

Article

Chemical Properties of Soil in Four-Field Crop Rotations under Organic and Conventional Farming Systems

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Abstract: In agriculture, the farming system significantly affects chemical soil properties. The organic system, which is based among others on the use of natural (organic) fertilizers, promotes increased soil contents of humus, organic C, and micronutrients. The conventional system, in turn, may cause soil acidification if high rates of mineral (particularly nitrogen) fertilization are used. The crop plant species also modifies soil chemistry by providing different (quantitatively and qualitatively) crop residues. The study was conducted over the period 2013–2016 in Czesławice (Lublin Region, Poland). The aim of this study was to determine the content of some chemical components determining the quality of loess soil on which four plant species were grown under organic and conventional farming systems. This research involved the determination of some parameters of the chemical composition of the soil: soil pH, total sorption capacity, humus content, macronutrient (P, K, Mg) and micronutrient (B, Cu, Mn, Zn) content, organic carbon, and total nitrogen content. The content of different forms of nitrogen, N-NO₃ and N-NH₄, was also determined. The experimental design included two crop rotations (organic and conventional) in which identical plant species were grown: potato—winter wheat—field bean—spring barley. The experiment was established on loess soil with the grain size distribution of silt loam and classified as good wheat soil complex (soil class II). It was carried out as a split-plot design in three replicates, and the area of a single plot was 80 m². Soil samples were taken using a soil sampling tube from an area of 0.20 m² (from the 0–25 cm layer) in each plot at the end of the growing season of the specific crops grown. Over the four year study period, it was found that the organic system contributed to an increased soil content of magnesium, boron, copper, manganese, zinc, organic carbon, and total nitrogen. Moreover, organic cropping promoted more favorable soil pH and higher soil humus content. Organic cropping significantly improved the total sorption capacity of the soil compared to conventional cultivation. Moreover, the organic system contributed to a higher soil content of nitrogen in the form of N-NH₄ and its lower content in the form of N-NO₃. Under the conventional system, in turn, a higher soil phosphorus and potassium content was observed. To sum up, the study confirmed the assumed hypothesis that the organic farming system would contribute to an improvement in the chemical quality indicators of loess soil. Regardless of the cropping system, potato and field bean had the most beneficial effect on soil chemistry, whereas cereal crops showed the weakest effect. Winter wheat and spring barley had an effect on significantly lower total sorption capacity of the soil and a significantly lower soil content of N-NO₃ and N-NH₄.

Keywords: crop rotation; organic system; conventional system; soil chemical composition

1. Introduction

Organic farming is increasingly popular worldwide. The organic cropping system is associated with the strict adherence to the principle that synthetic mineral fertilizers and crop protection chemicals should not be used. This type of crops should also be at an appropriate distance from conventional crops (a buffer zone) and traffic arteries. This, in turn, guarantees better qualitative soil parameters and better quality of agricultural produce [1,2]. Moreover, the organic farming system allows the amount of unavailable nitrogen compounds in soil to be reduced, which is in compliance with the EU's Nitrate Directive [3]. Such agricultural practices allow healthy and safe food to be produced, while at the same time respecting the natural environment because nutrient-rich and healthy soil is the "starting point" for food safety. Agriculture intensification is thought to be a cause of soil degradation and reduced biodiversity of numerous plant and animal taxa [4–6]. This paper presents the effect of organic and conventional agriculture on the chemical properties of loess soil. The novelty of this study is the determination of the chemical properties of loess soil in the context of two identical crop rotations (in the conventional and organic systems) and the effects of different crop plant species on soil. Organic matter (which is the basis for fertilization under the organic system) has an important influence on soil quality, improvement of its structure, increased water capacity, and soil water infiltration. Many studies reveal that practices used in organic agriculture generally increase soil biological activity through higher organic matter accumulation and higher micronutrient content. This is achieved by using catch crops, recycling of crop residues, use of animal manure and other organic fertilizers, and a reduction in farming operations such as, e.g., ploughing. Conventional farming, in turn, often contributes to excessive soil accumulation of nitrogen, phosphorus, and potassium compounds unavailable to plants [7,8]. The genus and species of the crop plant also have a substantial impact on chemical soil properties. Some previous research studies reveal that root crops [1] and Fabaceae/Leguminosae crops [9,10] contribute to a more favorable chemical composition of soils and their enzymatic properties than cereal crops. This is due to a more beneficial chemical composition of root and legume crop residues that enter the soil [11].

Given the above facts, this study hypothesized that growing crops in a four-field crop rotation (potato—winter wheat—field bean—spring barley) under the organic system (including application of an organic mineral fertilizer—Humac Agro) would contribute to an improvement in the chemical soil quality indicators and soil fertility compared to the conventional system (in which synthetic mineral NPK fertilizers and chemical crop protection products were used).

The aim of this study was to determine the content of some chemical components deciding the quality of loess soil on which four plant species were grown under organic and conventional farming systems in properly designed crop rotations in environmental terms.

2. Materials and Methods

A field experiment in growing crops in four-field crop rotations under organic and conventional farming systems was conducted over the period 2013–2016 (one crop rotation cycle) 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, and the area of a single plot was 80 m² (8 m × 10 m). The total area of the experiment (24 plots) was 1920 m².

The experiment included two farming systems:

1. conventional—mineral NPK* and organic fertilization (manure applied for potato), seed dressing, fungicide, herbicide, insecticide and retardants application, and mechanical weed control;
2. organic—organic fertilization (manure applied for potato) with the fertilizer Humac Agro**, and mechanical weed control.

* Mineral NPK fertilizers were applied in the following forms: ammonium nitrate (34% N), enriched superphosphate (40% P₂O₅), potassium chloride (60% K₂O).

** 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: N = 10.3 g kg⁻¹, P = 1.05 g kg⁻¹, K = 1.18 g kg⁻¹; Ca = 16.80 g kg⁻¹; Na = 12.80 g kg⁻¹, Fe = 14.50 g kg⁻¹; Zn = 64 mg kg⁻¹; Br = 77 mg kg⁻¹; Cu = 19 mg kg⁻¹; Se = 6 mg kg⁻¹; and moisture content—20%.

