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ORIGINAL PAPER

SOIL PROTECTIVE EFFICIENCY OF ORGANIC CULTIVATION OF CEREALS*

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Abstract

Organic farming is a management system which to an essential extent protects the natural environment, for example by preventing soil erosion. The objective of the research was to determine the effect of organic and conventional cultivation of cereals on the volume of soil losses and on the amount of plant nutrients washed away from the stands where the cereals were sown. A two-factor field experiment was carried out over a period from 2013 to 2016 at the Mountain Experimental Station situated in Czyrna near Krynica Górska (Poland). Experimental plots were set up on Eutri-Gleyic Cambisols, developed from eluvium of flysch rocks. The first factor included two farming systems: organic and conventional. The second factor involved three spring crops grown in pure stands: spring barley, spring triticale, and oats as well as three mixtures of cereals: spring barley + oats, spring barley + spring triticale, spring triticale + oats. The experimental plots were 22 m x 2 m in size. The soil losses were measured with the use of Słupik catchers. Based on the experiment results, it was found that on the stands with cereals grown using the conventional system, the losses of the following components were, on average, higher, i.e. the $N\text{-}NO_3$ losses: 55.8% higher, the $N\text{-}NH_4$ losses: 72.2% higher, and the P and K losses: 60.0% and 48.3% higher, respectively. As regards the soil loss, no statistically significant differences were found between the two farming systems. The cultivation of spring barley and mixture of spring barley + oats turned out to be the best at protecting the soil. Oats grown in pure stands were the least soil protective. The Leaf Area Index (LAI) applied to characterize the canopy of the organically grown cereals was 14% smaller than that of the cereals grown in the conventional system.

Keywords: farming system, organic farming, soil erosion, nutrient losses.

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INTRODUCTION

One of the objectives of organic farming is to provide the natural environment with care (SREDNICKA et al. 2016). In practice, it intends to improve the quality of water, soil, and air. There are many published papers containing the results of research on the effect of organic farming on the environment (GRANSTEDT et al. 2004, LORENZ AND LAL 2016). Some of these studies present a comparison of two farming systems (organic and non-organic) in order to determine the effect which these systems have on the intensity of erosion processes; most of these reports present the results that describe the erosion process with the use of empirical models such as USLE and RUSLE to forecast the process of soil erosion (AUERSWALD et al. 2003, ARNHOLD et al. 2014, AUERSWALD et al. 2018). Some other papers contain comparisons of farming systems with regard to those selected physical properties of soil that impact the erosion degree, i.e. infiltration coefficient, stability of soil aggregates (MAÈDER et al. 2002, SCULLION et al. 2002, PULLEMAN et al. 2003). However, there are only few papers to report the results of studies on the erosion intensity based on direct field observations. Therefore, an attempt has been made to study the soil-protective efficiency of spring cereals grown according to the principles of organic farming. Another reason why this particular issue has been addressed is the fact that more than half of organic farms in southern Poland have arable lands located on hillsides (KLIMA, MATEJSKA 2009). Water erosion occurs on the hillsides where organic farmers have their fields and cultivate crops. This environmentally unfavourable phenomenon is responsible for the diminishing thickness of the arable layer (top soil) (CHOWANIAK et al. 2016) and eutrophication of surface waters.

The objective of the research was to determine the effect of organically and conventionally grown cereals: spring barley, spring triticale, oats and mixtures thereof, on the volume of soil loss and the amount of plant nutrients carried away from the stands where the cereals tested were sown.

MATERIAL AND METHODS

The subject of the research study was a two-factor field experiment carried out from 2013 to 2016 at the Mountain Experimental Station, Department of Agrotechnology and Agricultural Ecology, University of Agriculture in Kraków. A split-block method was used to design the experiment. The Experimental Station is situated in Czyrna near Krynica Górska (545 m a.s.l.). The geographical coordinates of the Station are: N 49°25′; E 20°58′. The experimental plots have been set up on Eutri-Gleyic Cambisols, developed from eluvium of flysch rocks. The grain-size composition was as follow: 28% of sand, 29% of silt and 43% of clay particles, which classified of soil as medium skeletal loam. The climate at the experiment site is temperate-continental with a mean annual temperature ranging from 6 to 8°C. The precipitation totals during the plant growing season varied (Table 1). The weather conditions during the winter season (Table 2) did not generate intensified rill erosion because snow melted during solar thawing. An increase in the intensity of water erosion usually took place in the spring, mainly when the rainfall exceeded 20 mm. A rainfall below 20 mm rarely induced erosion because almost all rainwater drained into the soil profile. During the experiment, the surface runoffs occurred in the two snowmelt periods and after 15 rainfalls (Table 2).

