Original Research

Yield and Economic Results of Spring Barley Grown in Crop Rotation and in Monoculture

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Abstract

The study aimed to evaluate the yield and economic effectiveness of spring barley grown in crop rotation and cereal monoculture under three tillage systems. The experimental factors were crop sequence systems: 1) crop rotation (peas – spring barley – winter wheat) and 2) cereal monoculture (spring barley – winter wheat – winter wheat) and tillage systems: a) conventional tillage (CT), b) reduced tillage (RT), and 3) herbicide tillage (HT). Spring barley grain yield was significantly higher in crop rotation than in cereal monoculture. Also, yield was significantly higher under RT than under CT and HT. The number of weeds per m^{-2} in cereal monoculture was significantly higher than in crop rotation. Also, more weeds occurred under RT than under CT and HT. Air-dry weight of weeds was higher in cereal monoculture than in crop rotation and it was also higher under RT than under CT. In crop rotation, for each tillage system the production value (EUR ha^{-1}) was higher than in monoculture, whereas the highest production value (EUR ha^{-1}) was achieved in crop rotation in RT sites. The economic analysis showed a clear competitive advantage of RT sites with crop rotation over other sites. The proof is the highest gross margin and income from activity, and the lowest unit cost of production.

Introduction

Crop rotation is a factor integrating all elements of agricultural engineering, that is, tillage, organic and mineral fertilizers, and crop protection. It has a positive effect on the productivity and quality of crops [1-2], economic results [3], and health status of crops [4], as well as biological and chemical properties of soil [5]. Unfortunately, naturally correct crop rotation composed of root crops, leguminous plants, and other non-cereal

crops occurs more and more rarely. Instead, reduced sequencing of crops is practised, consisting mainly of cereals and rape. An exception is ecological farms with integrated agricultural production in which catch crops, long-term leguminous plants are grown, and organic fertilizers are used [6-7]. Tillage systems also have a significant influence on crop yield [8]. Depending on the type of crop rotation and the crops grown, soil and climatic conditions as well as technical resources of the farm and different tillage systems are adopted, i.e., plough tillage, reduced tillage, direct seeding, and strip-till, along with their modifications [9]. The crop sequence in crop rotation, tillage system, and habitat conditions have an aggregate effect, thus they each

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affect crop yield to a different extent [10]. De Vita et al. [11] and Montemurro and Maiorana [12] demonstrated that in hot and dry regions no-plough tillage gives better yield than conventional tillage, and in moderately humid conditions better production effects are obtained under conventional tillage rather than no-plough tillage [9]. Cereal monoculture leads to numerous occurrences of weeds and in particular to compensation of a few species that are highly competitive in relation to grains [7, 13]. However, effective elimination of such weeds from sown grains requires high expenditure on pesticides [14]. Another problem connected with cereal monocultures is diseases caused by a complex of foot rot pathogens and pests. Maintaining these agrophages within the acceptable economic injury levels also requires multiple applications of pesticides [14]. In crop rotation the occurrence of weeds, fungal pathogens, and pests is to a large extent reduced by the sequence of crops from different biological groups, catch crops, differentiated agricultural techniques, and the application of pesticides from different groups of chemicals. Thus, the number of plant protection treatments can be reduced, which has a positive effect on the natural environment and economic effects [3, 15-16].

Our studies aimed at evaluating the yield and economic results of spring barley sown in crop rotation and monoculture under different tillage systems.

Materials and Methods

Location and Plan of the Experiment

The field experiment started in 2009 on the Uhrusk Experimental Farm (51°18'N, 23°36'E) owned by the University of Life Sciences in Lublin (southeastern Poland), whereas the results presented in this paper date back to 2015-2017. The experiment was based on split blocks of 6 × 25 m, and was performed in 3 replications, whereas the factors were cropping systems: 1) crop rotation: peas – spring barley – winter wheat; and 2) cereal monoculture: spring barley – winter wheat – winter wheat. The other factor was tillage systems: a) conventional tillage (CT), b) reduced tillage (RT), and 3) herbicide tillage (HT). In CT, shallow ploughing (10-12 cm deep) and deep pre-winter ploughing (25-30 cm) were performed for spring barley. In RT, both ploughings were replaced with double tilling, and in HT only glyphosate (4 L ha^{-1}) was used. In spring the only procedure was harrowing and a tillage set was used under CT, whereas under RT and HT tilling was performed and a tillage set was used.

