AGRONOMY SCIENCE
wcześniej – formerly
Annales UMCS sectio E Agricultura

VOL. LXXVII (3) 2022

http://doi.org/10.24326/as.2022.3.3

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Effect of conventional and organic farming on crop yielding and water erosion intensity on sloping farmland

Wpływ rolnictwa konwencjonalnego i ekologicznego na plonowanie roślin uprawnych i intensywność erozji wodnej na terenach urzeźbionych

Summary. The pro-health and pro-environmental assets of organic farming are a reason why this system is now promoted in agriculture. The objective of the research was to determine the effect of conventional and organic crop production (potato, oat, and spring vetch) on the yield, water erosion, losses of NPK nutrients, LAI, infiltration, and fresh mass of earthworms. From 2019 to 2021, a two-factor field experiment was carried out at the Mountain Experimental Station located in Czyrna (Southern Poland). The first factor included farming systems: conventional and organic. The second factor consisted of 3 crops grown with the use of crop rotation: 1. potato with manure; 2. oat; 3. spring vetch. Based on the experiment performed, it was found that the yield of the organically grown crops was on average 18.8% lower compared to that grown conventionally. Under the organic farming system, the mass of sheet wash was on average 6.47% smaller than that under the conventional farming system. As regards the NPK nutrients emitted into the environment, their losses was about 50% lower than that under the conventional system of farming, where there were applied artificially synthesized fertilizers and pesticides.

Key words: conventional and organic farming system, eutrophication potential of agriculture, earthworms, weeds, losses of NPK nutrients

INTRODUCTION

In the EU, the organic farming system is now promoted, *inter alia*, under the European Green Deal [Ziętara and Mirkowska 2021]. In the literature, there are papers dealing with the pro-health advantages of the products achieved under the organic farming system. However, the organic farming is less effective in the terms of economic issues [Klima et al. 2019], the reference research confirmed a direct association to exist between the consumption of organic products and the lower frequency of occurrence of oncologic diseases and obesity [Barański et al. 2021]. On the other side, the effect of organic farming on the environment from the point of view of the quality of water (eutrophication potential), soil (pesticides contaminant, structure), and air (emissions of GHG) is better than conventional farming, especially in the water catchment areas [Pulleman et al. 2003, Gomiero et al. 2011, Lorenz and Lal 2016]. Organic agriculture promotes abundance of microorganisms, earthworms and weeds, sustaining biodiversity in the field, as well as infiltration and immobilization of biogenic molecules in the soil. These processes occur with more intensity in environments when microorganisms and earthworms are abundant (organic farming), because of bigger burrows gallery construct in the arable (or deeper) layers, which enables entering the more soil solution into the soil profile and then partially immobilize them. These processes were described e.g. by Le Bayon and Binet [2001] (Fig. 1).

Only a few papers addressed the impact of organic farming system on water erosion and following environmental consequences. This fact has become an incentive to undertake field research on eutrophication potential of conventional cultivation compared to organic one.

Hypothetically, abundance of earthworms (bigger burrow galleries) and covering the soil surface by weeds in organic agriculture performing on fields with slope will decrease the rates of infiltration and therefore the amount of NPK nutrients emitted into the environment.

The objective of the research was to determine the effect of conventional and organic farming on yielding, intensity water erosion and losses of NPK nutrients in the cultivation of potato, oat, and spring vetch.