In the conventional and organic systems, crops were grown in identical 4-field crop rotations (a 50% proportion of cereals):

Crop rotation A (organic cropping) and crop rotation B (conventional cropping):

1. Potato (*Solanum tuberosum* L.)
2. Winter wheat (*Triticum aestivum* L.)
3. Field bean (*Vicia faba minor* L.)
4. Spring barley (*Hordeum vulgare* L.)

The scheme of the experiment is shown in Figure 1.

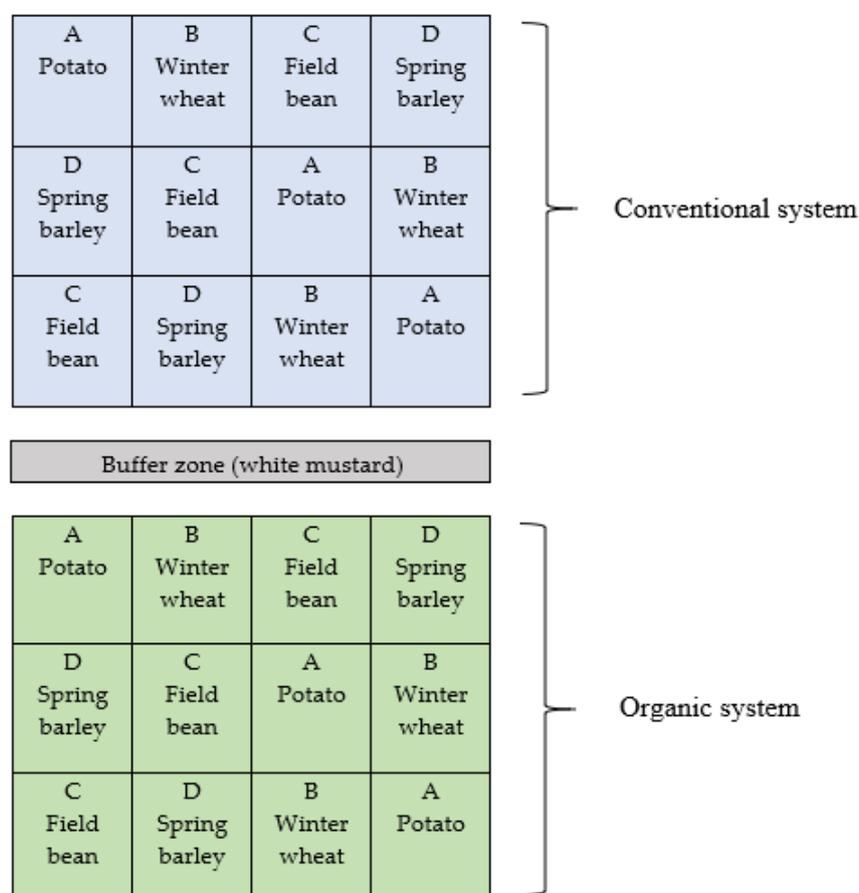


Figure 1. Design of the field experiment.

Over the next 4 years of research, the individual plants in the crop rotation were grown after identical previous crops (the plants “migrated” within the experimental design): potato—grown after spring barley, winter wheat—grown after potato, field bean—grown after winter wheat, spring barley—grown after field bean. Thus, it was a full crop rotation cycle (4 years), after which each plant in the crop rotation “returned to the same field” (beginning the next rotation cycle).

From 2010 (three years before the establishment of the experiment), the field with crop rotation A (organic) was managed following organic farming principles—a buffer zone (200 m) from conventionally farmed fields and no application of pesticides and artificial fertilizers (in 2011 the field received the Organic Farming Certificate awarded by the company “Eco-guarantee”). The following crops were

grown successively in it: winter wheat—oats—white mustard. The distance of the experimental plots from the nearest traffic artery was 800 m.

Crop rotations A and B were located on a loess-derived Luvisol, with the grain size distribution of silt loam (PWsp) [12] classified as good wheat soil complex and soil class II. In the year of establishment of the experiment (2012), the soil was characterized by slightly acidic pH (the pH in 1 M KCl was from 5.9—the conventional treatment, to 6.1—the organic treatment), a very high content of available phosphorus forms, a medium content of potassium, magnesium, manganese, as well as a low content of boron, copper, and zinc (Table 1). The soil characteristics in 2012 given in Table 1 were determined based on a mixed soil sample taken from the entire experimental area of the different farming systems. In 2012 the fields (in the organic and conventional systems) were not divided into specific plots. This was the initial period of the experiment—white mustard was grown in the entire area of both (organic and conventional) fields. In 2012 eight soil samples were randomly collected from both farming (organic and conventional) systems and composite samples were made from them. The purpose of taking these samples was to tentatively/initially determine the soil availability of nutrients that would be the object of study in the experiment established in 2013. Furthermore, the determination of the soil chemical composition in 2012 provided guidance for calculating fertilizer rates to be used during the crop rotation experiment (in the organic and conventional systems) over the period 2013–2016.

Table 1. Soil characteristics before the establishment of the experiment (2012) in the 0–25 cm soil layer—the soil under the white mustard crop.

Farming System	Soil pH 1 M KCl	Humus %	N %	P mg kg ⁻¹	K mg kg ⁻¹	Mg mg kg ⁻¹	B mg kg ⁻¹	Cu mg kg ⁻¹	Mn mg kg ⁻¹	Zn mg kg ⁻¹	Organic C g kg ⁻¹
Organic	6.1 a*	1.48 a	0.11 a	142 a	223 a	68.1 a	2.39 a	7.4 a	201 a	9.3 a	31.4 a
Conventional	5.9 a	1.41 a	0.09 b	159 b	241 b	64.3 b	2.17 b	7.0 b	185 b	9.1 a	31.0 a

* means within a row followed by different letters (a,b) are significantly different.

