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Effect of Farming System and Irrigation on Physico-Chemical and Biological Properties of Soil Under Spring Wheat Crops

Elżbieta Harasim and Cezary A. Kwiatkowski *

Department of Herbology and Plant Cultivation Techniques, University of Life Sciences in Lublin, Poland, Akademicka 13, 20-950 Lublin, Poland

* Correspondence: cezary.kwiatkowski@up.lublin.pl

Abstract

A field experiment in growing spring wheat (*Triticum aestivum* L. - cv. 'Monsun') under organic, integrated and conventional farming systems was conducted over the period of 2020–2022 at the Czesławice Experimental Farm (Lubelskie Voivodeship, Poland). The first experimental factor analyzed was the farming systems, which included: A. organic system (control) - without the use of chemical plant protection products and mineral fertilization NPK; B. conventional system - the use of plant protection products and NPK fertilization in the range and doses recommended for spring wheat; C. integrated system - use of plant protection products and NPK fertilization in an "economical" way - doses reduced by 50%. The experimental factor was irrigation strategy of spring wheat crops: 1. no irrigation - control; 2. double irrigation (at the beginning of crop vegetation and in the phase of critical water demand of wheat; 3. multiple irrigation resulting from the monitoring of drought in the agricultural field. The aim of the research was to determine the physical, chemical and enzymatic properties of loess soil under spring wheat crops as influenced by the factors listed above. The highest organic C content of the soil (1.11%) was determined in the integrated system with multiple irrigation of spring wheat, whereas the lowest one (0.77%) - in the conventional system without irrigation. In the conventional system, the highest contents of total N (0.15%), P (131.4 mg kg^{-1}), and K (269.6 mg kg^{-1}) in the soil were determined under conditions of multiple irrigation. In turn, the organic system facilitated the highest contents of Mg, B, Cu, Mn, and Zn in the soil, especially upon multiple irrigation of crops. It had also the most beneficial effect on the evaluated physical parameters of the soil. In each farming system, the multiple irrigation of spring wheat significantly increased moisture content, density and compaction of the soil and also improved its total sorption capacity (particularly in the integrated system). The highest count of beneficial fungi, the lowest population number of pathogenic fungi, and the highest count of actinobacteria were recorded in the soil from the organic system. Activity of soil enzymes was the highest in the integrated system, followed by organic system - particularly upon multiple irrigation of crops. Summing up, the present study results demonstrate varied effects of the farming systems on the quality and health of loess soil; however, the integrated system was proved to ensure its most stable and equalized physicochemical and biological parameters. The multiple irrigation of crops resulting from indications of soil moisture sensors mounted on plots (indicating the real need for irrigation) contributed to the improvement of almost all analyzed soil quality indices.

Keywords: loess soil; organic system; conventional system; integrated system; irrigation; soil quality properties; soil enzymatic activity

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1. Introduction

Wheat (*Triticum aestivum* L.), as one of the most important food crops globally, serves as a primary source of daily protein requirements and provides 20% of the calories consumed by man [1]. The yield of both winter and spring wheat varieties is influenced by numerous factors, including climatic conditions, farming systems (conventional, integrated, organic), as well as the physical, chemical, and biological properties of the soil. Proper soil pH and structure are fundamental factors that ensure optimal growth and yield of crops. Therefore, investigating the relationship between soil quality and crop yields is crucial, particularly in the context of changing farming systems [2–5].

Soil quality is determined by its physical, chemical, and biological properties and is closely related to its fertility and health. Various indicators provide early insights into the processes occurring in the soil and the availability of nutrients to plants. They also reflect the impacts of changes in agricultural land use or farming practices [6,7]. Improvements in soil quality are often equated with its enhanced physicochemical properties, such as the size and stability of aggregates, organic matter content, reduced bulk density, and soil resistance. In contrast, biological indicators of soil quality, such as overall diversity and biomass of organisms, genetic diversity of beneficial microorganisms, and activity of enzymes involved in nutrient cycling, are dynamic indicators closely linked to farming systems and agricultural practices [2,8]. They play a significant role in the proper development of plants, ultimately affecting not only the quantity but also the quality of the harvested crops [9,10]. Soil organisms perform numerous essential functions, like ensuring nutrient cycling and supplying nutrients to plants, modifying soil physical structure and water conditions, and influencing the elimination of undesirable organisms in cultivated lands. Therefore, a good quality of the soil promotes its productivity and, ultimately, impacts plant health [11,12].

Organic and integrated systems respond to the intensification of agricultural production (excessive use of mineral fertilizers and pesticides), which is considered an underlying cause of soil degradation and the resulting environmental pollution [13]. Evaluating the effectiveness of crop cultivation in various farming systems under changing climatic conditions has shown that organic and integrated agricultural systems are generally more resilient to climate change than the conventional system. This resilience is primarily due to farmers' careful management of soil, cultivated crop biodiversity, and care over the status of water resources. Pro-ecological and sustainable farming practices entail regular soil nourishment with natural fertilizers, reduced use of pesticides and mineral fertilizers, as well as employing various practices to maintain soil fertility. They also aid the preservation of soil biodiversity [14].

Contemporary development trends demand innovative solutions not only in agricultural technology but also in the precise dosage of water. On a global scale, the primary criterion for applying irrigation is the one associated with the climate conditions, particularly the quantity and distribution of precipitation. Pursuant to the global warming theory, manifested primarily by rising air temperatures, the frequency of droughts across various geographical regions is expected to increase, while research findings indicate that these changes are already in progress [15].

Thus, irrigation aims to maintain optimal conditions for plant growth, whereas its effectiveness is driven by the intensity and quantity of practices employed in different farming systems, as well as the location and amount of water in the soil [16]. Calow et al. [17] also emphasized the importance of integrated field irrigation management in ensuring optimal quality parameters of both the soil and agricultural crops. Soil water content directly and indirectly influences wheat growth. Its direct influence is related to the water available around the roots by means of which it is absorbed, while its indirect impact is associated with soil properties [18]. Water acts as a medium for transporting mineral particles, dissolved matter, and organic matter within the soil profile. The migration of water through soil pores affects the distribution of nutrients, minerals, and contaminants, thereby influencing soil fertility and the quality of the soil environment. Furthermore, water impacts physical soil properties such as texture, structure, and porosity, which in turn affect infiltration, water storage, and water availability for uptake by plants [19]. Understanding the long-term effects of irrigation on the fundamental characteristics and quality of soil is essential for sustainable land management and agricultural production, particularly in arid regions where water availability is limited [20].