MATERIAL AND METHODS

The research subject constituted a two factor field experiment conducted at an Experimental Station, from 2019 to 2021. The Experimental Station in Czyrna is maintained by the University of Agriculture in Kraków (N 49°25'; E 20°58', on altitude 545 m a.s.l.). The grain-size composition of mineral particles of the soil was as follow: 28% of sand, 29% of silt, and 43% of clay particles; therefore, this type of soil was classified according to WRB as a Endoeutric Stagnosol (Siltic, Endoskeletic) [WRB FAO 2015, Kabała et al. 2019]. The field experiment was designed with the use of a split-block method. The first factor of the experiment included two farming systems: conventional and organic. The second factor consisted of 3 crops that were grown in the crop rotation system: 1. potato with cattle manure (33 $t \cdot ha^{-1}$); 2. oat; 3. spring vetch. Under the conventional farming system, artificial mineral fertilizers were applied in accordance with the needs of crops. The following doses of fertilisers ($kg \cdot ha^{-1}$) were applied: for the potatoes: 47.2 of P (phosphorus), 104.0 of K (potassium), 115.0 of N (nitrogen); for the oat: 34.0 of P, 55.6 of K, 72.0 of N; for the spring vetch: 43.6 of P, 83.0 of K, 21.0 of N. Under the conventional farming system, the following active substances of various herbicides were used to control weeds within the crops grown: as for the potato crops: *metribuzin* contained in Sencor 600 SC, in a dose of 1.0 $dm^3 \cdot ha^{-1}$; as for the oat crops: *tribenuron methyl (sulphonylurea)* contained in Granstar, in a dose of 24.0 $g \cdot ha^{-1}$; and as for the spring vetch crops: *bentazone* in Basagran 480 SL, in a dose of 2.0 $dm^3 \cdot ha^{-1}$. Neither mineral fertilisers nor other crop protection products were applied under the organic farming system. To control weeds within the oat crops cultivated organically, the field with oat sown in the spring was harrowed. The field with spring vetch sown in the spring was not harrowed to protect seedlings from getting damaged. Mechanical weed removing techniques were twice applied to the potato crops grown under the organic as well as conventional farming system. Under the organic system, the potato beetle larvae were fought using a SpinTor insecticide (0.20 $dm^3 \cdot ha^{-1}$, *spinosyn A* and *spinosyn D*) authorised for use in organic agriculture. The weed infestation was analysed twice each year. Two weeks after applying herbicides, the first spring sample was performed on 0.25 m^2 surfaces using frame method (n = 4). Based on it, the abundance of weeds was determined. Prior to harvesting oat and spring vetch, the second series was performed with the use of an phytosociological method (n = 4), and this enables to express the overall degree of surface coverage by weeds. During that period, the potatoes were in a 79–81 (BBCH) phase [Hack et al. 1992].

The annually performed experiment was carried out on the small, 22 × 2 m plots (n = 4) lying on a 9% slope [Wischmeier and Smith 1978, Bogunovic et al. 2018]. For each of the crop cultivated, a period to measure the surface runoff began on the day of harvesting forecrop and lasted until the harvest of the follow-up. The surface runoff were measured by Słupik catchers [Smolska 2002]. The catchers were emptied after every rainfall or after a thawing (snow-melt) season to generate surface runoff. The volume of surface runoff was measured, and 1 litre of surface runoff was randomly collected from the suspended load for the purpose of detailed analysis. The mass of sheet wash was determined as soon as 1 litre of surface runoff completely infiltrated through a medium hard filter. The sediment including the filter was dried at 105°C. The filters with the sediment were cooled in a desiccator and weighed on an electronic balance with readability down to 0.0001 g. During the liquid phase of runoffs, the following was determined using colorimetric methods: the content of $N\text{-}NO_3$ using phenoldisulphonic acid and the content of $N\text{-}NH_4$ using a Nessler agent in a Beckman UV/VIS PU 6400 spectrophotometer [Elbanowska et al. 1999]. The contents of phosphorus and potassium were determined as soon as the sample was ten times compressed by an ICP-EAS method in a JY 238 ULTRACE Jobin Yvon Emission apparatus.