Habitat Conditions

Experimental soil was Rendzic Phaeozem [17], composed of sandy clay with 24.3% loamy intrusions and 13.5% dusty intrusions, alkaline reaction (pH$_{kCL}$ = 7.3), high content of assimilable forms of phosphorus (120 mg P kg^{-1} d.m.) and potassium (217 mg K kg^{-1}), and low content of magnesium (71 mg Mg kg^{-1}). In the multi-year period (1963-2013) the annual precipitation total in the analyzed area was above 600 mm, including 381 mm in the period from spring barley sowing to harvesting (from March until August). In the study years (2015-2017) monthly precipitation totals from March until August were considerably differentiated – the lowest ones were recorded in 2015 (203 mm) while in 2016 they were twice higher (426 mm). On the other hand, average monthly ambient temperatures during the barley vegetation period were similar in respective years. The distribution of precipitation totals and average ambient temperatures in respective months and years of the study are presented in Table 1.

Table 1. Rainfall and air temperature according to the meteorological observatory at Uhrusk

Year	Months						Total / Mean
	Mar	Apr	May	Jun	Jul	Aug	
Rainfall (mm)							
2015	39	34	62	16	45	7	203
2016	52	68	55	66	132	53	426
2017	31	60	72	27	100	39	328
1963- 2013	37	45	66	74	86	73	381
Air temperature (ºC)							
2015	4.7	7.7	13.1	17.1	21.7	22.2	14.4
2016	3.8	9.3	14.9	18.1	20.0	18.9	14.2
2017	5.8	7.4	14.2	17.9	20.1	20.1	14.3
1963- 2013	2.0	8.5	14.0	17.1	19.3	18.2	13.2

Fertilizers and Plant Protection

Spring barley of Tocada variety was sown between 1st and 5th April in all study years. Sowing density was 320 seeds per m^{-2}. 90 kg of nitrogen fertilizer was applied per ha^{-1} at two dates: before sowing (60 kg N ha^{-1}) and at the tillering stage (30 kg ha^{-1}). Phosphorus and potassium fertilizers were applied before sowing the barley in respective doses of 30 kg P ha^{-1} and 80 kg K ha^{-1}. The crops were protected against fungal diseases by means of fungicides such as: Alert 375 SC (1.0 L ha^{-1}) (s.a. flusilazole + carbendazim) at stage 32-33 according to BBCH scale and Tilt Plus 400 EC (1 L ha^{-1}) (propiconazol + fenpropidin) at BBCH stage 53-54. Herbicides used for weed control included: Chwastox Trio 540 SL (1.5 L ha^{-1}) (mecoprop + MCPA + dicamba), and Puma Uniwersal 069 EW (fenoxaprop-P-ethyl) (1.0 L ha^{-1}) at BBCH stage 23-24.

Features and Statistical Analysis

The experiment evaluated the following features: 1) grain yield, 2) grain weight per spike, 3) number of spikes per m^{-2}, 4) 1000 grains weight, 5) length of spike, 6) number and air-dry weight of weeds, 7) weeds species composition, 8) economic ratios: gross margin, income from activity, profitability ratio, unit cost, and economic efficiency ratios.

The grains were harvested with a Wintersteiger plot harvester, and grain weight per spike was calculated based on 40 randomly harvested spikes, the number of spikes was determined per 1 m^2 of each plot, and the weight of 1000 grains was determined by counting 2×500 grains. Weed infestation was assessed by botanical-weight method at the stage of wax maturity of barley (83-84 BBCH). The method involved determining the species composition and the number and air-dry weight of weeds per 1 m^2 of the plot. The area was selected at random (twice) by means of a 0.5 m×1.0 m frame. In order to determine air-dry weight, all weeds were collected from the frame surface, their roots were cut off, and they were placed in a well-ventilated room until their weight became fixed. The results obtained were analysed by statistical methods using one-way analysis of variance (ANOVA) by means of Statistica PL software. In turn, the significance of differences between mean values was verified by means of Tukey's HSD test for *P*<0.05.

Results and Discussion

Results

Grain Yield and its Components

Spring barley grain yield was significantly higher (by 25.6%) in crop rotation than in cereal monoculture (Table 2). Also, yield was significantly higher under

Table 2. Spring barley grain yield and its components (average from 2015-2017).