All crops grown in crop rotations A and B were sown at agronomically optimal dates (identical for the conventional and organic treatments). The seeding rate for the individual species and plant row spacing followed the relevant agronomic recommendations. The individual plant species were harvested following the agronomic recommendations at optimal crop maturity dates (Table 2).

Table 2. Sowing and harvest dates of the crop plants included in the experiment.

Crop Plant	Sowing Date	Harvest Date
Potato	26–30.04	17–19.09
Winter wheat	24–26.09	10–12.08
Field bean	10–14.04	05–08.09
Spring barley	19–23.04	15–17.08

Fertilization was adjusted to the specificity of the respective farming system (under organic cropping, animal manure fertilization, and Humac Agro), while under conventional cropping, animal manure fertilization and mineral NPK fertilization were adjusted to the initial soil nutrient availability). In organically grown crops, animal manure fertilization was applied at a rate of 25 t ha⁻¹, whereas in conventional crops at a rate of 25 t ha⁻¹. Organic fertilizer was applied and ploughed under during autumn ploughing (in October). Detailed information regarding the type and rates of fertilization in the conventional and organic crop rotations is presented in Tables 3 and 4.

Table 3. Fertilization applied in the conventional system.

Crop Plant	Mineral Fertilization in kg ha ⁻¹			Manure Fertilization in t ha ⁻¹
	N	P	K	
Potato	80 (before planting)	80 (before planting)	110 (before planting)	25 (autumn; before planting)
Winter wheat	90 (split doses) *	70 (before sowing)	100 (before sowing)	-
Field bean	25 (before sowing)	40 (before sowing)	60 (before sowing)	-
Spring barley	55 (before sowing)	45 (before sowing)	75 (before sowing)	-

* N—90 kg (35 kg before sowing, 30 kg in spring at the beginning of the growing season (BBCH 21–24), 25 kg at the turn of stem elongation and heading stages (BBCH 32–36).

Table 4. 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
	Potato	400 (before planting)
Winter wheat	380 (before sowing)	-
Field bean	190 (before sowing)	-
Spring barley	300 (before sowing)	-

Crop management operations in individual organically grown crops involved mechanical interrow cultivation (potato, field bean) 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—National Research Institute in Poznań [13] 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 type and amount of plant protection chemicals used in individual crops in the conventional system are shown in Table 5.

Table 5. List of plant protection chemicals included in the conventional system.

Plant Protection	Potato	Winter wheat	Field bean	Spring barley
Seed dressing	Prestige Forte 370 FS (a.i. imidachlopyrd—120 g L ⁻¹ and pencycuron 250 g L ⁻¹)—60 mL 100 kg ⁻¹ of potato	Divident 030 FS (a.i. difenoconazole—30 g L ⁻¹)—150 mL 100 kg ⁻¹ of seed	Nitragina (bacteria from the Rhizobiaceae family)—300 g ha ⁻¹	Vitavax 200 FS (a.i. carboxin—200 g L ⁻¹ , thiram—200 g L ⁻¹)—300 mL 100 kg ⁻¹ of grain
Herbicides	Sencor® Liquid 600 SC (a.i. metribuzin 600 g L ⁻¹)—1 L ha ⁻¹	Agroxone Max 750 SL (a.i. MCPA—750 g L ⁻¹)—1 L ha ⁻¹ , Puma Universal 069 EW (a.i. florasulam 6.25 g L ⁻¹)—0.8 L ha ⁻¹	Basagran 480 SL (a.i. bentazone 480 g L ⁻¹)—2.5 L ha ⁻¹	Agroxone Max 750 SL (a.i. MCPA—750 g L ⁻¹)—1 L ha ⁻¹ , Puma Universal 069 EW (a.i. florasulam 6.25 g L ⁻¹)—0.8 L ha ⁻¹
Fungicides	Altima 500 SC (a.i. fluazinam—500 g L ⁻¹)—0.3 L ha ⁻¹	Amistar 250 SC (a.i. azoxystrobin 250 g L ⁻¹)—0.6 L ha ⁻¹	Gwarant 500 SC (a.i. chlorothalonil—500 g L ⁻¹)—2 L ha ⁻¹	Delaro 325 SC (a.i. prothioconazole 175 g L ⁻¹ and trifloxystrobin 150 g L ⁻¹)—1 L ha ⁻¹
Insecticides	Actara 25 WG (a.i. thiamethoxam—250 g kg ⁻¹)—0.08 kg ha ⁻¹	Decis Mega 50 EW (a.i. deltamethrin—50 g L ⁻¹)—0.1 L ha ⁻¹	AcetGuard (a.i. acetamiprid-20%)—2 g 100 m ²	Fastac 100 EC a.i. (alpha-cypermethrin—100 g L ⁻¹)—0.12 L ha ⁻¹
Retardants	-	Moddus 250 EC (a.i. trinexapac ethyl—250 g L ⁻¹)—0.3 L ha ⁻¹	-	Cerone 480 SL (ethephon—480 g L ⁻¹)—1.5 L ha ⁻¹

The yield of the individual plant species in the crop rotation in both cultivation systems was determined in this research. The yield level of the individual species indicates the potentially available content of plant residues in the soil. The following was determined: primary yield, secondary yield, and belowground crop residues. At the agronomically optimal harvest date of the particular main crop

plant, plant material samples were collected (plants were pulled out from 1 m² of each study plot) in order to determine the following parameters (expressed on a t ha⁻¹ basis): primary yield (grain, seeds, roots, tubers, biomass), secondary yield (straw, stems, leaves), belowground crop residues (roots). Samples were taken at 4 randomly selected places on each plot, within a 0.25 m × 1.0 m frame.

To determine the comprehensive effect of farming systems and individual plant species in the crop rotation on soil chemistry, soil samples were taken from the 0–25 cm layer and soil availability of essential nutrients was determined. Soil samples were taken using a soil sampling tube from an area of 0.20 m² in each plot at the end of the growing season of the specific crops grown. Soil samples were taken at 4 randomly selected places on each plot (80 m²). In total, 96 soil samples were collected in the entire experiment (1920 m²). The test results gave the average of 4 samples taken on each plot.