The total area of the above-ground parts of crops (Leaf Area Index – LAI, $m^2 \cdot m^{-2}$) was measured every year during the dough stage of oat (BBCH 70–71). During that period, the spring vetch was at a stage of pods maturing (BBCH 81–83), and the potato at a stage of forming berries (BBCH 71–75). LAI was measured using a Sun Scan Canopy Analysis System device (Delta-T Great Britain 2014). The fresh mass of earthworms (after removing the content from their guts) was determined in the third decade of August after the oat and spring vetch harvest completed; here, a method of hand sorting was applied [Kliszcz and Puła 2020]. For the purpose of analysis, soil samples were collected from a 0.25 m^2 surface, where the thickness of topsoil was 18 cm. The results obtained (endogeic and anecic specimens) were converted to 1 m^2. The infiltration was determined in the third decade of August, after the oat and spring vetch harvest; it was determined using a field infiltrometer manufactured by Eijkelkamp (n = 4). The infiltrometer had two cylinders: a small one of a 30 cm diameter and a bigger one of a 54 cm diameter. The bigger cylinder served as a protection; it formed a water ring around the inner cylinder. The cylinders were inserted into the soil to a depth of 15 cm. The two cylinders were filled with water the amount of which equalled a precipitation total of 50 mm. Next, there was measured the time of water penetration in the inner cylinder. All results were depicted as an average on the basis of 3 year research.

During the growing season in 2021, the distribution of precipitation turned out to be most favourable for crop yielding. During the growing season in 2020, in April were water shortages (the temperature line is above the top end of the column representing precipitation; evapotranspiration exceed infiltration), whereas the growing season in 2019 was similar to that in 2020, except that water shortages occurred in June, and May was far above average in terms of the amount of rainfall. However, apart from the weather event on May 23, these rainfalls did not occur at the intensity that could cause increased water erosion. The weather conditions during winters did not cause the freeze-thaw erosion to intensify. The intensity of water erosion usually increased in the spring; it was mainly because the then precipitation was above 20 mm per weather event or snowmelt. The water coming with the precipitation up to 20 mm almost entirely infiltrated deeply into the soil profile (data unpublished).

Statistical analyses

FR-ANALWAR – 4.3 software was utilised to statistically analyse the results through the procedure of ANOVA. The significance of mean differences was tested among the objects using a multiple comparison procedure and a LSD Tuckey test at $\alpha = 0.05$ was applied.

The climate at the site of experiment is of a continental type with a mean annual temperature ranging from 6 to 8°C. During the crop growing season, the sum of monthly precipitations varied and therefore the evapotranspiration varied on this site (Fig. 2). Coefficient α (1°C = 2 mm) was taken from Gaussen [1954].

RESULTS AND DISCUSSION

Plants (potato, oat and spring vetch) have been selected for this area in terms of poor soils, which are often existed in a sloping agricultural landscape. Their cultivation, although sometimes necessary, may carry an environmental risk, especially with regard to the quality of the water catchments formed in this area and then used as a reservoir of drinking water. The results presented below reveal pros and cons for conventional and organic farming in sloped agricultural areas.

Table 1. Yielding of crops cultivated under conventional and organic farming systems

Object	Farming system		
	conventional	organic	$\bar{x}$
Yield units ($t \cdot ha^{-1}$)			
Potato	27.83	22.34	25.08
$LSD_{0.05}$	0.563		
Oat	3.94	3.28	3.61
$LSD_{0.05}$	0.157		
Spring vetch	0.613	0.579	0.596
$LSD_{0.05}$	0.031		
Yield in cereal units ($dt \cdot ha^{-1}$)*			
Potato	183.68	147.46	165.57
Oat	30.72	25.56	28.14
Spring vetch	8.95	8.45	8.70
$\bar{x}$	74.44	60.49	67.47
$LSD_{0.05}$	0.949		1.530

* Conversion factors to be used for converting the yield units to cereal units: potato: 0.66; oat: 0.78; spring vetch: 1.46 [Rozporządzenie Ministra… 2019].

Compared to the organic farming, the three crops yielded higher under the conventional system, namely: the yield of potatoes was 24.6% higher, of oat: 20.1% more, and of spring vetch: 5.9% more (Tab. 1). An average, in cereal units expressed yield was 23.1% higher under the conventional farming than that under the organic farming system (Tab. 1). In previous research, Klima et al. [2019] reported a similar result (+18%) as regards the yield of cereal crops under conventional system. That higher yielding potential of crops grown in crop rotation was a result mainly, of the application of mineral fertilisation and pesticides in the conventional farming system.

