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Integrated assessment of the impact of conventional and organic farming systems on soil biochemical indicators

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A b s t r a c t. Organic farming is system with a growing interest worldwide. The objective of this paper was an assessment of the after-effects of perennial cultivation of spring barley, oats, and red clover in both conventional and organic systems on the chemical properties, enzymatic activity, and potential biochemical soil fertility index of the soil. The study analyzed the activity of acid phosphatase, alkaline phosphatase, urease and dehydrogenases as well as the potential biochemical soil fertility index of soil and the chemical parameters of soil. Soil material was collected from spring wheat grown after spring barley, oats and red clover, occurring in conventional or organic systems in 2009-2019. It has been shown that, compared to a conventional system, the perennial cultivation of red clover and cereals in the organic farming system has contributed to a significant improvement in the chemical (pH_{KCl} by an average of 8%, total organic carbon – 18%, total nitrogen – 15%, $N\text{-}NH_4^+$ – 34%) and enzymatic (acid phosphatase – 29%, alkaline phosphatase – 67%, urease – 28% and dehydrogenases – 25%) soil quality indicators. The potential biochemical soil fertility index values were also significantly higher in soils in the organic farming system (by an average of 39%).

K e y w o r d s: enzymes activity, cultivation system, red clover, oats, spring barley

1. INTRODUCTION

In the European Union, organic farming is defined by Council Regulation (EC) No 834/2007 of 28 June 2007 (Council Regulation, 2007) as production using natural substances and processes that includes an overall system of farm management and food production that combines best environmental practices, the preservation of natural resources, a high level of biodiversity and the application of high animal welfare standards (Council Regulation, 2007). In practice, this means that plant production in organic systems is carried out without the use of chemical protective treatments (insecticides, herbicides, and fungicides), easily soluble synthetic NPK fertilizers, and synthetic growth regulators (Średnicka-Tober *et al*., 2016). In organic cultivation, natural organic fertilizers, green fertilizers, and varied crop rotation are used, which increase soil fertility. The exclusion of pesticides and chemical (synthetic) fertilizers from the food production process has a positive impact on the condition of the soil environment, groundwater or air (Seufert *et al*., 2012). In addition, organic farms are characterized by a much higher biodiversity of plants, animals, (including pollinators, soil fauna, and birds), and soil microorganisms as well as a greater diversity of landscape compared to conventional farms (Tuck *et al*., 2014). Conventional agriculture (*e.g.* the use of mineral fertilizers, pesticides and high levels of mechanization) may contribute to environmental degradation. This causes, among other things, soil acidification and erosion, greenhouse gas emissions, degradation of soil structure, loss of biodiversity, increase in the content of xenobiotics in the soil and then

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in food (Średnicka-Tober *et al.*, 2016; Fess and Benedito, 2018). Therefore, organic farms are seen as a sustainable alternative to intensive conventional farming systems.

The basis of agriculture, both organic and conventional, is fertile and productive soil. The factors determining a certain state of soil fertility and its yield potential are physical properties (granulometric composition, structure and texture, water conditions, temperature), physicochemical and chemical properties (acidification, salinity, content of primary and secondary minerals, organic matter, abundance in macro- and micro-nutrients), and biochemical and biological properties (species composition of mesofauna, macrofauna, microfauna and soil microorganisms, biomass and biological activity) (Nannipieri *et al.*, 2018). All these factors interact with each other, complementing and influencing the formation of a specific state of soil fertility (Frąc *et al.*, 2018; Piotrowska-Długosz *et al.*, 2021).