In the year preceding the establishment of the experiment (2012), the fields were not divided into individual plots (it was an organically grown white mustard crop (960 m²) from which 8 soil samples were collected and a conventionally grown white mustard crop (960 m²) from which 8 soil samples were taken).

Humus content was determined by the Liechterfeld method using 1n and 2n K₂Cr₂O₇ as an oxidizing agent. The K₂Cr₂O₇: H₂SO₄ ratio was 1:1. 2-h and 1-h heating in a water bath was carried out, and iodometric determinations were made. Soil pH was determined potentiometrically in 1 M KCl dm⁻³, total sorption capacity (cmol (+) kg⁻¹) with the Kappen's method, C organic content with the Tiurin's method, total nitrogen by the Kjeldahl method, content of different forms of nitrogen: N-NO₃ (with the colorimetric method with phenoldisulfonic acid) and N-NH₄ (with the method with Nessler's reagent), the content of available forms of phosphorus and potassium by the Egner-Riehm method, magnesium content—by atomic absorption spectrometry (AAS), and micronutrient content (B, Cu, Mn, Zn) by flame photometry.

3. Weather Conditions at the Study Site

In order to determine the temporal and spatial variability of meteorological elements and assess their impact on the vegetation of crops grown in the crop rotation, Selyaninov's K-hydrothermal factor was calculated [14], dividing the sum of monthly precipitation by one-tenth of the sum of average daily temperatures for a given month (Table 6).

Table 6. The hydrothermal index (K) during the growing seasons in 2013–2016.

Months	Years			
	2013	2014	2015	2016
I	1.03	1.14	0.98	1.11
II	0.93	0.88	1.01	0.91
III	1.12	1.09	1.12	0.90
IV	1.30	1.55	1.16	1.32
V	1.62	1.29	1.76	1.63
VI	0.56	1.51	0.57	0.26
VII	0.61	0.71	0.38	0.65
VIII	0.77	0.92	0.86	0.75
IX	0.86	0.90	0.65	1.02
X	0.97	1.04	1.13	1.20
XI	1.16	1.24	1.01	0.93
XII	0.89	0.95	0.82	1.03

Hydrothermal index value: K ≤ 0.5 extremely dry; 0.51–0.69 very dry; 0.70–0.99 dry; K > 1 no drought.

The calculated values of the hydrothermal coefficient indicate that in the first months of growth of spring plants (potato, field bean, spring barley) and during the entire growth period of winter wheat, the plants were well supplied with water. In May (2013 and 2015–2016), significant rainfall was recorded. In the summer months of 2013, 2015, and 2016 (June–August), there were dry periods

and even extremely dry in July 2015 and June 2016. The exception in this respect is the growing season in 2013 and 2014, which should be considered favorable in terms of water/thermal conditions for cultivated crops. In the period IX–III, winter wheat plants generally had favorable hydrothermal conditions (similar over the study period). Only in September 2015 a very dry period was recorded ($K = 0.65$).

4. Statistical Analysis

Analysis of variance (ANOVA) was used to statistically analyze the results by employing Statistica PL 13.3, while Tukey's test was applied to determine HSD values at $p < 0.05$. For the resulting data presented in the tables, the following were calculated: SD—Standard Deviation.

5. Results

The mean for the study period is given in the results tables because the year-to-year differences between the characteristics analyzed were statistically insignificant. No significant interaction was found between the main experimental factors: farming system and plant species and also no significant three-factor interaction was found between the main factors (farming system, plant species) and years.

The study results presented in Table 7 show that regardless of the plant species in the crop rotation, the conventional system resulted in a significantly higher primary yield and secondary yield than the organic system. However, the belowground crop residues (roots) were similar (not statistically different) in both farming systems. In the case of three species (potato, winter wheat, and spring barley), a significant reduction in primary yield and secondary yield was noted in the organic system. The primary and secondary yield of field bean did not differ significantly between farming systems.

Table 7. Primary yield, secondary yield, and belowground crop residues of plants in a 4-field crop rotation in the organic and conventional systems.

Crop Plant	Primary Yield (Grain/Seeds, Tubers) t ha ⁻¹		Secondary Yield (Straw, Stems, Leaves) t ha ⁻¹		Belowground Crop Residues (Roots) t ha ⁻¹	
	Organic System	Conv. System	Organic System	Conv. System	Organic System	Conv. System
Potato	26.8 a * ± 1.16 **	32.5 b ± 1.75	15.7 a ± 1.17	18.6 b ± 1.11	0.18 a ± 0.03	0.19 a ± 0.04
Winter wheat	5.14 a ± 0.31	5.66 b ± 0.38	3.86 a ± 0.29	4.02 b ± 0.32	0.11 a ± 0.02	0.12 a ± 0.03
Field bean	3.71 a ± 0.22	3.98 a ± 0.25	3.62 a ± 0.20	3.75 a ± 0.18	0.32 a ± 0.08	0.36 a ± 0.09
Spring barley	4.59 a ± 0.28	5.14 b ± 0.33	3.25 a ± 0.19	3.60 b ± 0.25	0.10 a ± 0.02	0.11 a ± 0.02
Mean	10.06 a	11.82 b	6.61 a	7.49 b	0.18 a	0.19 a
HSD(0.05)	for farming systems = 1.125		for farming systems = 0.812		for farming systems = n.s. ***	

* means within a row followed by different letters (a,b) are significantly different; ** SD—standard deviation; *** n.s.—not significant differences.

Regardless of the plant species in the crop rotation, a significantly higher soil humus content was found in organic crops than in conventional ones (Table 8). It should be noted that in the year preceding the establishment of the experiment (2012), the soil humus content was at a similar (statistically insignificant) level in both farming systems (Table 1). On average for both cropping systems, the cultivation of potato and field bean had the most beneficial effect on soil humus content, whereas the cultivation of winter wheat and spring barley a significantly weaker impact. Winter wheat and spring barley had a similar effect on soil humus content (Table 8). Soil pH, determined after harvest of the crops, was more favorable under the organic system relative to the conventional one, but this difference was not statistically significant. A similar tendency was observed for soil pH in the initial year of the study (Tables 1 and 8). When we consider the effect of the individual plant species used in the crop rotations on soil pH, we notice that the lowest soil pH was found in the soil under the spring barley crop, whereas it was significantly higher in the soil under field bean crops (Table 8).