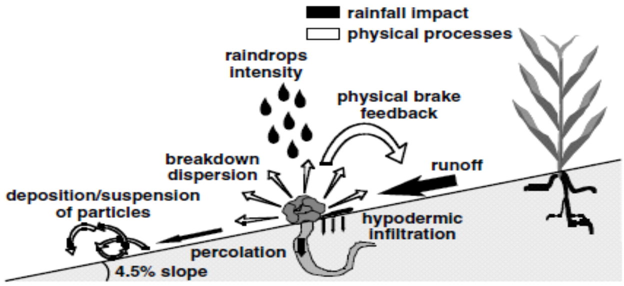


FIGURE 10.1 Interrelationships between earthworm surface casting activity, rainfall, surface runoff, infiltration, and soil erosion. (From Le Bayon, R.C. and F. Binet, 2001, *Pedobiologia*, 45:430–442.)

Fig. 1. The soil erosion process in the occurrence of earthworms and weeds [Le Bayon and Binet 2001]

Although, the synthetically derived substances could restrict the two important agroecosystem actors, i.e. weeds and earthworms, which are responsible largely for reduction of the water erosion intensity on arable lands. Weeds with their high soil surface covering potential (LAI) protect the soil surface against surface splash, and on the other hand, air tunnels made by earthworms in the soil improve water infiltration directly in the soil profile, prevent surface runoff (Fig. 1). The data in Table 2 show, that, under the two farming systems studied, the difference between the LAI averages is not statistically significant. Thereby, the weeds in organic farming have the compensation effect, because they cover soil surface when the crops are smaller. Based on the performed analyses of weed infestation, it was noticed that weeds were 2.2-times more abundant in the organic system than in the conventional one, especially in oat (3.2-times greater) – Table 3, and the weed coverage on the surface was 81% greater (Tab. 4), respectively. The larger surface coverage by weeds as reported under the organic system could reduce the splash that sets off the erosion process [Zambon et al. 2021]. Splash occurs where rain drops fall on and hit exposed or bare soil. Among all tested plants the spring vetch was the one with the greatest potential in covering soil surface (statistically significant; Tabs 2–4).

Potatoes were the least infested due to their cultivation in wide rows and the possibility of mechanical treatments in interrows during the growing season. In this research, conventionally cultivated potato had 2.39-times less number of weeds comparing to organic system. Kołodziejczyk et al. [2017] was noted 3.93-times less weeds in mechanical-chemical treatment compared to mechanical only. The cited authors indicate also that neighbouring plants in potato cultivation can uptake macroelements with their biomass (respectively, 21.0 kg·ha^{-1} N, 4.0 kg·ha^{-1} P, 29.0 kg·ha^{-1} K, for mechanical treatment only), and their results indicate that the mechanical-chemical treatment did not enhanced loss the nutrient to the environment (the rise of accumulated NPK nutrients in potato in the presence of pesticides compared to mechanical treatment only was 49.0 kg·ha^{-1}, and for weeds their absence generated free 33.0 kg NPK·ha^{-1}). These results were showed that potato can effectively exploit the added NPK resources, although the residues of pesticides remaining in the environment emerged nowadays an urgent issue.