Crop sequence (CS)	Tillage systems (TS)			Mean
	CT[a]	RT[b]	HT[c]	
Grain yield (t ha^{-1})				
Crop rotation	7.18	9.01	8.31	8.17
Cereal monoculture	6.30	7.10	4.85	6.08
Mean	6.74	8.06	6.58	-
$HSD_{0.05}$ for CS = 0.06, TS = 0.09, CS x TS = 0,15				
Grain weight per spike (g)				
Crop rotation	1.26	1.52	1.36	1.38
Cereal monoculture	1.18	1.26	0.91	1.12
Mean	1.22	1.39	1.14	-
$HSD_{0.05}$ for CS = 0.04, TS = 0.06, CS x TS = 0,10				
Number of spikes (m^2)				
Crop rotation	568	600	609	592
Cereal monoculture	534	563	532	543
Mean	551	581	571	-
$HSD_{0.05}$ for CS = 17, TS = 26, CS x TS = ns				
1000 grains weight (g)				
Crop rotation	52.4	58.5	58.2	56.4
Cereal monoculture	47.0	50.3	37.1	44.8
Mean	49.7	54.4	47.6	-
$HSD_{0.05}$ for CS = 3.1, TS = 4.6, CS x TS = 8.2				
Length of spike (cm)				
Crop rotation	7.24	7.75	7.16	7.38
Cereal monoculture	7.03	7.04	7.08	7.05
Mean	7.13	7.39	7.12	-
$HSD_{0.05}$ for CS = 0.12, TS = 0.18, CS x TS = 0.31				

CT[a] - conventional tillage, RT[b] – reduced tillage, HT[c] – herbicide tillage

RT than under CT and HT, where the difference was respectively 16.4% and 18.4%. Evaluating the effects of the interaction between CS and TS, it can be stated that in crop rotation the highest yield of barley was recorded under the RT system and the lowest under CT (20.3% lower). In monoculture the highest yield was also noted for RT and the lowest for HT (31.7% lower). Also, the components of the yield, i.e., grain weight per spike, number of spikes per m^{-2}, 1000 grains weight, and spike length reached higher values in crop rotation than in monoculture, respectively, by 18.8%, 8.3%, 20.6%, and 4.5%. Under RT, grain weight per spike, 1000 grains weight, and spike length were significantly higher than under CT and HT, and the number of spikes per m^{-2} was higher than under CT. The grain yield of barley
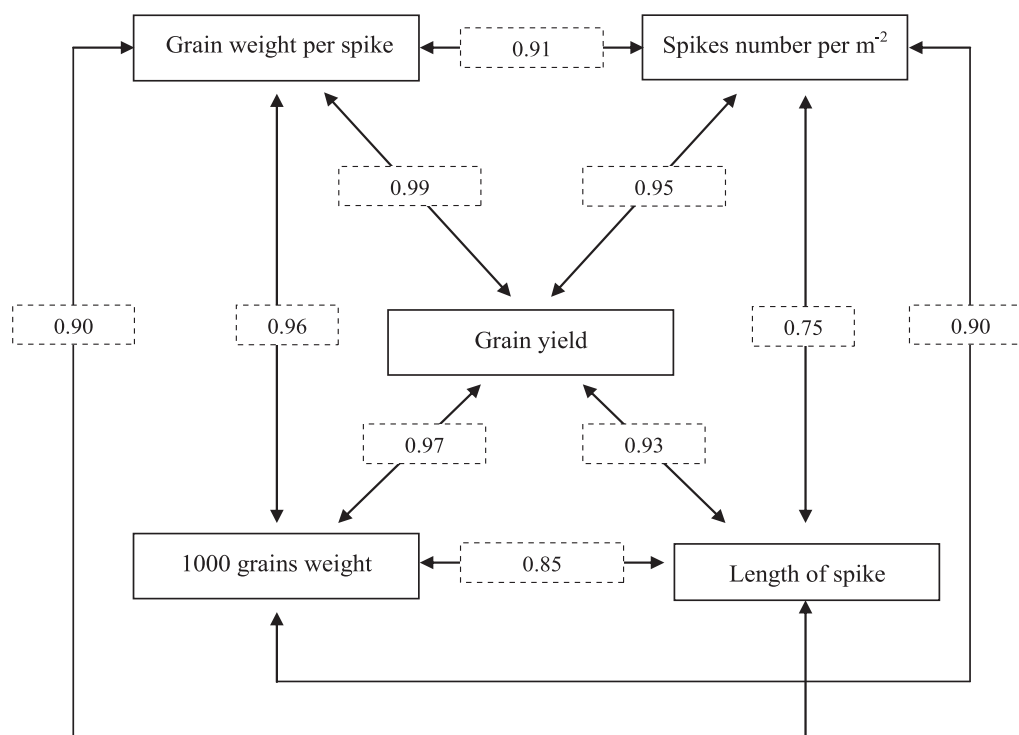
Fig. 1. Straight-line correlation (r) between spring barley grain yield and its components.