The aim of the conducted research was to determine the physicochemical and biological properties, as well as the enzymatic activity of loess soil under spring wheat crops, depending on three farming systems (conventional, integrated, organic) and the level of irrigation (multiple, double, and no irrigation). The hypothesis posited that the most favorable soil quality parameters would be provided by the integrated system – as a synthesis of conventional and organic management. It was also assumed that appropriately balanced multiple irrigation of wheat crops (based on water demands indicated by soil moisture sensors) would contribute to achieving the best indicators of soil quality and health.

2. Materials and Methods

2.1. Experiment Design and Field Management

A field experiment was conducted in the years 2020-2022 at the Czesławice Experimental Farm (51◦30′ N; 22◦26′ E Lubelskie Voivodeship, Poland). The experiment was set up as a split-block design in 3 replicates, and the area of a single plot was 50 m^2 (5 m × 10 m). The total area of the experiment (27 plots) was 1,350 m^2. It was located on a loess-derived Luvisol, with the grain size distribution of silt loam (PWsp), classified as good wheat soil complex (soil class II). Spring wheat (*Triticum aestivum* L. - cv. 'Monsun') served as a test plant in the experiment. Before the establishment of the experiment (2019-2021, autumn), the soil had a medium content of available macronutrients, its organic C content fitted within the range of 0.94-0.97%, and its pH was pH = 6.5. Hence, in each year of the study, the fields intended for the experiment were homogeneous in terms of the chemical composition of the soil, which ensured objective conditions for determining the effects of individual farming systems on changes in soil quality (Table 1).

Table 1. Soil characteristics prior to the experiment establishment in 2019-2021.

Specification	Organic system	Integrated system	Conventional system
Organic C (%)	0.95-0.97	0.94-0.96	0.95-0.96
Total N (%)	0.08-0.09	0.08-0.09	0.08-0.09
P (mg kg^{-1})	128.2-129.3	127.4-129.1	127.5-128.8
K (mg kg^{-1})	215.4-217.6	217.5-218.1	216.7-218.5
Mg (mg kg^{-1})	68.8-69.2	68.7-69.1	68.6-68.9
Soil pH (1M KCl)	6.5	6.5	6.5

The following factors were considered in the study: 1. Farming system: organic – without chemical plant protection nor NPK fertilization, conventional – with the use of the 100% recommended doses of pesticides and NPK mineral fertilizers, and integrated – with the use of reduced (by 50%) recommended doses of pesticides and mineral fertilizers. 2. Irrigation of crops: control treatment – no irrigation, double irrigation (at the 2-3 leaf stage and at the shooting stage), and multiple irrigation resulting from monitoring the drought status in the arable field. The water content of the soil was monitored throughout the growing season of wheat based on readings from moisture sensors mounted at two depth levels of the soil (0-15 and 15-20 cm), which enabled establishing the actual water content of the soil and replenishing water deficits by means of irrigation. A tubular irrigation system (drip irrigation) was used to irrigate the wheat crops, ensuring even distribution of water across the experimental plots. The readings of soil moisture sensors did not differ significantly due to similar amounts of precipitation in the individual growing seasons. Hence, similar volumes of water were used for irrigation in 2020-2022,

i.e.,

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a. double irrigation:

1. 250,000 L water/ ha (2020); 240,000 L water/ ha (2021); 260,000 L water/ ha (2022)
2. 200,000 L water/ ha (2020); 190,000 L water/ ha (2021); 210,000 L water/ ha (2022)

The total volume of water used was: 450,000 L water/ha (2020); 430,000 L water/ha (2021); 470,000 L water/ha (2022).

b. multiple irrigation:

1. 250,000 L water/ ha (2020); 230,000 L water/ ha (2021); 250,000 L water/ ha (2022)
2. 100,000 L water/ ha (2020); 110,000 L water/ ha (2021); 110,000 L water/ ha (2022)
3. 200,000 L water/ ha (2020); 190,000 L water/ ha (2021); 210,000 L water/ ha (2022)
4. 250,000 L water/ ha (2020); 240,000 L water/ ha (2021); 260,000 L water/ ha (2022)
5. 150,000 L water/ha (2020); 140,000 L water/ ha (2021); 160,000 L water/ ha (2022)

The total volume of water used was**:** 950,000 L water/ha (2020); 910,000 L water/ha (2021); 990,000 L water/ha (2022).

Mineral fertilization applied in tin the conventional system (in kg ha^{-1}) included the following NPK doses: N=80, P=60, and K=100, whereas in the integrated system it included the following NPK doses: N =40, P=20, K=30, and Mg=50. Mineral fertilization with N was applied in the form of 34% ammonium nitrate, 17% nitrogen (N) in its nitrate form (NO_3), and 17% nitrogen (N) in its ammonium form (NH_4), whereas P was applied in the form of 46% granulated triple superphosphate (in the P_2O_5 form), while K was applied in the form of 50% potassium salt (in K_2O form). In the organic system, no fertilization allowed in this system was applied, which enabled precise capturing of the effect of full (100%) and reduced (50%) doses of NPK mineral fertilizers (in the conventional and integrated system) on the soil quality of the test plant (spring wheat).

Wheat was cultivated in the conventional (ploughing) soil tillage system. The following plant protection treatments were applied in the conventional system (100% of recommended doses): Omnix 025 FS seed dressing (a.s. fludioxonil) − 200 mL 100 kg^{-1} of grain; Chwastox Trio 390 SL herbicide (a.s. MCPA+ mecoprop-P+ dicamba) at 3 L ha^{-1}, Puma Universal 69 EW herbicide (a.s. fenoxaprop-P-ethyl) at 1 L ha^{-1}, Glora 633 EC fungicide (a.s. fenpropidin+ prochloraz) at 1 L ha^{-1}, and Decis Mega 50 EW insecticide (a.s. deltamethrin) at 1 L ha^{-1}.

Treatments applied in the integrated system entailed 50% recommended doses of plant protection agents administered in the same terms as in the conventional system., i.e.: mechanical weed eradication was performed twice in all farming systems – before the emergence and at the onset of tillering of wheat. In each year of the experiment, wheat was harvested in the second decade of August.

2.2. Analyses of Soil

In order to determine the coupled effect of farming systems and irrigation strategies on the physicochemical and biological properties and enzyme activity of the soil under wheat crops, soil samples were collected from a layer of 0–25 cm and analyzed for the selected soil condition parameters. The soil samples were collected using a soil sampling tube from an area of 0.20 m^2 of each plot, in three replicates for each experimental treatment, 1 day after spring wheat harvest.