Table 2. Effect of farming system on LAI (m^2·m^{-2})

Specification	Farming system		
	conventional	organic	$\bar{x}$
Potato	1.91	1.84	1.87
Oat	2.26	2.24	2.25
Spring vetch	2.57	2.50	2.53
$\bar{x}$	2.24	2.19	2.21
$LSD_{0.05}$	n.s.*		0.146

* not significant

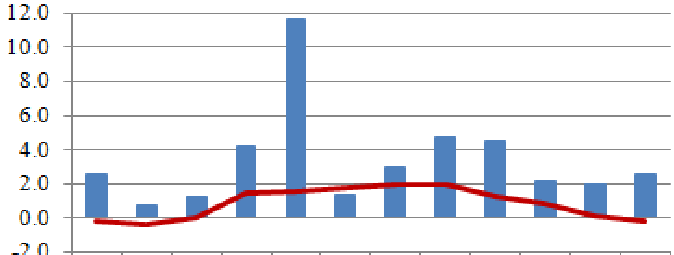
Table 3. Effect of farming system on reported total number of weeds (plants·m^{-2}) within crops grown during spring seasons

Specification	Farming system		
	conventional	organic	$\bar{x}$
Potato	21.9	52.3	37.1
Oat	26.6	85.9	56.3
Spring vetch	74.5	134.4	104.4
$\bar{x}$	41.0	90.9	65.9
$LSD_{0.05}$	2.63		3.35

Table 4. Coverage by weeds surface (%) as reported during oat and spring vetch harvesting period

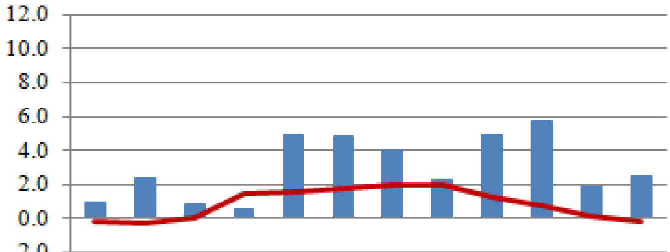
Specification	Farming system		
	conventional	organic	$\bar{x}$
Potato	13.1	28.8	20.9
Oat	20.0	37.6	28.8
Spring vetch	29.7	48.1	38.9
$\bar{x}$	21.0	38.1	29.5
$LSD_{0.05}$	0.01		1.29

2019



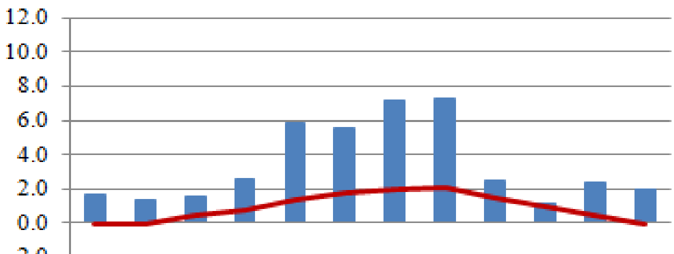
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
mm/20	2.6	0.8	1.3	4.3	11.7	1.3	3.0	4.7	4.5	2.1	2.0	2.6
temp/10	-0.2	-0.4	0.1	1.5	1.6	1.8	1.9	2.0	1.2	0.8	0.1	-0.2

2020



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
mm/20	1.0	2.3	0.8	0.6	4.9	4.9	4.0	2.3	4.9	5.8	1.9	2.5
temp/10	-0.1	-0.3	0.1	1.4	1.6	1.8	1.9	2.0	1.3	0.8	0.1	-0.2

2021



	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
mm/20	1.6	1.4	1.6	2.6	5.9	5.5	7.2	7.3	2.5	1.1	2.4	2.0
temp/10	0.0	-0.1	0.4	0.7	1.3	1.8	2.0	2.0	1.4	0.9	0.5	-0.1

Fig. 2. Gaussen-Walter climatograms for experimental area (2019–2021)

Infiltration has a major effect on reducing water erosion in soils. The research by Wainwright [1996] showed that the higher the infiltration rate, the lower the water erosion intensity, thereby amounts of sheet wash. The data in Table 5 demonstrate that the infiltration under the organic system was 13.6% higher than that under the conventional one.