An indicator of soil biological activity is, inter alia, the activity of soil enzymes (Nannipieri *et al.*, 2018). Soil enzymes play a key role in soil function, especially in the carbon cycle contained in dead organic matter, the release of nutrients from organic resources, and the decomposition of xenobiotics (Kompała-Bąba *et al.*, 2021). Enzymes are also associated with the multiplication of soil microorganisms, which play a key role in many soil processes, and the provision of basic soil ecosystem services (Alvarez *et al.*, 2018). Indicators based on the activity of soil enzymes provide in-formation on the state (quality) of the natural environment as well as on the nature of its changes (Futa *et al.*, 2020), making them a useful index for the sustainable management of soil and environmental stability (Lemanowicz *et al.*, 2020). Therefore, taking into account various soil parameters determining its fertility, the use of appropriate soil quality indicators is important (Bastida *et al.*, 2008). A complete assessment of soil quality can be obtained by simultaneous testing of the activity of a number of soil enzymes that quickly respond to changes in soil management (Kobierski *et al.*, 2020) in combination with the physicochemical properties and chemical properties of the soil (Bastida *et al.*, 2008; Lemanowicz *et al.*, 2020; Futa *et al.*, 2021; Wesołowska *et al.*, 2022).

Therefore, the research objective was to conduct an integrated assessment of the after-effects of perennial spring barley, oats, and red clover in both conventional and organic systems on the chemical properties, enzymatic activity, and potential biochemical soil fertility index of the soil.

2. MATERIAL AND METHODS

2.1. Study area and field experiment

Field tests were carried out at the Czesławice Experimental Farm (University of Life Sciences in Lublin, Poland, Europe). Experimental plots were established in three repetitions using the split-plot method. The area of one plot was 30 m^2. Field tests were carried out on Haplic Luvisol (LVha) soil. The field experiment covered two agricultural systems (Wesołowska *et al.*, 2022). The traditional system was based on full agricultural technology. However, in the organic system, no mineral fertilizers and pesticides were used. The research was conducted in 2009-2019. Detailed characteristics and methodology of soils can be found in the work of Wesołowska *et al.* (2022).

In the spring of 2020, spring wheat was sown as a test plant to evaluate the soil cultivated over 10 years (2010-2019) in 2 cultivation systems. No fertilizers or pesticides were used in spring wheat cultivation. As a consequence, soil properties have been shaped only by the previous 10 years of cultivation (Wesołowska *et al.*, 2022).

This paper analyzed the effects of spring barley (Sb), oats (O) and red clover (Rc) under conventional (C) and organic (Or) cultivation on soil chemical properties, enzyme activities and indicators of potential biochemical fertility of 10-year cultivated soils.

2.2. Sampling and analyses

Soil samples for analysis were collected in August 2020 from plots intended for the cultivation of spring barley, oats and red clover in a conventional and organic system. The analyzed soil sample was the average of 10 samples taken from each plot. Soil samples for biochemical analyzes were collected and stored in accordance with the ISO 18400 standard. The research covered soil parameters that determine the basic elements of their fertility and are directly related to maintaining the stability and integrity of the soil organic agroecosystem.

The pH_{KCl} value was determined using the potentiometric method in a KCl solution with a concentration of 1 mol dm^{-3} (1:2.5) (International Organization for Standardization, 2005). Total organic carbon (TOC) content was determined by burning soil samples using a TOC-VCSH apparatus with an SSM-5000A module (Shimadzu Corp.; Kyoto, Japan) (International Organization for Standardization, 1998a). Total nitrogen (TN) content was determined by the modified Kjeldahl method using a Kjeltech TM 8100 distillation unit (Foss; Hillerød, Denmark) (International Organization for Standardization, 1998b). The content of ammonium nitrogen ($N\text{-}NH_4^+$) and nitrate nitrogen ($N\text{-}NO_3^-$) was determined according to the ISO 14255 standard (International Organization for Standardization, 1998c).

We determined the activity of four soil enzymes, *i.e.* alkaline phosphatase, acid phosphatase, urease and dehydrogenases. The activity of alkaline phosphatase (APhal) and acid phosphatase (APhac) was determined by the Tabatabai and Bremner method (1969), urease (AU) by the Zantua and Bremner method (1975), and dehydrogenases (ADh) by the Thalmann method (1968). Using a CECIL CE 2011 spectrophotometer (Cecil Instruments), enzyme activity was determined colorimetrically.