2.3. Chemical Properties of Soil

The following parameters were determined:

C organic content was determined using a carbon analyzer (SDCHN435), total nitrogen content was analyzed by the Kjeldahl method, the content of available forms of phosphorus and potassium was assayed with the Egner-Riehm method, magnesium content was analyzed by means of atomic absorption spectrometry (AAS), and micronutrient content (B, Cu, Mn, Zn) by flame photometry; finally, the total sorption capacity (cmol (+) kg^{-1}) of the soil was determined with the Kappen's method.

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2.4. Physical Properties of Soil

Soil moisture content and bulk density as well as total and capillary porosity in the layers of 5–10 and 15–20 cm were determined in two replicates per plot using a 100 mL cylinder. Soil total porosity was determined by the pycnometric method. Soil capillary porosity was established by capillary infiltration method. Soil compaction was examined using an electronic probe (penetrometer) in the 0–30 cm layer, every 5 cm in five replicates per plot.

2.5. Enzymatic Activity of Soil

The enzymatic activity of the soil was established based on determinations of activities of five enzymes, i.e., dehydrogenase with the Thalmann method [21], acid phosphatase and alkaline phosphatase with the Tabatabai and Bremner method [22], urease with the Zantua and Bremner method [23], and protease with the Ladd and Butler method [24].

Dehydrogenase activity was determined in 5 g soil samples using 2,3,5-triphenyl tetrazolium chloride as a substrate, after incubation in 0.2 M trishydroxymethyl-aminomethane-HCl buffer (Tris-HCl pH 7.4) for 48 h, at 30°C. Enzyme activity was expressed as mg TPF kg^{-1} d.m. of soil d^{-1}.

Acid phosphatase and alkaline phosphatase activities were determined in 1 g soil samples using p-nitrophenyl phosphatedisodium as a substrate, after incubation in a modified universal buffer (acid phosphatase: pH 6.5; alkaline phosphatase: pH 11) for 1 h, at 37°C. Enzyme activity was expressed as mg PNP kg^{-1} d.m. of soil h^{-1}.

Urease activity was determined in 10 g soil samples using an urea solution as a substrate, after incubation for 18h, at 37°C. Enzyme activity was expressed as a unit: mg N-NH_4 kg^{-1} d.m. of soil 18 h^{-1}.

Protease activity was determined in 2 g soil samples using casein as a substrate, after incubation in 0.2 M Tris-HCl buffer (pH 8.0) for 1 h, at 50°C. Enzyme activity was expressed as mg tyrosine kg^{-1} d.m. of soil h^{-1}.

2.6. Biological Properties of Soil

The counts of useful fungi *Trichoderma* ssp. and parasitic fungi *Fusarium* ssp. were determined with the plate method according to the procedure described by Foght and Aislabie [25]. The total count of fungi was determined after 3 days of incubation at a temperature of 270°C, on a Martin's culture medium [26], with antibiotics added the reduce bacterial contamination [27]. To this end, 50 mg of streptomycin and 4 mL of a 1% Bengal rose solution were added to the culture medium before it had been spread onto plates. Once the total count of fungi had been determined, they were isolated from the plates on the same culture media, and the grown colonies were purified to pure cultures. The isolated fungi were identified based on their morphological traits according to the key posited by Domsch et al. [28].

The total number of actinobacteria was determined with the plate method using culture media with the addition of nystatin (50 μg·mL) according to the method by Walllace and Lochhead (29). The material was incubated for 14 days at a temperature of 28°C, and the growing colonies of bacteria cultured on the particular media were counted after 3-5 days using a colony counter [30].

2.7. Statistical Analysis

Statistical analysis of the study results was conducted with Statistica PL 13.3 software (TIBCO Software Inc., Palo Alto, CA, USA). The Tukey's Honestly Significant Difference (HSD) test was deployed to establish the significance of differences between the values, at an adopted significance level of $p \geq 0.05$. Due to a lack of significant differences between subsequent growing seasons (2020-2022), the results presented in tables (Tables 2–7) are mean values of the three-year study period. In addition, standard deviation (SD ±) was provided to all mean values presented in tables.

Table 2. Contents of total nitrogen, phosphorus, potassium, magnesium and organic C in the soil – mean values of the three-year study period.

Farming system	Wheat irrigation	Total N (%)	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	C-organic (%)
Organic	NI	0.06 ±0.004	121.5 ±0.9	201.8 ±1.0	63.5 ±0.4	0.80 ±0.013
	2I	0.07 ±0.002	121.7 ±1.0	203.2 ±1.1	70.1 ±0.4	0.87 ±0.023
	MI	0.09 ±0.002	122.2 ±1.1	209.3 ±1.3	71.3 ±0.6	0.95 ±0.033
Mean		0.07	121.8	204.8	68.3	0.87
Integrated	NI	0.07 ±0.001	124.4 ±1.2	212.2 ±1.4	56.8 ±0.3	0.83 ±0.031
	2I	0.09 ±0.002	125.6 ±0.8	216.3 ±1.4	65.7 ±0.4	0.98 ±0.02
	MI	0.10 ±0.002	126.0 ±0.9	223.1 ±1.5	71.0 ±0.5	1.11 ±0.036
Mean		0.09	125.3	217.2	64.5	0.97
Conventional	NI	0.08 ±0.003	127.1 ±1.2	244.3 ±1.6	52.2 ±0.5	0.77 ±0.014
	2I	0.11 ±0.005	128.3 ±1.4	258.9 ±1.7	60.3 ±0.6	0.80 ±0.022
	MI	0.15 ±0.006	131.4 ±1.3	269.6 ±1.9	70.4 ±0.7	0.91 ±0.037
Mean		0.11	128.9	257.6	61.0	0.83
HSD ($p \geq 0.05$) for farming system (A)		0.016	7.06	12.11	3.67	0.095
HSD ($p \geq 0.05$) for wheat irrigation (B)		0.017	n.s.	14.38	3.79	0.098
HSD ($p \geq 0.05$) for (A × B) interaction		0.023	n.s.	19.37	4.53	0.124

NI – no irrigation, 2I – double irrigation, MI – multiple irrigation, ±SD - standard deviation, n.s.- not significant differences.

Table 3. Contents of boron, copper, manganese, and zinc, and total sorption capacity of the soil under spring wheat crops – mean values of the three-year study period.

