. In contrast, in the conventional system, mineral fertilizers, including acidifying fertilizers, were applied during this period. Therefore, the pH\textsubscript{KCl} of the soil in the conventional system was lower than that in the organic system. Studies by Kwiatkowski and Harasim [43] showed that the organic farming system also promoted more favorable soil pH (this characteristic also showed higher values as affected by potato and field bean cropping than for cereal crops). Studies on the effect of organic farming on soil pH [4,44] indicate very small, sometimes <0.4 units, differences in pH between organic and conventional systems. According to Bai et al. [42], the farming system
does not directly affect soil pH. Generally, soil pH depends on the prevailing climatic conditions, grain size, the soil type and its buffering capacity and the type of fertilizer (organic/mineral) or soil amendment applied. It is, therefore, of paramount importance to specifically consider the local soil and management conditions [42]. By analyzing the influence of individual crop species in the rotation, it was shown that loess soils under winter wheat cultivation were characterized by lower pH$_{KCl}$ than those under sugar beet cultivation. Similar results were obtained by Kwiatkowski et al. [45], who studied the influence of organic and conventional farming systems and forecrops on the chemical properties and enzymatic activity of loess soil. Higher pH$_{KCl}$ values of the soil under sugar beet cultivation in both farming systems could be associated with the application of manure. Benke et al. [46] showed that applying solid cattle manure improves soil pH from acid to neutral. According to Schoenau and Davis [47], manure should be regarded as a beneficial soil conditioner.

In the present study, there was no clear relationship between the cropping system and plant species and HA, even though hydrolytic acidity, as a quantitative indicator of soil acidification, was closely related to the pH values [18]. Soils cultivated in the conventional system were generally characterized by significantly higher BC and CEC values than soils in the organic system; this result is not in agreement with the results of Kwiatkowski and Harasim [43]. The authors quoted above showed that the organic system contributed to significantly higher total sorption capacity of the loess soil (by about 15% on average) compared to the conventional system. In the present study, irrespective of the farming system, soils under sugar beet cultivation were characterized by lower average BC and CEC values compared to soils under winter wheat cultivation. On the other hand, Kwiatkowski and Harasim [43] observed that the total sorption capacity of soil, irrespective of the farming system, was significantly higher under faba bean and potato cultivation compared with winter wheat and spring barley cultivation. Šimanský and Tobiašová [48] did not observe significant differences between tillage, fertilization and preceding crop treatments in the values of hydrolytic acidity (HA), the sum of exchangeable cations (CEC). The cation exchange capacity (CEC) of soils depends on the amount and composition not only of clay minerals but also of soil organic matter (SOM) [49] and the type of cultivated plants [50]. The total sorption capacity is higher when the soil is rich in organic matter (which is supplied to the soil with organic fertilizers and crop residues). Root crops and legumes positively influence the soil organic matter balance and contribute to an increase in soil ion exchange capacity compared to cereal crops [43,45,50].

The main sources of organic matter in arable soils are plant parts, crop residues and roots of higher plants that died during vegetation, the quantity and quality of which depend on the farming system (e.g., conventional or organic), soil use (e.g., intensive or extensive) and crop species composition (e.g., monoculture or crop rotation) [45,51]. These factors also determine the biochemical processes and activity of soil microorganisms involved in the decomposition of organic matter [52]. By assessing the subsequent effect of different cultivation systems on soil chemical quality parameters (TOC, TN and TOC/TN) and the content of the available form of phosphorus, it was found that the effect of the applied treatments depended on the species of cultivated plants. The results presented in this paper show that winter wheat cultivation in the organic farming system contributed to a significant improvement of loess soil quality indicators and P content compared to the conventional (traditional) system. The opposite results were obtained for sugar beet cultivation. The research results presented in this paper are from a 10-year experiment. According to Marinari et al. [53], the minimum period of organic cultivation, after which the soils reached a stable state of chemical and microbiological parameters, was 7 years. After this period, these cited authors noted an increase in the content of total nitrogen and available phosphorus in organically cultivated soil. On the other hand, the results of a short-term (3 years) study by Kwiatkowski et al. [45] indicate that the organic farming system had a beneficial effect on the contents of organic C (TOC), total nitrogen (TN), available phosphorus (P) and pH of loess soil in comparison with the conventional (traditional) system.
Phosphorus is an essential plant nutrient. Soils generally contain an amount of P that is between 0.1 and 3.0 g·kg⁻¹ soil [54]. The content of available phosphorus generally decreased along the soil profiles, a finding that was in agreement with the study of, among others, Lemanowicz [54]. Soil enzyme activities can provide information on how soil management is affecting the potential to perform the processes in soils such as decomposition and nutrient cycling [51]. Studying the activity of enzymes involved in P cycling in the environment can provide information on the metabolic or functional responses of soils to changes in management practices [55]. Phosphatases belong to a large group of enzymes that catalyze organic phosphorus compounds and are used to assess the rate of mineralization of these compounds in the soil. They play an important role in the environment, as they stimulate the conversion of organic phosphorus compounds into inorganic phosphates available to plants and soil organisms [56]. The response to a deficiency of available phosphorus in the soil is phosphatase biosynthesis by both plant roots and microorganisms. Therefore, the activity of these enzymes is largely related to the concentration of plant-available phosphorus [26,54], which is confirmed by the obtained values of the correlation coefficient (r = 0.66 **–0.87 **; see Table 12). In the present study, higher AcPh and AlPh activities were found in soil under the organic winter wheat cultivation system, with statistically significant differences only in acid phosphatase activity. Sugar beet cultivation in the conventional system had a more favorable effect on the activity of these enzymes. These differences may have resulted from the different root secretions produced by the root system [29,56]. According to many authors [45,56,57], root secretions are a good source of nutrients for microorganisms, mainly from the rhizosphere. At the same time, it should be remembered that the effect of higher plants on soil enzymes depends on the chemical composition of the plant, which, even in the case of root secretions alone, may be different in different types, species and even varieties [29,58,59].