In addition, the potential biochemical soil fertility index (M) was calculated (Wyszkowska and Wyszkowski, 2003; Kalembasa and Symanowicz, 2012) based on the activity of urease (AU), dehydrogenases (ADh), alkaline phosphatase (APhal) and acid phosphatase (APhac), and organic carbon content (TOC) following the formula:

$$M = (AU\ 10^{-1} + ADh + APhal + APhac)\ TOC.$$

In this paper, the M index has been modified as TOC in g kg^{-1} instead of % as proposed by Wyszkowska and Wyszkowski (2003).

2.3. Statistical analysis

The statistical analysis was performed using a Microsoft Office Excel 2010 spreadsheet and Statistica 14.1 PL. Statistical assessment of the variability of the results was performed using the one-way analysis of variance method. The significance of differences between mean values was verified based on Tukey's HSD post-hoc test at a significance level of $p \leq 0.05$. For the selected parameters, the Pearson correlation coefficient was calculated, which is a statistical measure describing the linear relationship between two variables. The significance level was set at $p < 0.05$. The overall similarity of individual parameters was determined using Ward's cluster analysis. Principal component analysis (PCA) was used to interpret the relationship between the cultivation system, plant species and the properties of the tested soil.

3. RESULTS

The obtained results indicate that the chemical and biochemical properties and potential biochemical soil fertility index (M) of the studied cultivated soil were differentiated depending on the cultivation system (conventional and organic) and the crop species (spring barley, oats, red clover) (Table 1).

3.1. pH_{KCl} of the tested soils

The monitored soils were slightly acidic, with pH_{KCl} values ranging from 5.65 to 6.35 (Table 1). The studies showed pH_{KCl} values of soil grown in an organic system to be statistically significantly higher compared to conventional system (by an average of 8%), regardless of plant species. Analyzing the impact of individual plant species on the pH of the soil environment, it was found that the soils from under the spring barley were characterized by the lowest pH_{KCl}, and the highest pH_{KCl} was found in soils and from under the red clover. The differences shown were statistically significant (Table 1).

3.2. Content of total organic carbon (TOC) and total nitrogen (TN) and the TOC/TN ratio in the tested soils

The amount TOC and TN in the soils of the tested plots ranged from 7.03 to 12.05 g TOC kg^{-1} and from 0.83 to 1.25 g TN kg^{-1} (Table 1). Regardless of the crop species, it was observed that soils grown in the organic system were statistically significantly higher in TOC and TN compared to conventional cultivation (on average by 18 and 15%). When assessing the impact of individual plant species on the amount of TOC and TN in the soil of the tested plots, the lowest content of these components was found in the soil of plots with spring barley cultivation, and the highest in the soil with red clover cultivation. The differences shown were generally statistically significant (Table 1). The TOC/TN ratio of the soil was related to the species of the cultivated plant. The soils of spring barley and oat plots were characterized by a narrower TOC/TN ratio than the soil of red clover plots. The cultivation system had a varied impact on the TOC/TN ratio values in the soils of the research plots. In soils under the cultivation of spring barley in the organic system, statistically significantly higher TOC/TN values were recorded in comparison to the conventional system. The opposite tendency was observed in the soil of plots planted with red clover. The cultivation system did not significantly affect the average TOC/TN values in oat-grown soils (Table 1).

Based on TOC and TN, Ward's cluster analysis was used to demonstrate similarities between the studied objects. The first cluster included one case (CSb), the second two (OrSb, CO), and the third three (CRc, OrO, OrRc) (Fig. 1).

Table 1. pH_{KCl} and total organic carbon (TOC) content, and total nitrogen (TN) and TOC/TN ratio in the soil from the test sites