Farming system	Wheat irrigation	B (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Total sorption capacity of soil (cmol (+) kg^{-1})
Organic	NI	2.36 ±0.04	6.86 ±0.08	201 ±2.7	8.44 ±0.08	33.5 ±0.6
	2I	2.40 ±0.03	6.95 ±0.10	211 ±3.5	8.62 ±0.09	35.7 ±0.8

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	MI	2.56 ±0.05	7.27 ±0.11	218 ±4.2	8.91 ±0.08	36.9 ±1.0
Mean		2.44	7.03	210	8.66	35.3
Integrated	NI	2.30 ±0.04	6.64 ±0.08	184 ±2.5	8.14 ±0.04	33.4 ±0.9
	2I	2.33 ±0.04	6.72 ±0.09	188 ±2.2	8.26 ±0.05	38.0 ±1.1
	MI	2.38 ±0.05	6.79 ±0.07	193 ±3.0	8.40 ±0.06	42.0 ±1.1
Mean		2.34	6.72	188	8.27	37.8
Conventional	NI	2.09 ±0.02	6.41 ±0.06	168 ±2.1	8.01 ±0.05	34.3 ±0.8
	2I	2.11 ±0.03	6.47 ±0.07	171 ±2.2	8.09 ±0.06	35.6 ±0.7
	MI	2.16 ±0.03	6.54 ±0.08	177 ±2.4	8.11 ±0.07	39.3 ±1.2
Mean		2.12	6.47	172	8.07	36.4
HSD (p≥0.05) for farming system (A)		0.199	0.515	14.4	0.563	2.46
HSD (p≥0.05) for wheat irrigation (B)		n.s.	n.s.	8.9	0.461	2.17
HSD (p≥0.05) for interaction (A × B)		0.154	n.s.	n.s.	n.s.	2.59

NI – no irrigation, 2I – double irrigation, MI – multiple irrigation, ± SD - standard deviation, n.s.- not significant differences.

Table 4. Moisture content and total and capillary porosity of the soil – mean values of the three-year study period.

Farming system	Wheat irrigation	Soil moisture content (%)		Total soil porosity (%) in the 0-25 cm layer	Capillary soil porosity (%) in the 0-25 cm layer
		0-20 cm	20-35 cm		
Organic	NI	5.62 ±0.016	5.32 ±0.014	42.2 ±1.06	34.0 ±0.62
	2I	14.87 ±0.028	16.21 ±0.030	41.8 ±1.04	33.8 ±0.58
	MI	15.56 ±0.034	19.32 ±0.039	41.1 ±1.01	33.0 ±0.54
Mean		12.01	13.61	41.7	33.6
Integrated	NI	5.43 ±0.018	5.15 ±0.015	40.6 ±0.94	31.3 ±0.49
	2I	14.65 ±0.037	16.05 ±0.039	39.7 ±0.97	30.7 ±0.47
	MI	15.17 ±0.041	18.81 ±0.055	38.7 ±1.02	30.4 ±0.38
Mean		11.75	13.33	39.7	30.8
Conventional	NI	5.24 ±0.028	5.08 ±0.019	38.2 ±1.09	30.9 ±0.40

	2I	14.10 ±0.033	15.90 ±0.038	37.5 ±1.11	30.6 ±0.35
	MI	14.98 ±0.041	17.79 ±0.052	36.5 ±1.10	30.0 ±0.29
Mean		11.44	12.92	37.4	30.5
HSD (p≥0.05) for farming system (A)		n.s.	0.685	2.28	1.86
HSD (p≥0.05) for wheat irrigation (B)		0.865	0.987	n.s.	n.s.
HSD (p≥0.05) for interaction (A × B)		n.s.	n.s.	n.s.	n.s.

NI – no irrigation, 2I – double irrigation, MI – multiple irrigation, ± SD - standard deviation, n.s.- not significant differences.

Table 5. Density and compaction of the soil under spring wheat crops – mean values of the three-year study period.

Farming system	Wheat irrigation	Soil density (g cm^{-3}) in the 0-25 cm layer	Soil compaction (MPa) in the 0-25 cm layer
Organic	NI	1.41 ±0.014	1.51 ±0.017
	2I	1.58 ±0.018	1.67 ±0.022
	MI	1.64 ±0.026	1.97 ±0.032
Mean		1.54	1.72
Integrated	NI	1.46 ±0.013	1.54 ±0.019
	2I	1.54 ±0.022	1.75 ±0.025
	MI	1.65 ±0.024	1.95 ±0.027
Mean		1.55	1.75
Conventional	NI	1.51 ±0.016	1.59 ±0.019
	2I	1.61 ±0.019	1.88 ±0.032
	MI	1.65 ±0.021	2.09 ±0.034
Mean		1.59	1.85
HSD (p≥0.05) for farming system (A)		n.s.	0.096
HSD (p≥0.05) for wheat irrigation (B)		0.095	0.142
HSD (p≥0.05) for interaction (A × B)		n.s.	0.104

NI – no irrigation, 2I – double irrigation, MI – multiple irrigation, ± SD - standard deviation, n.s.- not significant differences.

Table 6. Enzymatic activity of the soil under spring wheat crops – mean values of the three-year study period.

Farming system	Wheat irrigation	Dehydrogenase (mg TPF kg^{-1} d.m.)	Acid phosphatase (mg PNP kg^{-1} d.m.)	Alkaline phosphatase (mg PNP kg^{-1} d.m.)	Urease (mg $N\text{-}NH_4$ kg^{-1} d.m.)	Protease (mg tyrosine kg^{-1} d.m.)
Organic	NI	2.07 ±0.029	61.07 ±1.63	73.64 ±2.19	35.32 ±1.17	12.14 ±0.08

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	2I	2.49 ±0.039	69.03 ±1.66	75.85 ±2.24	41.03 ±1.45	14.80 ±0.07
	MI	2.60 ±0.052	69.72 ±1.72	78.05 ±2.34	44.00 ±1.52	13.40 ±0.06
Mean		2.42	66.61	75.85	40.12	13.44
Integrated	NI	2.62 ±0.038	64.63 ±1.83	82.88 ±2.19	56.00 ±1.73	16.47 ±0.09
	2I	2.87 ±0.027	71.44 ±1.88	84.10 ±2.27	63.93 ±1.81	19.64 ±0.16
	MI	3.25 ±0.045	75.52 ±1.91	85.10 ±2.32	66.69 ±1.87	17.42 ±0.12
Mean		2.91	70.53	84.03	62.20	17.84
Conventional	NI	1.71 ±0.026	55.18 ±1.71	66.30 ±1.99	24.74 ±1.08	8.63 ±0.06
	2I	2.28 ±0.041	59.63 ±1.75	67.77 ±2.08	36.73 ±1.12	10.74 ±0.08
	MI	2.63 ±0.047	59.72 ±1.78	68.69 ±2.11	31.72 ±1.09	9.23 ±0.07
Mean		2.21	58.18	67.59	31.06	9.53
HSD (p≥0.05) for farming system (A)		0.207	3.901	4.453	6.021	2.146
HSD (p≥0.05) for wheat irrigation (B)		0.241	4.024	4.391	5.442	0.944
HSD (p≥0.05) for interaction (A × B)		0.371	4.045	n.s.	5.981	2.189

NI – no irrigation, 2I – double irrigation, MI – multiple irrigation, ± SD - standard deviation, n.s.- not significant differences.