Table 12. Significant correlation coefficients between the activity of the examined enzymes and pHKCl and the content of organic carbon (TOC), total nitrogen (TN) and available phosphorus (P) form.

| Parameter | Farming System | pHKCl  | TOC  | TN  | P  |
|-----------|----------------|--------|------|-----|----|
| AcPh      | Conventional   | −0.94 ** | 0.79 ** | 0.77 ** | 0.87 ** |
|           | Organic        | −0.69 * | 0.82 ** | 0.87 ** | 0.66 ** |
| AlPh      | Conventional   | 0.87 ** | 0.84 ** | 0.85 ** | 0.83 ** |
|           | Organic        | 0.77 ** | 0.70 *  | 0.73 ** | 0.79 ** |

Explanation: ** significant at α = 0.001; * significant at α = 0.01.

The higher AcPh activity shown in the present study, compared to AlPh, is due to the fact that phosphatases are enzymes that are highly sensitive to changes in soil pH. The optimum soil pH for alkaline phosphatase activity is 9.0–11.0, and for acid phosphatase, it is 4.0–6.5 [60]. Similar research results are presented by Kotroczó et al. [61] and Lemanowicz [54]. In our study, we found a significant positive value of the correlation coefficient between soil pHKCl and AlPh (r = 0.77–0.87 **) and a negative relationship between soil pHKCl and AcPh (r = −0.69 *−−0.94 **; see Table 12). Similarly, Acosta-Martinez and Tabatabai [62] observed a high significant value of the coefficient of correlation (r = 0.89 **) for the pH and the alkaline phosphomonoesterase activity relationship. A significant negative correlation coefficient for acid phosphatase activity and soil pH was also reported by Acosta-Martinez and Tabatabai [62] (r = −0.69 **) and Lemanowicz et al. [63] (r = −0.59 **). The results of the correlation analysis between AlPh and AcPh and sorption parameters were generally insignificant.

The activity of the tested phosphatases decreased with the depth of the soil profiles. This trend is related to the spatial distribution of humus, as well as soil microorganisms and the decreasing amount of carbon substrates available to both microorganisms and enzymes [26,64], as confirmed by the results of TOC and TN. Aon and Colaneri [65] showed strong correlations between the carbon content of organic compounds and the activity
of acid and alkaline phosphatase in agriculturally used soil. In our study, it was shown that, irrespective of the farming system, the activity of soil enzymes studied correlated significantly with the content of TOC and TN (r = 0.70 * − 0.87 **; see Table 12).

Dick et al. [28] used the measurement of phosphatase activity to determine the optimum soil pH, as the ratio of alkaline to acid phosphatase activity (enzymatic indicator of pH level AlPh/AcPh) proved to be a sensitive indicator of changes in soil pH. The enzymatic pH level indicator can be used to determine the changes occurring in soil [54,63]. According to the quoted authors, this index can be used as an indicator for assessing the soil pH suitable for the growth and development of crops and for determining the need for soil liming treatment [28]. In the studied soils, the values of the AlPh/AcPh ratio ranged from 0.35 to 0.49 (Table 8). According to Dick et al. [28], an AlP/AcP ratio value lower than 0.5 indicates acidification of the soil environment. This was not confirmed by our potentiometric studies of soil pH in 1 M KCl (Table 5). In the case of our research, the AlP/AcP index proved to be an unbelievable indicator of soil acidification. This proves that reliable results are obtained when examining several parameters.

5. Conclusions

The obtained results indicate that the residual effects of different cropping systems on physicochemical and biochemical soil properties depended on the crop species. The organic farming system contributed to an improvement in soil pH_{KCl}, chemical indicators of loess soil quality (TOC, TN and TOC/TN) and P content, as well as acid phosphatase and alkaline phosphatase activities, that were recorded in the organic farming system compared to the conventional system, but only for winter wheat cultivation. The obtained results were partially consistent with the postulated hypothesis. Therefore, research on the impact of an organic system of growing different species in rotation should be continued, and the results should be implemented.

Author Contributions: Conceptualization, S.W. and M.M.; methodology, B.F. and M.M.; validation, S.W., M.M. and B.F.; formal analysis, A.K.; writing—original draft preparation, B.F.; writing—review and editing, M.M.; visualization, A.K.; supervision, S.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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