Table 5. Effect of farming system on infiltration rate ($mm \cdot min^{-1}$)

Specification	Farming system		
	conventional	organic	x̄
Potato	6.91	7.34	7.12
Oat	8.48	9.36	8.92
Spring vetch	9.10	10.94	10.02
x̄	8.17	9.21	8.69
$LSD_{0.05}$	0.567		0.673

Table 6. Effect of farming system on fresh mass of earthworms ($g \cdot m^{-2}$)

Specification	Farming system		
	conventional	organic	x̄
Potato	24.45	27.84	26.14
Oat	20.15	22.32	21.24
Spring vetch	23.69	26.62	25.15
x̄	22.76	25.59	24.18
$LSD_{0.05}$	0.239		0.884

Table 7. Effect of farming system on mass ($kg \cdot ha^{-1}$) of sheet wash

Specification	Farming system		
	conventional	organic	x̄
Potato	4007.7	3775.1	3891.4
Oat	196.9	187.7	192.3
Spring vetch	199.4	173.6	186.5
x̄	1468.0	1378.8	1423.4
$LSD_{0.05}$	74.76		64.36

The second important factor of a higher infiltration under the organic farming, in addition to a greater amount of weeds there, was the increase in the mass of earthworms (12.4% more; Tab. 6). The endogeic group of earthworms (present in the tilled agroecosystems) make the horizontal-oriented burrows gallery, which also can enhance the infiltration rate with the strongest effect being for biopores with diameter >6 mm [Capowiez et al. 2009]. The results of air tunnels dug in the soil by earthworms on infiltration rates has been seldom addressed in the literature regarding sloping areas. But it is accepted that higher soil porosity (more earthworm burrow gallery) fosters higher infiltration. The results provided by Bouche and Al-Addan [1997] showed that the infiltration rate was positively correlated to earthworm biomass (r = 0.975), length, surface and volume of burrows (r = 0.99), but not linked with diameter of burrows, tortuosity or with earthworm number (probably due to present of juveniles with small size, which does not contribute significantly to the increase in infiltration). Their results indicate that the mean rate of infiltrated water on studied area was 150 $mm \cdot h^{-1}$ per 100 $g \cdot m^{-2}$ of earthworms.

Table 8. Average annual amounts of NPK nutrients ($kg \cdot ha^{-1}$) carried off by surface runoff

Specification	Farming system	Nutrients				
		$N\text{-}NO_3$	$N\text{-}NH_4$	P	K	Total
Potato	C	10.137	0.239	0.079	0.964	11.419
	O	3.720	0.093	0.034	0.285	4.132
	x̄	6.928	0.166	0.056	0.624	7.775
Oat	C	6.512	0.152	0.054	0.541	7.259
	O	3.604	0.089	0.032	0.274	3.999
	x̄	5.058	0.120	0.043	0.407	5.629
Spring vetch	C	3.803	0.107	0.068	0.712	4.690
	O	3.136	0.073	0.027	0.241	3.477
	x̄	3.469	0.090	0.047	0.476	4.083
On average	C	6.817	0.166	0.070	0.739	7.792
	O	3.486	0.085	0.031	0.266	3.868
	x̄	5.151	0.125	0.050	0.502	5.829
$LSD_{0.05}$						
For farming systems		0.448	0.012	0.0045	0.012	0.445
For crops		0.403	0.008	0.0038	0.022	0.420

C – conventional system, O – organic system

The average mass of earthworms was 18.8% higher in the fields where potatoes were grown than that in the fields where oat were grown (regardless the farming system) – Table 6. The reason thereof could be attributed to manure applied. Also, Sharpley et al. [2011] found that the fertilisation with manure enhanced the occurrence of earthworms in the soil with 2.70-times more than mineral fertilisation. Crittenden et al. [2014] informed that the conventional farming versus organic farming caused decreasing particular group of oligochaetes in ploughed soil, e.g. the abundance of common endogeic earthworm *A. caliginosa* decreased on average 1.65-times (for all samplings after plough), and total biomass of earthworms ($g \cdot m^{-2}$) in conventional managed plots was half (51.93%) than that in organically cultivated fields. Compared to the conventional system, a higher (12.4%) fresh mass of earthworms was achieved under the organic farming (Tab. 6), and this could be connected to manure applied and a larger number of root systems including those of the weeds, which can attract the soil mesofauna due to diversity of microbial hotspots accelerated in their rhizosphere (Tab. 3). On the basis of this data, could be marked that the higher plant biodiversity in organic agriculture fosters higher rates of soil organisms. The research results by Riley at al. [2008] pointed out the advantageous impact of the grass-legume mixture implemented into the organic cereal rotation (in the terms of number and activity of earthworms), even though one year of implementation (mown several times and ploughed down at frequent intervals). Also, there was statistically significant more biomass of earthworm (av. by 3.91 $g \cdot m^{-2}$) in spring vetch cultivation than in oat, regardless the system (Tab. 6).