Table 7. Counts of beneficial and pathogenic fungi and actinobacteria in the soil under spring wheat crops – mean values of the three-year study period.

Farming system	Wheat irrigation	Count of beneficial fungi (*Trichoderma* ssp.) in 1 g of soil from 0-25 cm layer	Count of pathogenic fungi (*Fusarium* ssp.) in 1 g of soil from 0-25 cm layer	Count of actinobacteria in 1 g of soil from 0-25 cm layer
Organic	NI	17,142 ±89	10,017 ±52	47,495 ±121
	2I	19,234 ±94	9,162 ±49	48,377 ±129
	MI	20,144 ±99	9,058 ±38	50,289 ±135
Mean		18,840	9,412	48,720
Integrated	NI	16,393 ±84	11,237 ±59	38,165 ±104
	2I	18,344 ±91	10,350 ±51	38,790 ±108
	MI	19,424 ±78	10,152 ±55	39,254 ±112
Mean		18,054	10,580	38,736
Conventional	NI	14,205 ±69	12,071 ±62	29,615 ±86
	2I	15,368 ±75	11,710 ±58	31,316 ±92

MI	16,337 ±81	10,986 ±54	33,452 ±97
Mean	15,303	11,589	31,461
HSD (p≥0.05) for farming system (A)	975.4	710.6	1,712.4
HSD (p≥0.05) for wheat irrigation (B)	961.5	709.4	1,653.3
HSD (p≥0.05) for interaction (A × B)	1,144.2	n.s.	1,699.2

NI – no irrigation, 2I – double irrigation, MI – multiple irrigation, ± SD - standard deviation, n.s.- not significant differences.

3. Results

3.1. Chemical Properties of Soil

The total nitrogen content of the soil under spring wheat crops was significantly affected by both experimental factors and their interaction. Regardless of irrigation level, the highest total N content of the soil was determined under conditions of the conventional farming system – 0.11% on average, i.e., being by 0.04 percentage points (p.p.) higher than in the organic system and by 0.02 p.p. higher than in the integrated system. In each farming system, the multiple irrigation of wheat crops contributed to the highest content of total nitrogen in the soil, compared to the control treatment without irrigation, whereas in the case of the conventional and organic systems – also compared to the double irrigation. Significantly the highest total N content (0.15%) was determined under conditions of the conventional system × multiple irrigation interaction (Table 2).

The content of phosphorus in the soil depended on the farming system, and reached 128.9 mg kg^{-1} in the conventional system, thus being ca. 6% higher compared to that determined in the organic system. In the integrated system, the phosphorus content of the soil showed only an ascending trend compared to the organic system. Irrigation level had no statistically significant effect on P content of the soil, only a tendency for the highest phosphorus content was noted in each farming system upon multiple irrigation (Table 2).

Phosphorus content of the soil differed significantly between the farming systems. Under conventional system conditions, it reached 257.6 mg kg^{-1} on average, thus being ca. 16% higher than in the integrated system and by as much as ca. 21% than in the organic system. Worthy of notice is also that the content of K in the soil from the integrated system was significantly higher than in the soil from the organic system – by ca. 6% on average. Wheat crop irrigation (double or multiple) elicited a statistically significant effect on potassium content of the soil only in the conventional system – with a ca. 6% higher potassium content determined upon double irrigation and its ca. 10% higher content noted under conditions of multiple irrigation, compared to the control without irrigation. Among all experimental treatments, significantly the highest content of potassium in the soil (reaching 269.6 mg kg^{-1}), was recorded under conditions of the conventional system × multiple irrigation interaction (Table 2).

Different correlations were observed between the farming systems and magnesium (Mg) content of the soil. The most beneficial in this respect turned out to be the organic system, where the mean Mg content of the soil was at 68.3 mg kg^{-1}, being nearly 6% higher than in the integrated system and ca. 11% higher than in the conventional system. Irrespective of the farming system, no irrigation of wheat crops resulted in a significantly lower content of Mg in the soil compared to both multiple and double irrigation. Significantly the lowest Mg content of the soil (barely 52.2 mg kg^{-1}) was determined under conditions of the conventional system × no irrigation interaction (Table 2).

The integrated system had the most beneficial effect on C organic content of the soil under spring wheat, which reached 0.97% on average and was significantly higher compared to the organic and conventional systems (by ca. 11% and ca. 15%, respectively). Irrespective of the farming system, the

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multiple irrigation had a significant effect on C organic content of the soil compared to the control treatment, by 16% (organic system), 15% (integrated system), and 15% (conventional system). Significantly the highest content of organic carbon in the soil (1.11%) was noted under conditions of the integrated system × multiple irrigation interaction (Table 2).

The content of boron in the soil under spring wheat crops was significantly the lowest in the conventional system, and lower by ca. 10% compared to the integrated system and by ca. 13% compared to the organic system. Crop irrigation treatments had no statistically significant effect on B content of the soil. Only a tendency for its highest content was noted along with irrigation intensification. In turn, a significant effect was demonstrated for the interaction between the organic system and multiple irrigation, where B content of the soil reached 2.56 mg kg^{-1} (Table 3).

The content of copper in the soil was significantly modified only by the farming systems, with its significantly highest content determined in the organic system, compared to the conventional system. The multiple irrigation of spring wheat crops caused only a tendency for a higher B content of the soil, whereas the effect of the double irrigation on its content was even less noticeable (Table 3).

Both experimental factors significantly modified the content of manganese in the soil, which reached 210 mg kg^{-1} in the soil from the organic system and was by ca. 11% and ca. 18% higher than in the soil from integrated and conventional systems, respectively. At the same time, the integrated system contributed to a significant increase in Mn content, compared to the conventional system. The multiple crop irrigation applied in each farming system caused a significant increase in Mn content of the soil, compared to no irrigation strategy (control), and the same effect was observed upon double irrigation applied in the organic system (Table 3).

The content of zinc in the soil under spring wheat crops was the highest in the organic system (8.66 mg kg^{-1} on average). Conditions ensured by this system caused a statistically significant increase in the content of this element compared to the conventional system (by ca. 7%). In turn, Zn content of the soil from the integrated system showed statistically insignificant (intermediate) values compared to the conventional and organic systems. In each farming system, the double irrigation and, particularly, the multiple irrigation of wheat crops contributed to a significant increase in zinc content of the soil, compared to no irrigation strategy (Table 3).