Table 8. Soil humus content (in %) and soil pH (in 1 M KCl dm⁻³) in the 0–25 cm soil layer.

Crop Plant	Humus Content			Soil pH		
	Organic System	Conventional System	Mean	Organic System	Conventional System	Mean
Potato	1.59 a * ± 0.06 ***	1.48 b ± 0.05	1.54 A **	6.5 a ± 0.2	6.2 b ± 0.2	6.4 A
Winter wheat	1.50 a ± 0.04	1.39 b ± 0.02	1.44 B	6.3 a ± 0.1	6.3 a ± 0.1	6.3 A
Field bean	1.53 a ± 0.07	1.50 a ± 0.07	1.52 A	6.5 a ± 0.1	6.5 a ± 0.1	6.5 A
Spring barley	1.49 a ± 0.02	1.37 b ± 0.01	1.43 B	6.3 a ± 0.1	6.2 a ± 0.1	6.2 B
Mean	1.53 a	1.43 b	-	6.4 a	6.3 a	-
HSD(0.05)	for farming systems (a) = 0.092 for plant species (b) = 0.096 interaction (a × b) = n.s. ****			for farming systems (a) = n.s. for plant species (b) = 0.29 interaction (a × b) = n.s.		

* means within a row followed by different letters (a,b) are significantly different; ** means within a column followed by different letters (A,B) are significantly different; *** SD—standard deviation; **** n.s.—not significant differences.

The data presented in Table 9 show that the organic system contributed to significantly higher total sorption capacity of the soil (on average by about 15%) compared to the conventional system. Regardless of the farming system, the total soil sorption capacity was found to be significantly higher under the influence of field bean and potato crops compared to the cultivation of winter wheat and spring barley (on average by about 23–29%).

Table 9. Total sorption capacity of soil in the 0–25 cm soil layer.

Crop Plant	Total Sorption Capacity cmol (+) kg ⁻¹		
	Organic System	Conventional System	Mean
Potato	40.4 a * ± 1.2 ***	34.7 b ± 1.0	37.5 A **
Winter wheat	33.4 a ± 0.9	26.2 b ± 0.6	29.8 B
Field bean	42.7 a ± 1.4	36.8 b ± 1.1	39.7 A
Spring barley	29.7 a ± 0.8	25.3 b ± 0.7	27.5 B
Mean	36.5 a	30.7 b	-
HSD(0.05)	for farming systems (a) = 4.98 for plant species (b) = 5.12 interaction (a × b) = n.s. ****		

* means within a row followed by different letters (a,b) are significantly different; ** means within a column followed by different letters (A,B) are significantly different; *** SD—standard deviation; **** n.s.—not significant differences.

Soil macronutrient content was significantly modified by farming system. Regardless of the plant species in the crop rotations, the conventional system contributed to a significant increase in soil phosphorus and potassium content, on average by 7%. In turn, the soil magnesium content was significantly higher (on average by 7%) under organic system conditions. What is important, the soil samples collected in 2012 (representing the condition of the soil before the establishment of the experiment) demonstrate that a significantly higher P and K content and a significantly lower Mg content were observed in the soil in the conventional field relative to the organic one already at that time (Tables 1 and 10). Regardless of the cropping system, significantly the lowest soil phosphorus content was found in the plots where field bean was grown, compared to the other treatments. The crop plants did not affect significantly soil potassium content. The cultivation of potato contributed to the highest magnesium content in the soil (significantly higher relative to the plots with field bean crops) (Table 10).

The organic farming system caused a significant increase in soil boron and copper content (respectively by 8 and 4%) relative to the conventional system. However, similar relationships for soil B and Cu content between both fields (organic and conventional) were observed already in the initial year of the study (2012) (Tables 1 and 11). The soil content of the analyzed micronutrients was also dependent on the plant species in the crop rotation. The cultivation of potato and field bean promoted significantly the highest B accumulation in the soil in comparison with the soil under winter wheat. Potato and field bean also contributed to a higher Cu content in the soil relative to both cereal crops (Table 11).

Table 10. Soil macronutrient content (in mg kg⁻¹ soil) in the 0–25 cm soil layer.

Crop Plant	P			K			Mg		
	Organic System	Conv. System	Mean	Organic System	Conv. System	Mean	Organic System	Conv. System	Mean
Potato	161 a * ± 6 ***	175 b ± 9	168 A **	264 a ± 11	280 b ± 13	272 A	74 a ± 3	69 b ± 2	71 A
Winter wheat	155 a ± 4	169 b ± 7	162 A	251 a ± 8	272 b ± 10	261 A	70 a ± 2	65 b ± 2	67 A
Field bean	144 a ± 3	150 a ± 4	147 B	256 a ± 7	267 a ± 9	261 A	68 a ± 3	61 b ± 1	64 B
Spring barley	159 a ± 5	171 b ± 8	165 A	255 a ± 8	279 b ± 12	267 A	71 a ± 4	68 b ± 3	69 A
Mean	155 a	166 b	-	256 a	274 b	-	71 a	66 b	-
HSD(0.05)	for farming systems (a) = 9.7 for plant species (b) = 10.2 interaction (a × b) = n.s. ****			for farming systems (a) = 15.5 for plant species (b) = n.s. interaction (a × b) = n.s.			for farming systems (a) = 3.8 for plant species (b) = 2.9 interaction (a × b) = n.s.		

* means within a row followed by different letters (a,b) are significantly different; ** means within a column followed by different letters (A,B) are significantly different; *** SD—standard deviation; **** n.s.—not significant differences.

Table 11. Boron and copper content (in mg kg⁻¹) in the 0–25 cm soil layer.