Crop plant	Farming system	pH_{KCl}	TOC (g kg^{-1})	TN (g kg^{-1})	TOC/TN
Spring barley	Conventional (CSb)	$5.65{\pm}0.01^{a}$	$7.03{\pm}0.05^{a}$	$0.83{\pm}0.01^{a}$	$8.43{\pm}0.16^{a}$
	Organic (OrSb)	$6.18{\pm}0.01^{d}$	$9.97{\pm}0.06^{c}$	$1.05{\pm}0.01^{b}$	$9.50{\pm}0.08^{cd}$
Oats	Conventional (CO)	$5.73{\pm}0.02^{b}$	$9.30{\pm}0.04^{b}$	$1.03{\pm}0.01^{b}$	$9.10{\pm}0.18^{b}$
	Organic (OrO)	$6.32{\pm}0.02^{e}$	$10.62{\pm}0.09^{d}$	$1.16{\pm}0.03^{c}$	$9.22{\pm}0.18^{bc}$
Red clover	Conventional (CRc)	$5.79{\pm}0.01^{c}$	$11.62{\pm}0.08^{e}$	$1.15{\pm}0.02^{c}$	$10.14{\pm}0.20^{e}$
	Organic (OrRc)	$6.35{\pm}0.04^{e}$	$12.05{\pm}0.03^{f}$	$1.25{\pm}0.01^{d}$	$9.63{\pm}0.06^{d}$

a-f – various indicators show a significant difference at $p \leq 0.05$.

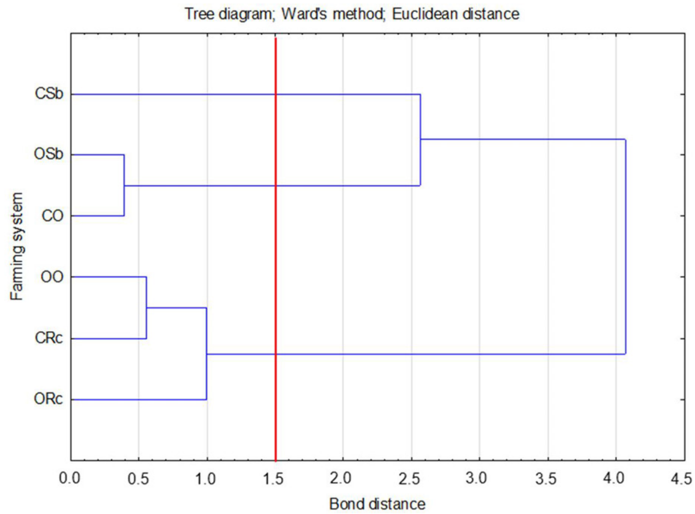

Fig. 1. Ward's dendrogram for TOC and TN.

It was shown that the greatest similarity occurred in plots with spring barley in the organic system (OrSb) and oats in the conventional CO system (Fig. 1).

3.3. Content of ammonium nitrogen (N-NH_4^+) and nitrate nitrogen (N-NO_3^-) in the tested soils

The value of ammonium nitrogen (N-NH_4^+) and nitrate nitrogen (N-NO_3^-) in the soils of the studied plots ranged from 8.53 to 19.86 mg N-NH_4^+ kg^{-1} and from 51.74 to 71.34 mg N-NO_3^- kg^{-1} (Table 2). Regardless of the crop, it was observed that soils in organic cultivation were characterized by a statistically significantly higher content of ammonium N forms compared to conventional cultivation (by an average of 34%). When assessing the impact of individual crops on the N-NH_4^+ content in the soil, regardless of the cultivation method, the lowest content of this ingredient was found in the soil of plots with spring barley, and the highest in the soil under oat cultivation (Table 2). The demonstrated differences were statistically significant. The soils in the organic system were characterized by a statistically significantly lower content of nitrates in the form of N compared to conventional cultivation (by an average of 12%), regardless of the crop species. However, when assessing the influence of crop plants on the N-NO_3^- content in the soils of the plots, it was found that the soil from oat cultivation had the lowest content of this ingredient, and the soil from oat cultivation had the highest content of red clover (Table 2).

3.4. Enzymatic activity of the tested soils

The activity of APhac, APhal, AU and ADh depended on the cultivation system and plant species (Table 3). It was shown that regardless of the crop species, the activity of most enzymes in organic soils was statistically higher than in soil for conventional crops (on average by 29, 67, 28, and 25%). The opposite tendency was observed only in the case of urease activity in the soil of red clover plots. It was shown that the lowest enzymatic activity was observed in plots with spring barley. Higher activity of dehydrogenases, urease and alkaline phosphatase was found in the soil under red clover cultivation. The highest APhac activity was recorded in oat soil (Table 3).