The integrated system promoted the total sorption capacity of the soil, which was by ca. 7% higher, on average, compared to that determined in the organic system. In turn, the total sorption capacity of the soil noted under conditions of the conventional system did not differ significantly when compared to both the integrated and organic system. Considering changes in this parameters under the influence of crop irrigation frequency, its significantly the highest values were noted upon multiple irrigation, compared to no irrigation, but also compared to the double irrigation (in the conventional and integrated systems). Significantly the highest total sorption capacity of the soil (42.0 (cmol (+) kg^{-1}) was determined under conditions of the integrated system × multiple irrigation interaction (Table 3).

3.2. Physical Properties of Soil

Farming systems caused no significant differences in the moisture content of the soil determined in a soil layer of 0-20 cm. Only a tendency was noted for a higher moisture content under conditions of the organic system. The moisture content in this soil layer was highly significantly affected by wheat crop irrigation level. On plots with no irrigation (control), the moisture content of the soil fitted within the range of 5.24–5.62% in all farming systems. In turn, the double irrigation caused a significant increase in the moisture content in this soil layer to 14.10–14.87%, whereas multiple irrigation – to 14.98% in the conventional system, 15.17% in the integrated system and 15.56% in the organic system. Differences determined in the moisture content of this soil layer between the double and multiple irrigation strategies were statistically insignificant (Table 4).

The moisture content analyzed in the deeper soil layer (20-35 cm) was statistically significantly influenced by the farming systems. The highest moisture content, reaching 13.61% on average, was determined in the soil from the organic system. It was higher by ca. 0.28 p.p. from that noted in the soil from the integrated system and significantly higher – by ca. 0.69 p.p. – compared to the soil from the conventional system. Irrigation of wheat crops resulted in a significant increase in the moisture content of the soil from all farming systems compared to the soil from control plots (without irrigation). In the case of the double irrigation, the moisture content increased by ca. 10.82-10.90 p.p., whereas in the case of the multiple irrigation – by ca. 14.00 p.p. in the organic system, 13.66 p.p. in the integrated system, and 12.71 p.p., in the conventional system. Analyses conducted in the 20-35 cm soil layer also demonstrated significant differences in its moisture content between the double and multiple irrigation strategies, reaching on average3.11 p.p. in the organic system, 2.76 p.p. in the integrated system, and 1.89 p.p. in the conventional system (Table 4).

The total porosity of the soil analyzed in its 0-25 cm layer was significantly influenced by the farming system. Its highest value (41.1%) was determined in the soil from the organic system, and slightly lower one (39.7%) in the soil from the integrated system. The total porosity of the soil from the conventional system was significantly lower (by ca. 2.3 p.p.) compared to that noted in the soil from the integrated system and by ca. 4.3 p.p. lower compared to the soil from the organic system. Wheat crop irrigation had no statistically significant effect on the total porosity of the soil. Only a tendency was noted for its lower value along with irrigation intensification (with the lowest total porosity determined under conditions of multiple irrigation) (Table 4).

The correlations observed for the capillary porosity of the soil analyzed in its 0-25 cm layer differed slightly from those noted for the total porosity. Significantly the lowest capillary porosity of the soil was determined under conditions of conventional and integrated systems compared to the organic system (lower by 3.1 p.p. and 2.8 p.p., respectively). The double and, particularly, the multiple irrigation of wheat crops contributed to diminished capillary porosity of the soil; however, differences noted between the irrigation strategies were statistically insignificant (Table 4).

The farming systems caused no significant differences in soil density. Only a tendency was noted for greater soil density under conditions of the conventional system. Different was the case with wheat crop irrigation strategies, where even double irrigation caused a significant increase in soil density (under conditions of organic and conventional systems), compared to the control (no irrigation), while multiple irrigation strategy produced the same effect in all farming systems, where soil density was higher by ca. 14% (organic system), ca. 12% (integrated system), and ca. 9% (conventional system) than in the control (Table 5).

Regardless of wheat crop irrigation, soil compaction determined under conditions of the conventional system (reaching 1.85 MPa on average) was significantly higher compared to that found under conditions of integrated and organic systems (by ca. 5% and ca. 7%, respectively). Even double irrigation of wheat crops caused a significant increase in soil compaction in each farming system, whereas multiple irrigation resulted in significantly greater soil compaction (by ca. 23-24%) not only compared to the control soil (without irrigation) but also compared to the soil from double-irrigated plots (conventional system – soil compaction increase by ca. 10%, integrated system – by ca. 10%, and organic system – by ca. 15%). Significantly the highest soil compaction (2.09 MPa on average) was determined under conditions of the conventional system × multiple irrigation interaction (Table 5).

3.3. Enzymatic Activity and Biological Properties of Soil

Enzymatic activity of the soil under spring wheat crops was found to be significantly affected by the adopted experimental factors (Table 6). All enzymes analyzed in the present study exhibited significantly the highest activities under conditions of the integrated system, compared to the organic system, and particularly compared to the conventional system. An increase in the activity of dehydrogenase determined in the integrated system compared to the organic and conventional systems reached 26% and 32%; that of acid phosphatase – ca. 12% and 23%; that of alkaline phosphatase – ca. 10% and 20%; that of urease – ca. 36% and 100%, and that of protease – ca. 23% and 100%, respectively. The irrigation of spring wheat crops had varied effects on the enzymatic activity of the soil. In the case of dehydrogenase, significantly the most beneficial effect was caused by multiple irrigation (activity increase by ca. 20 -35%), but also by double irrigation (activity increase by ca. 17-25%), compared to the control (no irrigation). In the case of acid phosphatase, multiple irrigation increased its activity compared to the control by ca. 8-13% (conventional and organic system) and 15% (integrated system), whereas double irrigation – by ca. 7% (conventional system) – 12% (integrated and organic system). In turn, differences in the activity of alkaline phosphatase upon the influence of multiple and double irrigation were statistically insignificant. In contrast, effect of multiple irrigation on the activity of these enzymes was statistically significantly positive compared to the control (no irrigation) only in the organic system – enzyme activity increase by ca. 6%. Activities of urease were at similar (statistically insignificant) levels in the soil from plots with multiple and double irrigation, but higher (a significantly positive correlation) compared to the soil from control plots without irrigation, i.e., by ca. 18% (conventional system), 15% (integrated system), and 17% (organic system). Significantly the lowest urease activity was determined under conditions of the conventional system × no irrigation interaction. Protease activity was significantly the highest under conditions of double irrigation in each farming systems compared to both the soil from plots with multiple irrigation (by ca. 10-15%), but most of all compared to the soil from control plots (without irrigation – by ca. 17–20%). The integrated system × multiple irrigation interaction promoted significantly the highest activities of dehydrogenase and acid phosphatase, whereas the integrated system × double irrigation interaction caused statistically highest activity of protease. In turn, the lack of irrigation in the interaction with conventional system contributed to significantly lowest activity of urease (Table 6).