Table 1

Monthly total precipitations (mm)

Years	Months												Apr--Aug	Jan--Dec
	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		
2013	74.1	26.6	38.4	24.7	118.0	202.4	33.1	32.9	109.6	18.0	92.9	29.7	411.1	800.4
2014	45.8	21.2	39.2	51.1	137.8	58.3	134.4	113.6	72.7	39.6	45.2	42.5	495.2	806.4
2015	58.8	32.2	45.4	50.5	123.8	43.5	52.1	83.7	82.5	51.3	43.8	52.1	353.6	719.7
2016	21.6	73.8	36.6	62.4	56.2	62.0	221.9	136.5	23.1	88.5	65.8	56.1	539.0	904.5
1961-2010	43.9	39.4	45.7	62	99.6	118.6	111.2	91	76.6	54.7	42.6	53.6	482.3	838.9

Table 2

Snow-melt seasons and rainfalls causing surface runoff (2013-2016)

Snow-melt seasons and dates of rainfall	Water storage on snow (mm)	Duration of rainfall (min)	Rainfall total (mm)	Maximum intensity (mm min^{-1})
Year 2013				
21-31.01	26.5			
2-3.05		1202	47.6	0.1
4-5.06		1325	46.2	0.08
25.06		103	72.9	1.1
Year 2014				
16.05		41	32.8	1.4
1.07		32	24.4	1.0
9-10.07		1410	46.9	0.08
11.08		34	25.3	1.3
Year 2015				
8-14.01	21.3			
29.04		30	22.3	1.0
21-22.05		192	28.6	0.16
16.08		40	36.4	1.5
Year 2016				
14.05		41	35.1	1.4
3.06		32	21.9	0.9
24.06		49	25.2	0.7
16-17.07		1108	59.1	0.05-1.4
9-10.08		527	30.2	0.08

The first factor of experiment included 2 farming systems: organic and conventional. The second factor involved 3 spring cereals in pure stands: spring barley, spring triticale, oats as well as 3 cereal mixtures: spring barley + oats, spring barley + spring triticale, and spring triticale + oats. Mineral fertilizers were applied in the conventional farming; their doses were calculated as follows: P (phosphorus) 34 kg ha^{-1}, K (potassium) 55.6 kg ha^{-1}, N (nitrogen) 72 kg ha^{-1}. In order to control weeds in cereals, Granstar herbicide, i.e. tribenuron methyl (sulphonylurea), was applied in a dose of 24 g ha^{-1}. Pesticides and mineral fertilizers were not applied in the organic farming. The weeds were controlled through harrowing in cereals sown in spring. The following crop rotation was used both in the conventional and the organic farming system: 1) growing potatoes with manure (33 t ha^{-1}), 2) spring cereals, 3) oats + vetch mixture.

Every year, the experiment was repeated 4 times on small, 22 x 2 m plots lying on a 9% mountain slope (Wischmeier, Smith 1978, Bogunovic et al. 2018). The period when measurements were taken lasted from the date of forecrop harvest until the date of follow-up crop that was to be assessed. The surface runoff was measured with the use of Słupik catchers (Słupik 1975, Smolska 2002). Such a catcher consisted of a foil bag fixed on a steel rack. The rack used had a 2 m wide inlet. The catchers were installed at the bottom edge of each plot. They were emptied after every rainfall or after a snowmelt season that generated a surface runoff. The volume of the surface runoff was measured, and 1 litre of surface runoff was randomly collected from the suspension to perform detailed determinations. The volume of the surface wash was determined after 1 litre of surface runoff passed through a medium hard filter. The sediment and the filter were dried at a temp. of 105°C. The filters with the sediment were cooled in a desiccator and weighed. During the liquid phase of runoffs, the following components of solution were determined using colorimetric methods: $N\text{-}NO_3$ using phenoldiphulsonic acid and the content of $N\text{-}NH_4$ using a Nessler reagent in a Beckman UV/VIS PU 6400 spectrophotometer. The contents of phosphorus and potassium were determined as soon as the sample was ten times compressed by an ICP-EAS method (JY 238 ULTRACE, Jobin Yvon Emission).