The mass of sheet wash was 6.47% higher under the conventional than that under the organic farming system (Tab. 7). In the terms of particular crops, among plants with negligible sheet wash amounts in comparison to potato (oat, spring vetch; over 20-times less sheet wash, on average), the legume generated less sheet wash (by 7.51%) than oat in organic system (n.s.). To reduce such high surface erosion on slopes in potato cultivation, Tiessen et al. [2007] proposed several tillage implements with high anti-erosion effectiveness of potato crops cultivated on sloping fields (reduce depth of tillage, contour tillage using a mouldboard plough with the furrow turned upslope rather than chisel plough).

The mineral fertilisers applied under the conventional system and a larger mass of sheet wash caused the average annual mass of NPK components in fertilisers (carried off by surface runoff) to double in this systems compared to the organic system (Tab. 8). The lower infiltration level in conventionally cultivated fields (Tab. 5) could be a major reason thereof. However, interestingly for potato, amounts of $N\text{-}NO_3$ ($kg \cdot ha^{-1}$) catched in surface runoff in organic system was close to the values for oat and spring vetch in this system (3.720, 3.604, and 3.136, respectively; Tab. 8). Additionally, Cambardella et al. [2015] confirmed in their research that – as for the regions where maize was organically grown – the content of nitrates ($N\text{-}NO_3$) in the ground water was half the amount of that in the regions where maize was conventionally cultivated.

The obtained results of the three-year research highlights the pro-environmental aspects of organic farming, which diminished the amounts of NPK nutrients emitted into the environment on average 3.868 $kg \cdot ha^{-1}$ comparing to conventional cropping, on average 7.792 $kg \cdot ha^{-1}$ (Tab. 8). The positive effect of organically grown crops on water quality might be used to promote organic agriculture, in particular, catchment areas of rivers, which are a source of drinking water for urban inhabitants.

CONCLUSIONS

1. The yield of organically grown crops was 18.8% lower than that of conventionally cultivated plants.

2. Regard the organic farming system, oat was the most accompanied by weeds in comparison to conventionally cultivated one (3.2-times more); other plants were weeded the organic fields as follows: potato 2.39-times more and spring vetch 1.80-times more, in comparison to pesticide-present cultivation.

3. Compared to the conventional farming, the fresh mass of earthworms was 12.43% larger under the organic farming of potatoes, oat, and spring vetch.

4. Under the organic farming, the mass of sheet wash was 6.47% lower than that under the conventional farming.

5. The amount of NPK nutrients emitted into the environment from organically grown crops was half the amount of those emitted from the conventionally cultivated plants, where artificially synthesized fertilisers and pesticides were applied. This effect was most evident in the organic cultivation of potatoes, where the surface runoff of nitrates was comparable to the values for the other plants (3.72 kg $N\text{-}NO_3 \cdot ha^{-1}$, on average 3.37 kg $N\text{-}NO_3 \cdot ha^{-1}$, respectively).

6. The differences in soil surface coverage (LAI) were statistically insignificant between organic and conventional farming systems, due the increased presence of weeds in the organically cultivated crops.

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The source of funding: This work is financially supported by the Ministry of Science and Higher Education of the Republic of Poland.

Received: 27.05.2022
Accepted: 26.08.2022