was significantly correlated with grain weight per spike, number of spikes per m^{-2}, 1000 grains weight, and spike length (Fig. 1). Significant correlations also occurred between the number of spikes per m^{-2} and the length of spike, grain weight per spike, and 1000 grains weight and between spike length and grain weight per spike and 1000 grains weight. On the basis of the components of the analysis of variance it can be stated that grain yield and its elements were to a larger extent determined by CS than by TS (Table 3).

Table 3. Analysis of variance for grain yield and its components.

Specification	Value	CS[a]	TS[b]	CS x TS
Grain yield	F	6341.2	1272.9	817.7
	P	**	**	**
Grain weight per spike	F	232.7	76.4	37.4
	P	**	**	**
Spike number per m^{-2}	F	37.6	4.8	2.9
	P	**	*	ns
1000 grains weight	F	68.1	8.2	11.9
	P	**	**	**
Length of spike	F	51.5	7.2	8.3
	P	**	*	*

CS[a] – crop sequence, TS[b] – tillage system, *P<0.05;
**P<0.01; ns – not significant

Weed Infestation Rates

The number of weeds per m^{-2} in cereal monoculture was significantly higher than in crop rotation (Table 4). Also, more weeds occurred under RT than under CT and HT systems. Significant differences in this feature were also recorded between CT and HT. Similarly, air-dry weight of weeds was higher in cereal monoculture

Table 4. Number and air-dry weight of weeds in spring barley (average from 2015-2017).

Crop sequence (CS)	Tillage systems (TS)			Mean
	CT[a]	RT[b]	HT[c]	
Number of weeds (m^2)				
Crop rotation	6.5	13.9	10.3	10.2
Cereal monoculture	11.3	21.2	18.0	16.8
Mean	8.9	17.6	14.2	-
$HSD_{0.05}$ for CS = 2.2, TS = 3.1, CS x TS = ns				
Air-dry weight of weeds (g m^{-2})				
Crop rotation	18.0	31.3	23.4	24.2
Cereal monoculture	27.2	40.0	37.6	34.9
Mean	22.6	35.7	30.5	-
$HSD_{0.05}$ for CS = 7.3, TS = 9.1, CS x TS = 14.0				

CT[a] - conventional tillage, RT[b] – reduced tillage,
HT[c] – herbicide tillage

Table 5. Species composition of weeds in spring barley per m² (average from 2015-2017).

Species composition	Crop rotation			Cereal monoculture		
	CT[a]	RT[b]	HT[c]	CT	RT	HT
Sonchus oleraceus L.	2.5	1.0	-	1.5	-	2.8
Papaver rhoeas L.	1.5	1.8	2.5	2.5	6.5	4.2
Galium aparine L.	1.5	2.2	-	-	4.0	2.0
Viola arvensis Murray	0.8	-	0.3	-	-	1.2
Stellaria media (L.) Vill.	-	0.2	-	0.5	-	1.0
Anthemis arvensis L.	-	1.0	-	0.8	2.5	-
Amaranthus retroflexus L.	-	-	0.2	0.2	1.5	-
Echinochloa crus-galli (L.) P. Beauv.	-	-	1.8	-	2.2	-
Avena fatua L.	-	4.3	3.0	2.0	2.0	2.2
Matricaria inodora L.	-	0.9	-	1.8	0.5	-
Fallopia convolvulus (L.) A. Löve	0.2	0.5	1.5	2.0	-	2.4
Galinsoga parviflora Cav.	-	0.2	-	-	0.8	-
Apera spica-venti (L.) P. Beauv.	-	1.8	1.0	-	1.2	2.2
Number of weed species	5	10	7	8	9	8

CT[a] - conventional tillage, RT[b] – reduced tillage, HT[c] – herbicide tillage

than in crop rotation and it was higher under RT than under CT.