Table 2. Content of ammonium nitrogen (N-NH_4^+) and nitrate nitrogen (N-NO_3^-) in the soils of the tested objects

Crop plant	Farming system	N-NH_4^+	N-NO_3^-
		(mg kg^{-1})	
Spring barley	Conventional (CSb)	8.53 ± 0.11^{a}	69.43 ± 1.33^{d}
	Organic (OrSb)	10.67 ± 0.42^{b}	58.40 ± 4.42^{b}
Oats	Conventional (CO)	14.87 ± 0.07^{d}	66.63 ± 2.75^{cd}
	Organic (OrO)	19.86 ± 0.43^{f}	51.74 ± 2.25^{a}
Red clover	Conventional (CRc)	12.64 ± 0.09^{c}	71.34 ± 1.29^{d}
	Organic (OrRc)	17.77 ± 0.81^{e}	63.86 ± 1.55^{c}

a-f – various indicators show a significant difference at $p \leq 0.05$.

Table 3. Soil enzymatic activities and potential biochemical soil fertility index

Crop plant	Farming system	ADh	AU	APhac	APhal	M
Spring barley	Conventional (CSb)	13.05±0.10[a]	9.82±0.14[a]	46.81±0.88[a]	16.20±0.05[a]	541. 25±0.72[a]
	Organic (OrSb)	15.14±0.34[b]	12.12±0.09[b]	56.37±0.67[b]	35.62±0.67[d]	1079.69±3.88[b]
Oats	Conventional (CO)	13.35±0.36[a]	9.73±0.18[a]	71.25±0.40[c]	22.23±0.28[b]	1064.56±5.26[b]
	Organic (OrO)	20.62±0.29[d]	15.64±0.17[e]	91.93±3.15[e]	32.84±4.50[cd]	1588. 62±4.33[c]
Red clover	Conventional (CRc)	19.43±0.17[c]	12.97±0.14[d]	58.39±0.79[b]	29.61±0.58[c]	1191.27±4.74[b]
	Organic (OrRc)	21.51±0.37[e]	12.42±0.17[c]	79.23±0.74[d]	43.46±0.52[e]	1749.21±1.81[c]

a-e – various indicators show a significant difference at $p \leq 0.05$.

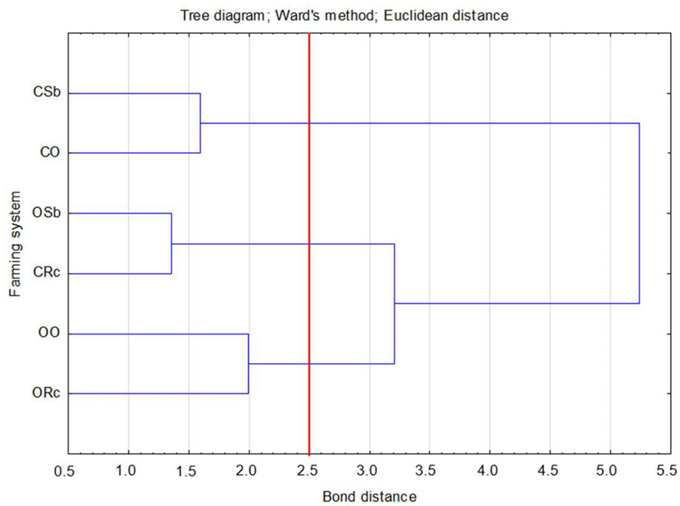

Fig. 2. Ward's dendrogram for APhac, APhal, AU, ADh.

Figure 2 shows a tree dendrogram based on APhac, APhal, AU, ADh. Each of the three outbreaks consisted of two cases: the first (OrSb and CRc), the second (CSb and CO), and the third (OrO and OrRc). It was found that the greatest similarities were observed in plots with spring barley in the organic system (OrSb) and red clover in the conventional system (CRc) (Fig. 2).