Every year during the graining phase (BBCH 70-71), plant samples were collected from a 0.5 x 0.5 m surface of every plot in order to determine the area of cereal leaves. 20 plants were taken from every sample for the purpose of determining the area of their leaves. The area of leaf blades was measured using automatic planimeter, i.e. LI-COR 3100 Area Meter. Based on the known shoot density on 1 m^2, the canopy Leaf Area Index (LAI) value was computed.

ANOVA was applied for statistical analyses of the results. The significance of mean differences among the objects was tested with the multiple comparison procedure and the Tukey's range test was applied at a significance level of $\alpha = 0.05$. The results were also described by linear regression.

RESULTS AND DISCUSSION

The mineral fertilizers and pesticides applied in the conventional farming impacted the content of nutrients in the soil and its pH value (Table 3). They also resulted in the mean grain yield of cereals grown in this system being 18% higher than in the organic farming system (Figure 1). These findings are close to the results reported by Klima et al. (2014), who noted an 11% decrease in the grain yield of cereals grown organically under the mountainous conditions. The decrease in the grain yield analysed in this study was caused, among other things, by a reduced density of spikes and panicles in the organic system, lower by an average 14% (Figure 1). The results

Table 3

Effect of farming system on chemical and physical properties of soil (0-20 cm)

(mg kg^{-1})										pH	
N- NO_3		N-NH_4		P		K		C-org			
*C**	*O*	*C*	*O*	*C*	*O*	*C*	*O*	*C*	*O*	*C*	*O*
28.00	26.01	11.01	10.00	12.90	12.00	26.70	26.20	19.3	19.0	5.60	5.80
LSD $_{0.05}$											
0.352		0.217		0.588		0.426		ns**		0.195	

* *C* – conventional, *O* – organic, ** not significant

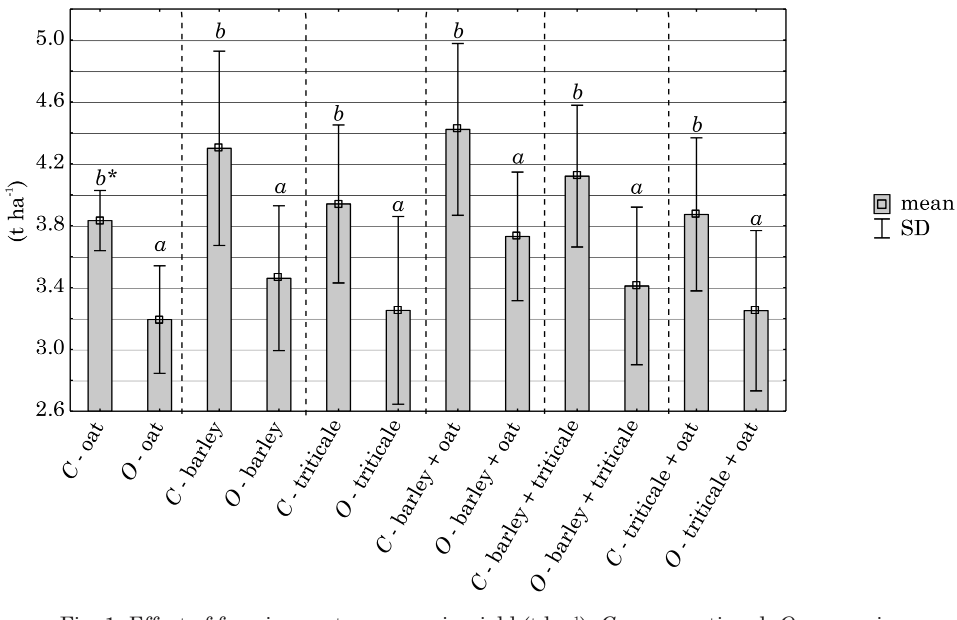

Fig. 1. Effect of farming system on grain yield (t ha^{-1}): *C* – conventional, *O* – organic.
* Mean values followed by a different small letter within each crop indicate a significant difference according to the Tukey's test HSD (P = 0.05)

of the research performed by DAWSON et al. (2008) show that the mineral fertilization applied in a conventional system affects the production of tillers by cereal plants so that those plants develop more tillers.