Crop Plant	B			Cu		
	Organic System	Conventional System	Mean	Organic System	Conventional System	Mean
Potato	2.57 a * ± 0.9 ***	2.28 b ± 0.9	2.42A **	7.94 a ± 0.9	7.25 b ± 0.9	7.60 A
Winter wheat	2.21 a ± 0.9	2.09 b ± 0.9	2.15 B	6.58 a ± 0.9	6.41 b ± 0.9	6.50 B
Field bean	2.33 a ± 0.9	2.24 b ± 0.9	2.29 A	6.82 a ± 0.9	6.79 b ± 0.9	6.80 A
Spring barley	2.36 a ± 0.9	2.16 b ± 0.9	2.26 A	6.61 a ± 0.9	6.49 b ± 0.9	6.55 B
Mean	2.37 a	2.19 b	-	6.99 a	6.73 b	-
HSD(0.05)	for farming systems (a) = 0.104 for plant species (b) = 0.136 interaction (a × b) = n.s. ****			for farming systems (a) = 0.153 for plant species (b) = 0.099 interaction (a × b) = n.s.		

* means within a row followed by different letters (a,b) are significantly different; ** means within a column followed by different letters (A,B) are significantly different; *** SD—standard deviation; **** n.s.—not significant differences.

Soil magnesium and zinc content was significantly dependent on both experimental factors. The organic system resulted in a higher Mn and Zn content in the soil by about 7 and 5%, respectively, compared to the conventional system (Table 12). The data contained in Table 1 reveal that such a relationship for the soil Mn content occurred already before the establishment of the experiment (2012). The soil Zn content, on the other hand, was similar in the organic and conventional fields at that time. Regardless of the farming system, the cultivation of potato and field bean contributed to an increase in the soil content of these macronutrients (on average by 13%—Mn; 10%—Zn) relative to winter wheat and spring barley crops (Table 12).

Table 12. Manganese and zinc content (in mg kg⁻¹) in the 0–25 cm soil layer.

Crop Plant	Mn			Zn		
	Organic System	Conventional System	Mean	Organic System	Conventional System	Mean
Potato	214 a * ± 0.9 ***	194 b ± 0.9	204 A **	9.64 a ± 0.9	9.22 b ± 0.9	9.43 A
Winter wheat	181 a ± 0.9	177 b ± 0.9	179 B	8.47 a ± 0.9	8.30 b ± 0.9	8.38 B
Field bean	211 a ± 0.9	189 b ± 0.9	200 A	9.17 a ± 0.9	8.76 b ± 0.9	8.96 A
Spring barley	176 a ± 0.9	170 a ± 0.9	173 B	8.29 a ± 0.9	8.03 b ± 0.9	8.16 B
Mean	195 a	182 b	-	8.89 a	8.58 b	-
HSD(0.05)	for farming systems (a) = 12.4 for plant species (b) = 11.8 interaction (a × b) = n.s. ****			for farming systems (a) = 0.377 for plant species (b) = 0.313 interaction (a × b) = n.s.		

* means within a row followed by different letters (a,b) are significantly different; ** means within a column followed by different letters (A,B) are significantly different; *** SD—standard deviation; **** n.s.—not significant differences.

Organic cropping contributed to a significant increase in organic carbon and total nitrogen content in the topsoil layer (on average by 5 and 8%, respectively) compared to conventional cropping (Table 13). In 2012 (before the establishment of the experiment), the field intended for organic cropping was characterized by a similar soil organic C as the conventionally managed field. In turn, the soil total N content in 2012 was significantly higher in the organic field than in the conventional one (Table 1). Regardless of the farming system, the individual crop plant species did not have a significant effect on soil organic C content. On the other hand, the cultivation of potato and field bean contributed to a significantly higher total N content in the soil compared to winter wheat and spring barley

(Table 13). As far as the soil C/N ratio is concerned, it was significantly dependent on the farming system. A narrower C/N ratio was found for the soil in the organic plots than in the conventionally tilled plots. The crop plants did not modify significantly the C/N relation in the soil. A statistically significant correlation (the narrowest C/N ratio) was found when field bean was grown organically (Table 13).

Table 13. Organic carbon and total nitrogen content and C/N ratio in the 0–25 cm soil layer.

Crop Plant	Organic C g kg ⁻¹			Total N kg ⁻¹			C/N	
	Organic System	Conv. System	Mean	Organic System	Conv. System	Mean	Organic System	Conv. System
Potato	33.7 a * ± 1.1 ***	31.4 b ± 0.8	32.5 A **	3.25 a ± 0.11	3.00 b ± 0.09	3.12 A	10.3 a	10.5 a
Winter wheat	32.5 a ± 1.0	31.0 b ± 0.7	31.7 A	3.11 a ± 0.08	2.82 b ± 0.07	2.96 B	10.4 a	10.9 a
Field bean	31.6 a ± 0.6	31.3 a ± 0.6	31.4 A	3.26 a ± 0.12	2.99 b ± 0.07	3.12 A	9.7 b	10.5 a
Spring barley	32.9 a ± 0.5	31.2 b ± 0.4	32.0 A	3.09 a ± 0.09	2.87 b ± 0.06	2.98 B	10.6 a	10.9 a
Mean	32.7 a	31.2 b	-	3.18 a	2.92 b	-	10.2 a	10.7 b
HSD(0.05)	for farming systems (a) = 1.32 for plant species (b) = n.s. interaction (a × b) = n.s. ****			for farming systems (a) = 0.186 for plant species (b) = 0.128 interaction (a × b) = n.s.			for farming systems (a) = 0.44 for plant species (b) = n.s. interaction (a × b) = 0.53	

* means within a row followed by different letters (a,b) are significantly different; ** means within a column followed by different letters (A,B) are significantly different; *** SD—standard deviation; **** n.s.—not significant differences.

The experimental factors were found to have a significant impact on the soil content of the nitrogen forms studied. The conventional system contributed to a higher soil content of N-NO₃ (by about 8%) relative to the organic system. The organic system, in turn, resulted in higher soil availability of N-NH₄ (by about 9%) in comparison with conventional cropping. Regardless of the farming system, the soil availability of both nitrogen forms was found to be higher under the influence of potato and field bean cropping than in the case of cereal crops (Table 14).