3.5. Potential biochemical soil fertility index (M)

In this paper, a synthetic indicator – called potential biochemical soil fertility index (M) – was calculated, expressing the relationship between soil enzyme activity and soil fertility. The values of the M indicator were within 541.25 and 1749.21 (Table 3). As with most of the parameters described above, M values were statistically significantly higher in organic soils compared to the conventional system (by an average of 39%), regardless of crop species. In turn, analyzing the influence of the plant species on the potential biochemical soil fertility index, it was shown that the lowest M values were recorded in soils under spring barley cultivation, and the highest in soils under red clover cultivation (Table 3).

3.6. Principal component analysis (PCA) of the soil properties

Figure 3 shows the results of principal component analysis (PCA). Factors 1 and 2 explain a total of 84.67% of the variance in the analyzed soil parameters. Factor 1 explains 68.97% of the variability of the studied indicators. It is strongly correlated with most parameters except TOC/TN and N-NO_3^-. The strongest correlation with TOC/TN and N-NO_3^- is factor 2, which explains 15.70% of the variability of the tested features.

On the basis of the PCA, it was found that pH_{KCl} and N-NH_4^+ content and APhal and ADh activity are strongly correlated, because the closer the vectors are located, the greater the positive correlation between the variables is. Therefore, if the activity of ADh increases, APhal also increases, and as pH increases, so does the content of

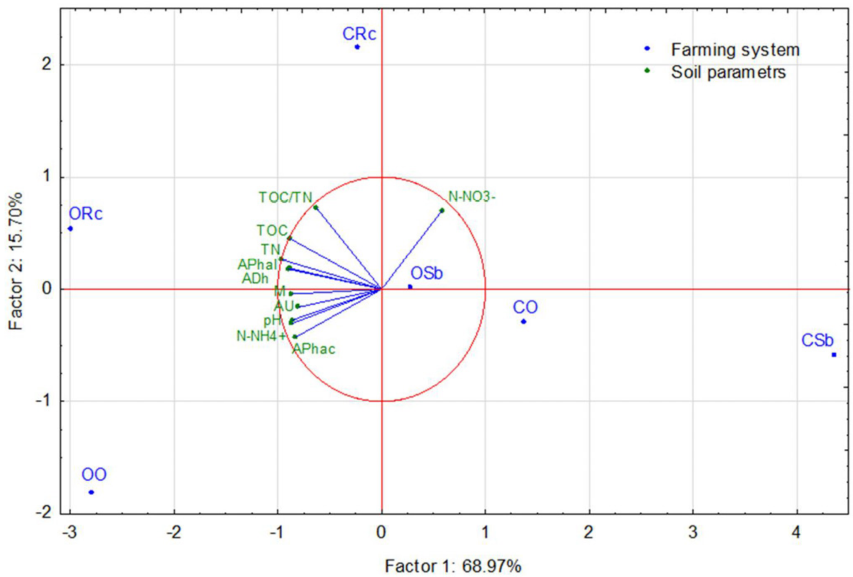

Fig. 3. Biplot. Projection of variables on a plane of the first and second factors.

N-NH_4^+. On the other hand, the content of N-NO_3^- with APhac is negatively correlated with each other; with an increase in N-NO_3^-, the activity of APhac decreases. Taking into account the first factor, it was shown that the OrRc and OrO variants had the highest values of all parameters except N-NO_3^-.

4. DISCUSSION

The obtained research results confirm the thesis that perennial cultivation of spring barley, oats, and red clover in the organic system has a positive effect on the chemical and biochemical parameters of the soil and the fertility index of the soil environment compared to the conventional system. The tillage system has a significant impact on the fertility, quality, and health of the soil (Lal, 2015; Vanegas *et al*., 2018).

In this experiment, many years of cultivation using the organic system contributed to the improvement of the pH_{KCl} of the soil compared to the conventional system. Similar results were obtained by other authors (Bobul'ská *et al*., 2015; Bai *et al*., 2018, Kwiatkowski and Harasim, 2020; Wesołowska *et al*., 2022). According to Bobul'ska *et al*. (2015), this is related to the increase in the content of organic matter in the soil of organic farms, which has a positive effect on the buffer capacity of the soil, thanks to which the soil reaction has not been reduced at sites with organic cultivation. Despite the positive impact of organic farming on soil pH and organic matter content, soil reactions should be constantly tested, as soils are naturally acidified by acidic precipitation and calcium uptake by plants (Bobul'ská *et al*., 2015).