The key factor that affects the intensity of erosion processes is the plant cover (MCHUNU, CHAPLOT 2012). In our study, the mineral fertilization used in the conventional system impacted the LAI (Leaf Area Index). The data in Table 4 demonstrate that in the conventional system, the mean LAI value

Table 4

Effect of farming system and crop on leaf area index (m^2 m^{-2})

Crop	Farming system		Mean
	C	*O*	
Oat	1.83	1.59	1.71
Spring barley	2.17	1.80	1.98
Spring triticale	1.95	1.67	1.81
Spring barley + oat	2.11	1.86	1.98
Spring barley + spring triticale	2.02	1.80	1.91
Spring triticale + oat	1.88	1.71	1.79
Mean	1.99	1.73	1.86
$LSD_{0.05}$			
Farming system	0.050		
Crop	0.128		
Farming system x crop	ns		

C – conventional, *O* – organic, ns – not significant

was 14% higher than that in the organic system. PETCU et al. (2011) also prove that the LAI value for the organically cultivated plants is lower.

During the experiment, the surface runoffs occurred in the two snowmelt periods and after 15 rainfalls. The values of LAI (Table 4) and the quantity of spikes and panicles per surface unit (Figure 2) affected the volume of surface washes. The two farming systems did not differ significantly as regards the soil losses. The results presented (Table 5) suggest that the volume of surface runoffs tends to be larger under the organic farming system. In their studies, REGANOLD et al. (1987) reported four-fold higher soil losses in the conventional farming than in the organic system. In the present study, soil losses was 5.4% higher, on average, on the plots cultivated using the organic farming system compared to the conventional system. The difference between the results obtained by REGANOLD et al. (1987) and ours was a consequence of the low erodibility of the mountainous soil we examined. This in turn was due to a large amount of colloidal clay in the soil. A larger soil loss in the organic farming was mainly the effect of less effective splash counteraction (the plant cover expressed as LAI was significantly smaller in the organic farming); raindrops hit bare soil surface, i.e. not covered by plants, and the

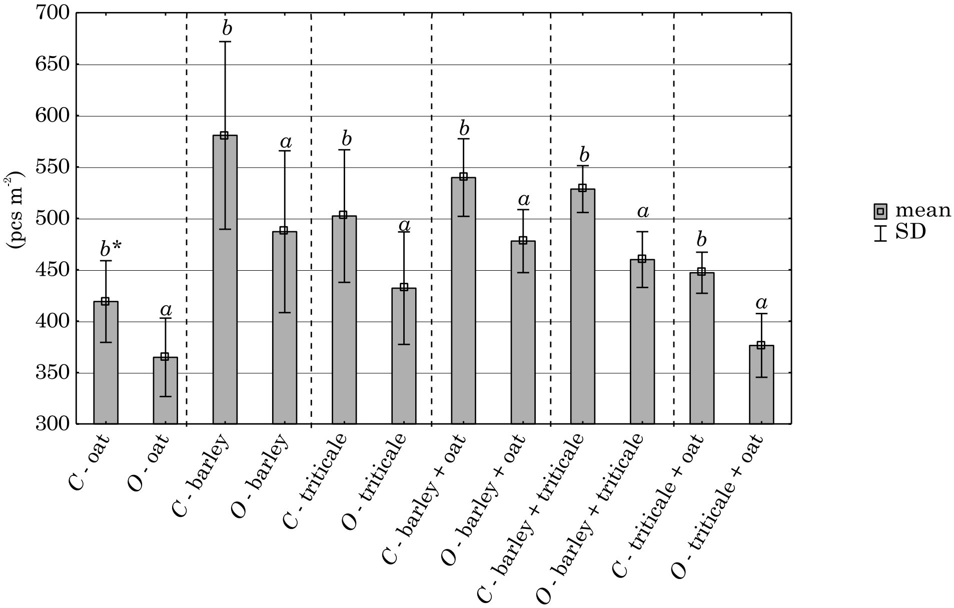

Fig. 2. Number of spikes (pcs m^{-2}) and panicles per 1 m^2 of cereals grown using conventional and organic systems: *C* – conventional, *O* – organic.
* Mean values followed by a different small letter within each crop indicate a significant difference according to the Tukey's test HSD ($P = 0.05$)

Table 5

Effect of farming system and crop on soil loss (kg ha^{-1})

Crop	Farming System		mean
	conventional	organic	
Oat	182.2	191.8	187.0
Spring barley	151.8	164.5	158.1
Spring triticale	170.2	176.9	173.6
Spring barley + oat	159.2	167.0	163.1
Spring barley + spring triticale	163.5	171.9	167.7
Spring triticale + oat	179.6	188.3	183.9
Mean	167.7	176.7	172.2
$LSD_{0.05}$			
Farming system	ns		
Crop	23.27		
Farming system x crop	ns		

C – conventional, *O* – organic, ns – not significant water splash activates the water erosion process by detaching fine soil particles and scattering them (FERNÁNDEZ-RAGAA et al. 2017, NEARING et al. 2017). Plants counteract splash, hence they inhibit water erosion and this effect is directly proportional to the LAI value. Figure 3 and Figure 4 show the correlation between the volume of surface wash and the LAI value in the two farming systems analysed.