Crop sequence in crop rotation and tillage systems differentiated the species composition of weeds (Table 5). Plots under the CT system where barley was sown in crop rotation were most numerously populated by: *Sonchus oleraceus, Papaver rhoeas*, and *Galium aparine*; under the RT system – *Avena fatua, Galium aparine, Papaver rhoeas,* and *Apera spica-venti*; and under the HT system – *Avena fatua, Papaver rhoeas*, and *Echinochloa crus-galli*. In cereal monoculture plots under CT the following species were predominant: *Papaver rhoeas, Avena fatua*, and *Fallopia convolvulus*; under RT– *Papaver rhoeas, Galium aparine*, and *Anthemis arvensis*; and under HT – *Papaver rhoeas, Sonchus oleraceus*, and *Fallopia convolvulus*.

Economic Evaluation of Spring Barley Crops

A significant aspect of the study was the evaluation of economic effects of spring barley crops depending on the crop sequence system (crop rotation and cereal monoculture) and tillage system (CT, RT, and HT). The highest value of spring barley production was achieved in crop rotation in sites under RT (EUR 1296.4 ha⁻¹) – Table 6. Comparing barley grown in crop rotation and in cereal monoculture, it must be stated that in crop rotation under each tillage system the value of production was higher than in monoculture. Gross margin value pointed to the reasonableness of growing barley in crop rotation under RT. The value was higher respectively by EUR 123.4 per ha⁻¹ and EUR 263.3 per ha⁻¹ than under HT and CT. In monoculture the analyzed economic category assumed lower values than in crop rotation; however, the best values were achieved under the RT system. For each tillage system, the costs of mineral fertilizers accounted for about 56% of direct costs, while the cost of pesticides was 26%. A significant economic category in the evaluation of production profitability is income from activity calculated as a difference in the value of production and overall costs, taking direct payments into account. The highest production profitability was achieved in crop rotation under the RT system. This method is also recommended on the account of the lowest unit production costs and the profitability ratio amounting to 213.1%. In addition, the best solution in terms of economy was using Roundup 360 SL herbicide under the HT system, and at the same time reducing the costs as a result of lower consumption of fuel than under the CT system (Table 6).

The gross margin and income from activity are supplemented by economic efficiency ratios pointing to the existence of relationships between the analyzed variables (Table 7). Ratio A, determining the amount of direct costs of producing 1 ton of barley grain, testifies to the advantage of RT over CT and HT. This variant generated the lowest direct cost per 1 ton of main product, that is, €38.98. In monoculture, under each tillage system this ratio was higher than in crop rotation, which suggests that this method is more capital-consuming. Ratios B and C indicate large differences between the analyzed variants.

Table 6. Selected economic categories per 1 ha of spring barley under different tillage systems.

Crop sequence (CS)	Tillage systems (TS)			Mean
	CT[a]	RT[b]	HT[c]	
Value of output (EUR ha^{-1})				
Crop rotation	1033.1	1296.4	1195.7	1175.5
Cereal monoculture	906.5	1021.6	697.8	874.8
Mean	969.8	1159.7	946.7	-
Gross margin (EUR ha^{-1})				
Crop rotation	676.8	940.1	816.7	819.3
Cereal monoculture	550.2	665.3	318.9	518.6
Mean	613.5	803.5	567.8	-
Net income with direct payments (EUR ha^{-1})				
Crop rotation	522.2	800.0	681.3	667.8
Cereal monoculture	395.6	525.2	183.5	368.1
Mean	458.9	662.6	432.4	-
Unit cost (EUR t^{-1})				
Crop rotation	87.2	67.5	75.1	76.6
Cereal monoculture	99.4	85.7	128.7	104.6
Mean	93.3	76.6	101.9	-
Profitability ratio (%)				
Crop rotation	165.0	213.1	191.6	189.9
Cereal monoculture	144.8	167.9	111.8	141.5
Mean	154.9	190.5	151.7	-

CT[a] - conventional tillage, RT[b] – reduced tillage,
HT[c] – herbicide tillage

The difference between the value of production per €1 of direct costs in the variant with the highest (RT in crop rotation) and the lowest (CT in crop rotation) levels of the ratio in the analyzed period was on average €12.98. Gross margin per tonne of the main product also points to a clear advantage of the RT system in crop rotation. The profitability of crop growing depends on the yield, production costs, and grain prices. For this reason, the analysis takes into account the ratio expressing the relationship between the selling prices of barley grain and unit cost (D). The most advantageous relationship is observed, likewise for previously mentioned ratios, with reference to the RT system, where the price was twice higher than the unit production cost. Income from activity per 1 ton of grain (E) ranged from €88.79 (RT) to €72.73 (CT) for crop rotation, and from €73.97 (RT) to €37.83 (HT) for monoculture. Direct payments had a significant impact on the level of income from the cultivation of barley. Their income share increased along with reduction in the level of income from activity (Table 7).