This study shows that organic cultivation of cereals and red clover contributed to a significant improvement in the chemical parameters of loess soil, *i.e.* TOC and TN, compared to the conventional system. Wesołowska *et al*. (2022), Kwiatkowski and Harasim (2020), Vanegas *et al*. (2018), and Wang *et al.* (2011) also reported higher TOC and TN content in soils of fields with organic crops compared to conventional crops. Furthermore, the lower TOC and TN content in conventional sites may be related to practices such as the application of chemical plant protection products. This exerts a selective pressure on microorganisms which, over time, can modify the physicochemical and biological characteristics of the soil (Vanegas *et al*., 2018). It is well known that increasing the TOC and TN content in arable soil is associated with agrotechnics, cultivation systems, crop rotation and crop species (Dębska *et al*., 2012; Szostek *et al*., 2022). This is related to, among other things, the number of crop residues and the agrotechnical requirements of arable crops (Vanegas *et al*., 2018). This is confirmed by our own research, in which the lowest content of TOC and TN was found in soil grown with spring barley, and the highest in soil grown with red clover.

The TOC/TN ratio in the studied soils was dependent on the crop species. In soils cultivated with spring barley and oats, a narrower TOC/TN ratio was found compared to those cultivated with red clover. On the other hand, the farming system did not have a clear impact on the values of this indicator in the analyzed soils. The TOC/TN ratio is an important parameter characterizing the biological activity of the soil, which affects the C and N cycle in agroecosystems and the distribution of crop residues (Dannehl *et al*., 2017).

An increase in the content of organic matter in the soil has a positive effect on increasing the N pool, but a significant part of this component is not easily available to plants and microorganisms. It must be released in absorbable inorganic forms ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$) (de Moraes and Urquiaga, 2011). It has also been found that agrotechnics also affects the availability of nitrogen for plants (Chausali and Saxena, 2021). The rate of nitrogen mineralization is greater in conventional crops than in organic systems. Although organically cultivated soil with high organic matter content and microbial populations appears to have a high capacity to supply nitrogen, resulting in lower mineralization and more nitrogen accumulation in the soil (Bowles *et al*., 2015). Our own long-term research showed that soils cultivated under an organic system had a statistically significantly higher abundance of ammonium nitrogen, compared to conventional cultivation. The opposite results were obtained for nitrate nitrogen.

The physical and chemical properties, as well as the biological and enzymatic activity, of soil affect the quality and health of the soil and its yield potential (Piotrowska-Długosz *et al*., 2021). The obtained results confirm the usefulness of enzymatic activity measurements for the assessment of soils under different methods of cultivation. Soil enzyme activity, which varies depending on the cultivation system, plant species and type of fertilization, is a sensitive indicator of changes in agroecosystems (Piotrowska *et al*., 2012; Błońska *et al*., 2017; Futa *et al*., 2020). The conducted research shows that in the organic system the activity of APhac, APhal, AU and ADh was statistically higher compared to the conventional system. This was due to the increased content of organic matter in the soil. The increased content of organic matter in the soil has a positive effect on an increase in biological activity by providing appropriate substrates for microorganisms (Liu *et al*., 2012; Galindo *et al*., 2020), which, in turn, can stimulate the synthesis of soil enzymes (Nannipieri *et al*., 2018). Our own research showed that, regardless of the cultivation method and plant species, the activity of the tested soil enzymes significantly correlated with the content of TOC ($r = 0.59 – 0.88$), TN ($r = 0.63 – 0.96$), $N\text{-}NH_4^+$ ($r = 0.61 – 0.99$) and pH_{KCl} ($r = 0.62 – 0.76$), (Table 4). This confirms the significant impact of the quantity and quality of organic matter on the activity of the tested enzymes.