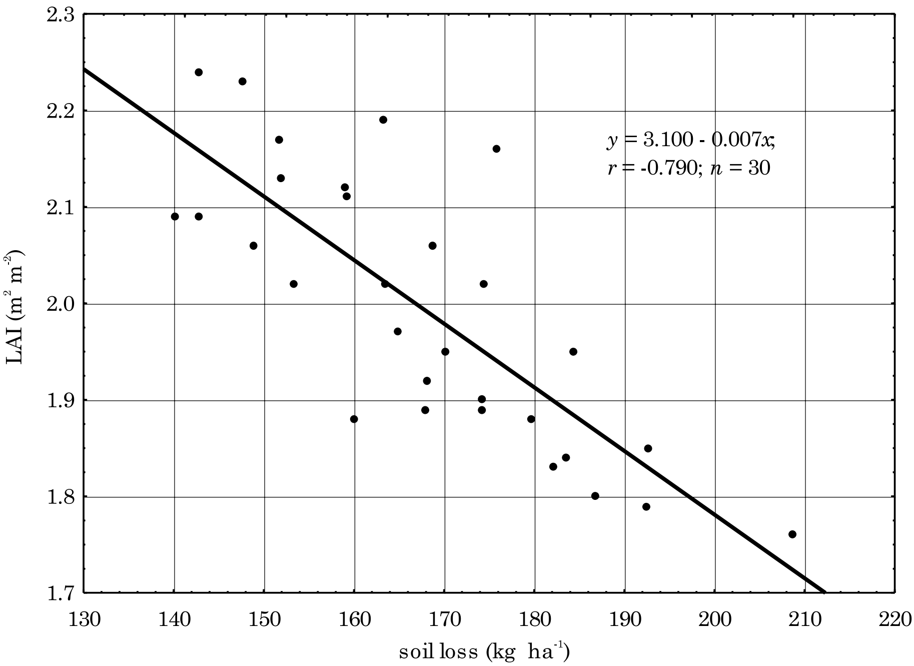

Fig. 3. Correlation between volume of surface wash (kg ha^{-1}) and Leaf Area Index (LAI) value (LAI) in cereals grown using conventional system

The higher the LAI value and the higher the density of canopy, the more effective the plants' protection of soil against direct hits by raindrops, and therefore against the splash erosion caused by the impact of hitting raindrops (KLIMA, WIŚNIOWSKA-KIELIAN 2006, CADARET et al. 2016, NISHIGAKI et al. 2016).

Of the cereals cultivated, spring barley and the spring barley + oats mixture proved to be the best at protecting the soil. Oats grown in pure stands turned out to be the least soil-protective cereal. The soil protective capacity of the plant cover can be presented in the following descending order: spring barley > spring barley with oats > spring barley with triticale > spring triticale > spring triticale with oats > oats.

The analysis of nitrogen, phosphorus and potassium losses revealed statistically significant differences within both farming systems studied and the cereals with regard to all the macronutrients analysed (Table 6). The losses of all the analysed components were higher on the plots under the