Table 14. Nitrogen forms in soil in the 0–25 cm soil layer.

Crop Plant	N-NO ₃ mg kg ⁻¹ d.m.			N-NH ₄ mg kg ⁻¹ d.m.		
	Organic System	Conventional System	Mean	Organic System	Conventional System	Mean
Potato	31.7 a ± 1.4 ***	33.9 b ± 1.6	32.8A**	2.33 a ± 0.11	2.18 b ± 0.10	2.25 A
Winter wheat	28.5 a* ± 0.9	31.1 b ± 1.1	29.8 B	1.91 a ± 0.08	1.74 b ± 0.06	1.82 B
Field bean	31.9 a ± 1.0	34.4 b ± 1.5	33.1A	2.47 a ± 0.13	2.24 b ± 0.09	2.35 A
Spring barley	27.8 a ± 0.7	30.6 b ± 0.8	29.2 B	1.83 a ± 0.06	1.65 b ± 0.04	1.74 B
Mean	30.0 a	32.5 b	-	2.13 a	1.94 b	-
HSD(0.05)	for farming systems (a) = 2.33 for plant species (b) = 2.19 interaction (a × b) = n.s. ****			for farming systems (a) = 0.178 for plant species (b) = 0.194 interaction (a × b) = n.s.		

* means within a row followed by different letters (a,b) are significantly different; ** means within a column followed by different letters (A,B) are significantly different; *** SD—standard deviation; **** n.s.—not significant differences.

6. Discussion

Organic agriculture is based on sustainable agricultural land management and protection of the natural environment and natural resources, which prevents soil and water degradation. Soil fertility plays a key role in all farming systems because it is the basis for food production [6,8,15].

The chemical composition of the soil depends, among other factors, on the yield potential of crops (both primary and secondary yield and belowground crop residues) [16]. The present study shows that primary and secondary yield of potato, winter wheat, and spring barley was significantly lower in the organic system than in the conventional one. Field bean also produced lower yields in the organic system, but at a level not statistically significant (Table 7). Other scientific reports show that in most cases crop yields are lower in the organic system than in the conventional one [17–19]. Exceptions are species that tolerate extensive cultivation conditions (spelt wheat, proso millet) [20].

In the opinion of Schrama et. al. [21], organic farming is considered more sustainable but less productive than conventional farming. Initially, yields in the organic farming system were lower,

but then they approached those obtained under the conventional system, while requiring lower nitrogen inputs. Closure of the yield gap between organic and conventional farming can be a matter of time and organic farming may result in greater spatial stability of soil biotic and abiotic properties and soil processes.

The study results presented in this paper show that cropping in a four-field crop rotation under organic farming system contributed to a significant improvement in the quality indicators of loess soil compared to the conventional (traditional) system. Particularly distinct differences (statistically proven) in favor of the organic system were found with respect to humus, C-organic, N-total, magnesium, boron, copper, manganese, and zinc content (Table 8, Table 11, Table 12, Table 13) The organic farming system also promoted more favorable soil pH and total soil sorption capacity (this characteristic also showed higher values as affected by potato and field bean cropping than for cereal crops) (Tables 8 and 9). As far as the above-mentioned parameters are concerned, the high soil content of the studied nutrients in the organic system was also affected by their high availability determined in 2012 (before the establishment of the experiment). This had an impact, in particular, on the high humus and total N content in the soil in the organic crop rotation. The soil content of three micronutrients (B, Cu, Mn) determined before the establishment of the experiment was also significantly higher in the organic field than in the conventional one. The initial organic C content in the soil was similar in the organic and conventional fields (Table 1). Therefore, it did not have a major effect on the content of this nutrient found in this crop rotation study during the period 2013–2016 (Table 13). Both fields (the organic and conventional ones) were located in the same land plot belonging to the Czesławice Experimental Farm (plot No. 1001). The soil in both fields is classified in the same soil quality class and agricultural land suitability class (soil class II and good wheat soil complex). The fields were separated from each other by a 200 m wide buffer zone (white mustard). It turns out that a certain variation in soil nutrient availability was found in the fields separated by such a distance, as shown in Table 1.

In a study by Woźniak et al. [9], the soil taken from plots sown with pea and durum wheat was characterized by similar total sorption capacity (statistically not significant). Nonetheless, some authors note that total sorption capacity is greater in the case of high soil richness in organic matter (which is supplied to the soil with organic fertilizers and crop residues). This parameter is also dependent on the crop plant species. Root and legume crops positively affect soil organic matter balance and contribute to higher soil ion exchange capacity in comparison to cereal crops [1,22,23].

The obtained results are confirmed in the literature of the subject. Reganold [24] found a higher C-organic and N content in organically farmed fields in comparison with conventional ones. Drinkwater et al. [25] also recorded a higher C-organic and N content as well as a higher nitrogen mineralization rate in fields with organically grown tomatoes compared to conventional tomato cropping. Likewise, Wang et al. [8] note that soil C-organic content depends largely on the type of fertilization. The use of organic fertilizer (manure) has the most beneficial effect on the content of this nutrient. The study results presented in this paper also come from a short-term (four-year) field experiment that included one crop rotation cycles. Therefore, due to the study timeframe they can be considered to be reliable. The study by Kwiatkowski et al. [1] reveals that the organic farming system promoted a more favorable chemical composition and enzymatic 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. The soil organic C and total N content was found to be higher in the organic system despite that the availability of these nutrients in the soil before the establishment of the experiment was higher in the conventional system [1]. This proves that the organic system promotes greater accumulation of these nutrients in the soil. This is due to the fact that crop yields in the conventional system are generally higher, which is associated with the greater uptake of nitrogen and other nutrients from the soil. In the conventional system, NPK fertilizers and crop protection products were used and they contribute to better condition and health of plants as well as to higher crop yields. Fertilizers applied in organic farming are mineralized to a greater degree and they stimulate soil enzymatic activity, which leads to higher nitrogen release. This is one of the reasons for

a higher total N content in organically cultivated soils [1,8,21]. Similar relationships were found in the present study—the lower total N content in the soil (Table 13) was a consequence of significantly higher crop yields obtained in the crop rotation under the conventional system (Table 7).