The counts of beneficial fungi in the soil under spring wheat crops were similar under conditions of organic and integrated systems (a statistically insignificant difference) but significantly higher from those determined in the conventional system, i.e., by ca. 19% and ca. 15%, respectively. The counts of the beneficial fungi were significantly modified by irrigation strategies. Generally, significantly the lowest count of beneficial fungi was determined in the soil from plots without irrigation, compared to the plots with double irrigation and, particularly, compared to the plots with multiple irrigation (where the difference reached ca. 15% in all farming treatments). Multiple irrigation applied in the conventional and integrated systems also contributed to a significantly higher number of beneficial fungi compared to double irrigation. Significantly the lowest count of positive fungi was determined under conditions of the conventional system × no irrigation interaction (Table 7).

Significantly the lowest count of pathogenic fungi was determined in the soil from the organic system. In the integrated system, their number was higher by ca. 11%, whereas in the conventional system by ca. 19%. In addition, a statistically significant difference was noted in the count of this fungi (by ca. 8%) between the soil samples from integrated and conventional systems. Intensification of irrigation of spring wheat crops generally contributed to diminished counts of pathogenic fungi in the soil; however, the differences in their numbers determined upon multiple and double irrigation were statistically insignificant. To recapitulate, the no irrigation strategy applied to spring wheat crops increased the count of pathogenic fungi by ca. 9% (conventional system) and 10% (integrated and conventional system), compared to the multiple irrigation approach (Table 7).

The numbers of actinobacteria in the soil under spring wheat crops varied depending on the farming system. Significantly the highest number of actinobacteria was determined in the soil from the organic system, i.e., higher by ca. 21% than in the soil from the integrated system and by ca. 36% than in the soil from the conventional system. Multiple and double irrigation of wheat crops caused significant differences (reaching ca. 5%) in the count of these bacteria in all farming systems except for the integrated one. In turn, no irrigation strategy (control plots) caused a noticeable decrease in the number of actinobacteria in the soil compared to multiple irrigation in the conventional (by ca. 12%) and organic (by ca. 6%) systems. Interestingly, no irrigation in the integrated system caused statistically insignificantly lower number of actinobacteria in the soil (by only 3%) compared to the multiple irrigation strategy. Significantly the highest number of actinobacteria in 1 g of soil under spring wheat crops (48.7×10^3) was under conditions of the organic system × multiple irrigation

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interaction, whereas significantly the lowest one (29.6×10^3) under conditions of the conventional system × no irrigation interaction (Table 7)

4. Discussion

4.1. Chemical Properties of Soil

The results obtained from this field experiment demonstrate that the effects of farming systems on the chemical composition of loess soil under spring wheat crops varied. The conventional system proved to have the most favorable effect on total nitrogen, phosphorus, and potassium contents of the soil. In contrast, the organic and integrated systems produced the highest levels of magnesium and organic carbon. Likewise in the present study, Wang et al. [31] noted a reduction in organic carbon content of the soils under conventionally-grown crops. In turn, Lal [32] emphasized that the organic and integrated systems positively influenced soil organic matter compared to the conventional system. However, results of a study by Maucieri et al. [33] showed that organic farming was not superior over the conventional farming regarding the accumulation of organic matter (organic carbon) in the soil. Other studies also pointed to improved soil quality indicators along with the progressing agro-ecological practices (integrated and organic systems) [34,35]. The findings from these studies also correspond to observations made by other authors [36,37]], who reported a decrease in phosphorus and potassium contents in the soil cultivated in the organic system. Our previous investigations [38,39] demonstrated that the organic system contributed to increased levels of magnesium, boron, copper, manganese, zinc, organic carbon, and total nitrogen in the soil. Moreover, organic farming promoted more favorable soil pH and a higher humus content, significantly improving the total sorption capacity compared to the conventional system [40]. Conversely, the conventional system produced higher phosphorus and potassium levels in the soil. Al-Busaidi et al. [41] found that long-term intensive agronomy (conventional farming) negatively impacted phosphorus content of the soil, leading to its excess accumulation.

Wang et al. [31] emphasized that conventional farming practices, characterized by intensive tillage and a high input of synthetic chemicals, critically depleted soil carbon resources. In contrast, alternative practices, such as reducing doses of agrochemicals and adopting organic systems, were found to enhance soil carbon content. Another study [42] indicated no impact of organic farming on organic carbon levels of the soil.

In the present research, the highest levels of boron, copper, manganese, and zinc were determined in the soil from the organic system, while the lowest ones were assayed in the soil from the conventional system. This relationship was also supported by findings from other studies. Bhanuvally et al. [43] demonstrated that in the case of various crops, the ecological farming improved soil chemical composition by increasing the availability of macro- and microelements and the content of organic carbon in the soil. The dynamics and transformations of microelements (Zn, Cu, Fe, Mn, B, and Mo) in the soil are regulated by various factors, such as pH, electrical conductivity, and organic matter content, which consequently modifies various physicochemical reactions, thereby affecting the availability of microelements. Soil organic matter fosters a reduced environment (a lower redox potential) and increases the availability of cations of microelements in the soil. It fixes more Zn, Cu, B, and Mo compared to Fe and Mn, as the former are less sensitive to redox changes [44].

The results of a study by Wang et al. [45] indicated that appropriate water resource management in the soil, coupled with rational fertilization, significantly increased ammonium nitrogen, phosphorus, and potassium levels, and substantially enhanced soil moisture content. These changes, in turn, facilitate the earlier availability of nutrients in the soil for the cultivated plants. The above findings correspond with the results of the present study, as the most favorable soil chemical composition was noted under irrigation management (multiple irrigations based on soil moisture sensor readings) in the interaction with the integrated farming system. Also, D'Odorico et al. [46] and Slaboch and Malý [47] emphasized that optimizing soil moisture content had a significant impact on ensuring physicochemical parameters of the soil that are beneficial for cultivated crops, particularly

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under conditions of the integrated farming system [48]. In the study by Leogrande et al. [49], the application of crop irrigation significantly increased contents of organic carbon as well as available forms of P, Mg and Na in the soil. In turn, the results of a study by Fadl et al. [20] demonstrated that irrigation led to an 8.00% increase in soil organic matter content and a 7.22% increase in nitrogen resources compared to the control treatment without irrigation.