Considering the relationship between the crop species and the activity of all the enzymes studied, it was found that the lowest enzymatic activity was detected on the plots with spring barley cultivation. In contrast, the highest activity of APhac, APhal, AU and ADh was recorded in the soil under the cultivation of red clover. Soils under oat cultivation were characterized by the highest activity of acid phosphatase. Crops producing a lot of biomass (red beet, red clover, peas) introduced more organic matter into the soil than cereals. As previously shown, the activity of the tested enzymes strictly depends on the amount of organic matter in the soil. This may be related to the diversity of root secretions, as they are a substrate for microorganisms, especially those inhabiting the rhizosphere (Sawicka *et al*., 2020). The influence of plants on the activity of soil enzymes is correlated with the chemical composition of the plant and its secretions, which may be different for different types, species and even varieties (Błońska *et al*., 2017).

Synthetic indicators expressing the relationship between soil enzyme activity and soil fertility can be used to assess the effect of a cultivation system on the biological activity of the soil environment (Bastida *et al*., 2008). For this purpose, the potential biochemical index of soil fertility (M) was determined (Wyszkowska and Wyszkowski, 2003; Kalembasa and Symanowicz, 2012; Barone *et al*., 2019). This indicator takes into account the activity of the analyzed enzymes and is useful for determining the best treatment in terms of soil fertility (Barone *et al*., 2019). M values were statistically significantly higher in organic soils compared to the conventional system, regardless of the crop species, while the potential biochemical soil fertility index varied depending on the crop species. At the same time, the lowest M values were recorded in soils under spring barley cultivation and the highest in soils under red clover cultivation. In the present study, the potential biochemical index of soil fertility (M) significantly correlated with TOC, TN, $N\text{-}NH_4^+$, and pH_{KCl} (Table 4).

Table 4. Significant correlation coefficients between the activity of the examined enzymes and pH_{KCl} and the total organic carbon (TOC), total nitrogen (TN), and available nitrogen form ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$)

Parameter	pH_{KCl}	TOC	TN	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$
ADh	0.62*	0.59**	0.63**	0.91**	n.s.
AU	0.76**	0.63*	0.70*	0.71*	-0.77**
APhac	0.65*	n.s.	0.72**	0.99**	-0.66*
APhal	0.70*	0.85**	0.88**	0.61*	n.s.
M	0.65*	0.88**	0.96**	0.90**	n.s.

Significant at: *$\alpha = 0.001$, **$\alpha = 0.0001$, n.s. – not significant at $p > 0.05$.

The obtained data show that soil fertility and ecosystem functions depend on organic matter resources. It constitutes an extremely important pool of nutrients in the biogeochemical cycle, and also improves the physical, chemical and biological properties of the soil (Błońska *et al*., 2017; Bai *et al*., 2018; Piotrowska-Długosz *et al*., 2021). Increasing soil TOC in agricultural ecosystems is a promising solution to mitigate climate change (Koishi *et al*., 2020). Organic farming seems to be one of the ways of adapting agricultural production to climate change and sustainable development and provides hope for food security.

5. CONCLUSIONS

The obtained results confirm the usefulness of enzymatic tests for the assessment of soils used in different ways. Based on the results obtained, it was found that the perennial cultivation of red clover and cereals in the organic farming system contributed to a significant improvement in the chemical (pH_{KCl} by an average of 8%, TOC – 18%, TN – 15%, $N\text{-}NH_4^+$ – 34%) and enzymatic (APhac– 29%, APhal – 67%, AU – 28%, and ADh – 25%) compared to a conventional system. This was due to the higher content of organic matter in soils under organic management. The potential biochemical soil fertility index (M) values were also significantly higher in organic soils. It was also found that the species of cultivated plants influence the enzymatic activity and chemical properties of the soil. The highest activity of the tested enzymes and the highest contents of TOC, TN and $N\text{-}NO_3^-$ were found in the soil for the cultivation of red clover. The plots with spring barley were characterized by the lowest enzymatic activity and the lowest content of TOC, TN and $N\text{-}NH_4^+$. Analyzing the biochemical properties of the soil under the cultivation of the test plant, more favorable conditions for growing red clover in an organic system were found compared to a conventional system.

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

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