In the present study, a lower phosphorus and potassium content was found in the soil under organic crops than for conventional ones (Table 10). Such a relationship, associated with the higher P and K content in the soil collected from the conventionally managed field, was also found before the establishment of the experiment in 2012 (Table 1). Among the crops tested in the experiment, field bean had a significantly lower effect on the P and Mg content in the soil (Table 10). Other authors [1,26,27] also noted a decrease in phosphorus and potassium content in the soil of organically cultivated fields. In a study conducted by Gosling and Shepherd [28], potassium and phosphorus concentrations were also proven to be much lower in organically cultivated soil relative to the conventional farming system. They found the greatest difference in soil potassium content between the oldest, managed for 54 years, traditional farms and organic farms. It is thought that changes in soil potassium and phosphorus content in fields managed organically over a period of less than 10 years can be undetectable because such fields draw from phosphorus and potassium reserves accumulated before the change of the farming system, that is, from fertilizers that were used excessively during conventional farming. It is also thought that long-term organic farming, without at least limited phosphorus and potassium soil amendment, can lead to decreased soil fertility and reduced yields [28–30]. The present study demonstrated that regardless of the cropping system, potato had the most favorable effect on improvement of the soil quality indicators analyzed (Table 10). Other authors [31–33] also indicate the positive role of root crops in determining soil chemistry. In turn, other studies prove that legume crops contribute to greater soil accumulation of available forms of phosphorus, potassium, and magnesium than cereal crops [22].

In this research, the organic cropping system contributed to a significantly higher soil content of magnesium and micronutrients (B, Cu, Mn, Zn). The cultivation of potato and field bean also promoted higher micronutrient availability in the soil than cereal cropping (Tables 11 and 12). The soil content of micronutrients (Zn, Cu, Fe, Mn, B, and Mo) largely depends on soil pH and soil organic matter content as well as on microbial activity. The research of other authors [34,35] reveals that a large amount of organic matter in the soil promotes lower reduction potential and contributes to higher availability of micronutrient cations in the soil. Organic matter is also a source of organic C in the soil. It increases water-soluble and exchangeable forms of micronutrients. In a study by Dhaliwal et al. [34], adding organic matter to the soil resulted in the increased occurrence of complex forms of micronutrients. Moreover, organic matter accumulated in the soil had an effect on transformations of the adsorbed fractions into micronutrient forms more available to plants. Apart from that, soil organic matter has a direct and indirect impact on nutrient transformations [36] and favored the binding of micronutrients such as B, Cu, Zn, and Mo, in particular [34,36]. The above cited findings were confirmed in this study because organic farming (associated with a larger amount of organic matter in the soil) resulted in higher soil micronutrient availability.

The present study reveals that the crop plant species significantly affected the organic C and total N content in the soil. On the other hand, the C/N relation was insignificant if we compare the effect of the specific crop plants studied (Table 13). The literature of the subject shows that the amount and type of organic matter as well as the rate of its degradation (soil biological activity) have the greatest influence on the C/N ratio [10,37,38]. Similar observations can be found in the papers by Nannipieri et al. [39], Jurado et al. [40], and Biernat et al. [3].

In this study, the organic cropping system caused a decrease in the amount of N-NO₃ in the soil (Table 14). Biernat et al. [3] and Nannipieri et al. [39] also found a decrease in the amount of N-NO₃ in the soil in an organic crop rotation compared to conventional cultivation. As demonstrated in the present study, the crop plant species has a large impact on the amount of N-NO₃ and N-NO₄ in soil (root and legume crops contribute to increasing the content of these forms of nitrogen, whereas cereal crops reduce their content) (Table 14). Similar findings are reported by Woźniak [9]; in this

author's study, the cultivation of bean contributed to higher accumulation of both these forms in the soil compared to wheat cropping.

The effects of the transition from conventional farming to organic farming cannot be captured over a short period of time [7,28,41]. When comparing different soil activity parameters after 21 years (with a seven-year crop rotation period), Fließbach et al. [30] found better parameters for organically managed soils compared to conventional soil cultivation. Similarly, Birkhofer et al. [42] and Joergensen et al. [43] observed more favorable soil quality indicators under the organic system compared to the conventional one.

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. A study by Marinari et al. [44] demonstrated that the minimum period of organic farming after which soils achieve better physico-chemical and biological parameters is seven years. After the seven-year period, these authors observed an increased content in total nitrogen, nitrates, and available phosphorus as well as higher soil enzymatic activity. Gosling and Sheperd [28], on the other hand, compared different soil quality parameters in organic farms over a period of at least 15 years with soil quality in conventional farms (run over the same period of time as the relevant organic farms) and did not find significant differences in soil organic matter and nitrogen content.

7. Conclusions

The results of the four-year study (one crop rotation cycles) reveal that the organic farming system promoted a more favorable chemical composition of loess soil relative to the conventional system. The positive effect of the organic system was manifested in better soil pH, higher total sorption capacity, and a higher content of humus, C-organic, N-total, Mg, B, Cu, Mn, and Zn. However, the soil phosphorus and potassium content was lower than that under the conventional system. The soil chemical composition was also related to the yield of the individual crop plants in the crop rotation under both farming systems. The determined relationships also resulted from the initial chemical composition of the loess soil in organic and conventional cropping as determined before the establishment of the experiment. Furthermore, the organic system contributed to a higher soil content of the nitrogen form N-NH₄ but to a lower content of N-NO₃ (whose soil content was higher in the conventional system).

The individual plant species grown in crop rotations affected soil chemistry differently. Generally, potato and field bean had the most beneficial effect on the chemical soil quality indicators, followed by winter wheat and spring barley. Field bean negatively influenced soil P, K, and Mg accumulation. Moreover, potato and field bean had an effect on higher total sorption capacity and higher soil content of both nitrogen forms (N-NO₃, N-NH₄) compared to cereal crops (winter wheat, spring barley).

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