4.2. Physical Properties of Soil

In the current study, the physical properties of the soil were more closely related to the irrigation strategies applied to the spring wheat crops than to the farming systems adopted. However, the conventional system resulted in a lower soil moisture content and its reduced total and capillary porosity. Woldeyohannis et al. [50] pointed to a correlation between the intensification of cultivation practices typical of the conventional system and the increasing soil density. In turn, Gajda et al. [51] observed that the increase in organic matter content of the soil under organic cultivation led to a decrease in its bulk density. In the present study, a tendency towards higher soil density was noted in the conventional system compared to the organic system, while the compaction of soil under conventionally cultivated wheat was significantly the greatest. Sainju et al. [52] have claimed that soil aggregation (overall and capillary porosity) is associated with agricultural practices that result in a high organic matter content (including organic carbon) and with optimal soil moisture content maintained. This thesis was also supported by the current study findings, as the most favorable values of these soil quality indicators were recorded under multiple irrigation of the wheat crops coupled with their cultivation in the organic system.

Literature works on the subject [53–55] indicate that organic farming improves certain physical properties of soil compared to conventional farming. In particular, it increases the stability of wet soil aggregates, saturated hydraulic conductivity, and water resources available to plants. Also, it generally increases soil porosity, thereby enhancing cumulative water infiltration. However, organic farming exerts either a varied or none effect on soil compaction indicators (i.e., bulk density and compaction), which partially corresponds with the results of the present study.

Previous studies have proved that soil density and compaction are fundamentally associated with its moisture levels. In the absence of precipitation, rational irrigation of crops proves to be an effective method for managing these parameters [56]. An important aspect of the organic system is also the limited use of chemicals. In the conventional system, these chemicals can adversely affect soil structure and reduce its water-holding capacity. Methods deployed in organic farming, such as crop rotation, reduce soil water demand while increasing yields over the long term [57–59].

4.3. Biological Properties and Enzymatic Activity of Soil

Furtak and Gałązka [60] have claimed that organic agriculture positively influences soil quality compared to conventional farming systems. The organic system favorably modifies the structure of soil microbial communities and stimulates soil enzymatic activity. Agronomic practices associated with the organic and integrated systems positively impact the organic carbon content of the soil, which translates into microbial biomass (including the biomass of saprophytic fungi) and soil enzyme activity compared to the conventional system [35,51]. Also, Wang et al. [31] reported that the organic farming significantly increased soil microbial biomass by 63-139% (depending on the year of study), and boosted soil microbial activity by 52-117% compared to the conventional farming. Organic farming was also reported to contribute to reducing the occurrence of *Fusarium oxysporum* in the soil due to a higher organic carbon content [61]. Also, Nannipieri et al. [62] demonstrated that the composition of soil microbial communities was more desirable (dominance of beneficial microorganisms) under conditions of a higher organic carbon content in the soil. This is confirmed by the results of the current study, where the most favorable parameters of beneficial microbial communities were determined in the organic system, followed by the integrated system. Conversely, the soil enzyme activity in this study was highest in the integrated system followed by the organic system. Thus, the conventional system contributed to a significantly lower number of beneficial fungi

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and actinobacteria, while promoting the highest count of pathogenic fungi in the soil. Furthermore, the intensive chemicalization of agriculture resulting from the conventional farming system had adversely affected enzyme activity in the soil under spring wheat crops.

A deficiency of organic and mineral nutrients in the soil can lead to nearly complete inactivity of soil enzymes [63]. In the study by Fließbach et al. [34], the intensification of agricultural practices generally contributed to diminished activities of soil enzymes. The microbial biomass of the soil determined in the integrated system was 25% lower compared to that noted in the organic system. Regarding enzyme activity, dehydrogenase levels were 39-42% lower in the soil from the integrated system compared to the organic system soils. Our previous study [38] demonstrated that analyses of the enzymatic activity of soil in a five-crop rotation showed significantly higher activities of all enzymes tested (particularly of dehydrogenase, protease, and urease) in the organic system compared to the conventional one, regardless of the crop species. It is noteworthy that the high enzymatic activity in the organic and integrated systems was partially due to the influence of plant biomass in crops where pesticides were not used or were applied in limited doses. This corroborates previous findings reported by other authors [40,64–66], and was also confirmed in the present study. The activity of soil enzymes, including in particular dehydrogenases, is dependent on the high organic matter content of the soil, its stratification, and extent of degradation. Additionally, the degradation of organic matter and enzymatic activity are more efficient under good soil moisture and temperature conditions [67,68]. These findings are confirmed by the results of the present study, where the highest enzymatic activity in loess soil was observed as a result of rational irrigation of spring wheat crops in the integrated system (with the highest organic carbon content recorded). Gajda et al. [51] noted that arable soil under organic cultivation exhibited 2-2.5 times greater microbial activity than the soil under conventional cultivation. In turn, Terashima and Mihara [12] who compared organic and conventional systems in terms of the overall soil quality, found the most significant differences in biological properties (microbial communities) and enzymatic activity of the soil, with more beneficial changes observed in the organic system. Lesser differences were noted in soil chemical properties, while the least differences pertained to its physical properties. The current study results confirm these relationships to some extent.

5. Conclusions

The results of this study on the quality of loess soil under spring wheat crops indicate that farming systems exerted varied effects on its chemical, physical and biological properties, as well as its enzymatic activity.

The organic system produced the highest levels of magnesium, boron, copper, manganese, and zinc in the soil. It also contributed to the most favorable biological properties of the soil, such as the highest number of beneficial actinobacteria and fungi, alongside the lowest number of pathogenic fungi. Additionally, it positively affected certain physical properties of the soil, such as its moisture content, density, and porosity.

In turn, the integrated system yielded the highest organic carbon content, the highest sorption capacity, and the highest enzyme activity (including dehydrogenase, acid and alkaline phosphatase, protease, and urease) of the soil. At the same time, it ensured favorable chemical and physical parameters of the soil, as well as its microbiological composition.

In contrast, the conventional system produced the highest levels of total nitrogen, phosphorus, and potassium in the soil. However, its drawbacks included the lowest levels of organic carbon and microelements in the soil, unbeneficial biological parameters, and the weakest enzymatic activity, followed by a deterioration of most physical soil parameters.

Irrigation of spring wheat crops (particularly multiple irrigation) resulted in a noticeable improvement in all assessed soil quality indicators compared to the control plots (without irrigation), regardless of the farming system. This was due to the optimal water supply to the soil ensured based on the readings from soil moisture sensors. Particularly beneficial effects of multiple irrigation on soil quality and health were observed in the interaction with the organic or integrated systems.

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