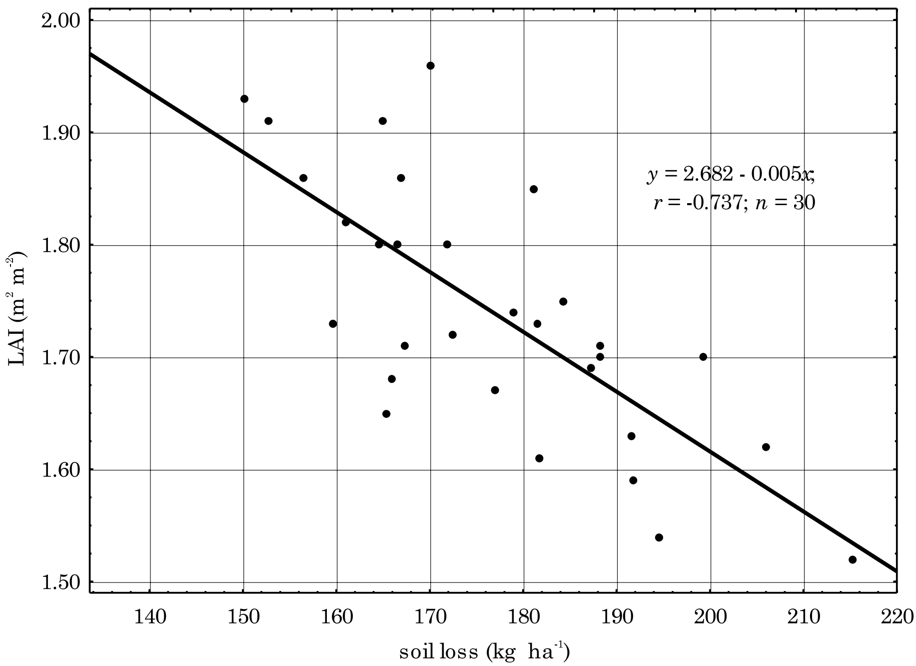

Fig. 4. Correlation between volume of surface wash (kg ha^{-1}) and Leaf Area Index (LAI) value (LAI) in cereals grown using organic system

conventional system, i.e. the N-NO_3 losses were on average 55.8% higher, the N-NH_4 losses were 72.2% higher, and the losses of P and K were 60.0% and 48.3% higher, respectively. These findings confirm the pro-environmental value of the organic farming system. The fertilisation applied in the conventional system, including the application of easily soluble mineral fertilizers, certainly contributed to higher losses of nutrients in this system. Similarly to the analyses performed by other authors (Xia et al. 2007, 2013), the losses of the components analysed depended on the intensity of surface wash; thus, the soil protectiveness of the cereals studied, which is linked with the washing away of individual components, can be presented according to the order mentioned above. The ordered sequence starts with spring barley and ends with oats. The next factor that influences the intensity of nutrient losses is the concentration of nutrients in the soil (Kuhn et. al 2012); according to the results presented, in the conventional system, the concentrations of N-NO_3, N-NH_4, P, and K arising from the fertilization applied were 7.7%, 10.0%, 7.5% and 1.9% higher, respectively (Table 3). Many authors reported a decrease in the nutrient losses attributed to the reduced fertilization (Uhlen 1994, Korsæth, Eltun 2000).

Table 6

Mean annual loads (kg ha^{-1}) of nutrients carried away with surface runoff from stands where cereals were cultivated according to organic and conventional farming systems

Crop	Farming system	Nutrients			
		$N\text{-}NO_3$	$N\text{-}NH_4$	P	K
Oat	*C* *O* mean	6.212 3.473 4.842	0.144 0.086 0.115	0.052 0.031 0.039	0.515 0.266 0.390
Spring barley	*C* *O* mean	5.921 3.202 4.561	0.104 0.076 0.090	0.035 0.022 0.028	0.457 0.224 0.340
Spring triticale	*C* *O* mean	6.091 3.383 4.737	0.132 0.095 0.113	0.048 0.031 0.039	0.498 0.249 0.374
Spring barley + oat	*C* *O* mean	5.139 2.991 4.065	0.103 0.059 0.081	0.034 0.017 0.026	0.457 0.190 0.324
Spring barley + spring triticale	*C* *O* mean	5.517 3.081 4.299	0.102 0.079 0.091	0.039 0.021 0.030	0.457 0.224 0.340
Spring triticale + oat	*C* *O* mean	6.084 3.401 4.743	0.131 0.087 0.109	0.048 0.031 0.039	0.515 0.257 0.385
Conventional Organic Mean		5.827 3.255 4.541	0.119 0.080 0.099	0.044 0.026 0.035	0.481 0.232 0.357
$LSD_{\alpha\ 0.05}$					
Farming system		0.0734	0.0089	0.0084	0.0262
Crop		0.1892	0.0241	0.0203	0.0674
Farming system x crop		0.1803	ns	ns	ns

C – conventional, O – organic, ns – not significant

CONCLUSIONS

1. The canopy (Leaf Area Index) of the cereals grown using the organic system was smaller than that of the cereals grown under the conventional system.

2. As regards the soil loss, no statistically significant differences were found between the two farming systems studied.

3. The organic farming system was characterized by a lower emission of nutrients to the environment and this was linked with a lower concentration of those components in the soil.

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