Discussion

As a rule, crop productivity in crop rotation is considerably higher than in monoculture, which is due to the fact that in crop rotation the yield-forming possibilities of the habitat, elements of agricultural engineering (fertilization, tillage, plant protection), and the yield-forming potential of crops are utilized in an effective manner [2, 6]. In crop rotation, the plants make much better use of nutrients from fertilizers and soil and are more competitive to weeds, fungal pathogens, and pests. However, more and more often for various reasons (organizational, economic, structural) multi-species crop rotation is abandoned in favour of crop sequence involving 2-3 species of cereal plants or cereal and industrial plants as well as in favour of cereal monocultures. Such a situation leads to an intensified occurrence of agrophages, which in turn necessitates using more pesticides. According to Woźniak and Soroka [13] and Shahzad et al. [10], cereal monoculture leads to increased infestation with weeds and, as a consequence, a decrease in yield. Also in our studies we found an increased number and mass of weeds in cereal monoculture as compared to crop rotation. In addition, grain yield was reduced by 25.6% in comparison to crop rotation. Barley grain yield and the field's weed infestation rate are also determined by the tillage system [10-11]. In our studies grain yield was 16.4-18.4% higher under RT than under CT and HT. Studies carried out by Woźniak and Kwiatkowski [8] showed that higher barley yield was obtained under conventional tillage rather than under reduced tillage, although they found the highest number and biomass of weeds in the study site. Similarly, in our studies RT plots were more infested with weeds than CT and HT plots, whereas the highest rate of weed infestation was recorded in monoculture on RT plots. However, it is important that most weeds occurred only in the barley maturing period, that is, in the second half of the vegetation period, whereas their number and biomass could not be a hazard to barley. On the other hand, weeds that occurred in the first part of the vegetation period, that is, after the emergence of barley, were effectively eliminated by herbicides.

The decision about which grain cultivation method should be used is determined not only by natural conditions or intended quality results but also by economic factors [18-19]. Expenditure connected with the tillage system and the effects of tillage are important elements affecting the profitability of growing crops [20]. Direct production costs (seed material, fertilizers, pesticides, crop insurance) play a special role. These costs are proportionally related to production scale and they have a direct impact on the volume and value of production [21]. Mineral fertilizers have the highest share in the structure of direct costs. As recounted by Nasalski [22], such fertilizers account for 46% of the direct costs of growing spring barley. In our studies,

Tabela 7. Economic efficiency ratios per 1 ha of spring barley under different tillage systems.

Ratios	Crop sequence (CS)	Unit of measure	Tillage systems (TS)			Mean
			CT[a]	RT[b]	HT[c]	
A	Crop rotation	EUR t^{-1}	48.91	38.98	45.44	44.44
	Cereal monoculture		55.74	49.46	77.85	61.02
	Mean		52.33	44.22	61.65	-
B	Crop rotation	EUR	2.94	15.93	13.66	10.84
	Cereal monoculture		11.14	12.55	7.97	10.55
	Mean		7.04	14.24	10.82	-
C	Crop rotation	EUR t^{-1}	94.27	104.34	98.28	98.96
	Cereal monoculture		87.34	93.71	65.75	82.26
	Mean		90.80	99.03	82.01	-
D	Crop rotation	EUR	1.65	2.13	1.92	1.90
	Cereal monoculture		1.45	1.68	1.12	1.42
	Mean		1.55	1.91	1.52	-
E	Crop rotation	EUR t^{-1}	72.73	88.79	81.98	81.17
	Cereal monoculture		62.79	73.97	37.83	58.20
	Mean		67.76	81.38	59.91	-
F	Crop rotation	%	20.38	13.30	15.62	16.43
	Cereal monoculture		26.90	20.26	58.01	35.06
	Mean		23.64	16.78	36.81	-

CT[a] - conventional tillage, RT[b] – reduced tillage, HT[c] – herbicide tillage
Ratios shown in the table: A - Direct costs per 1 tonne of main product; B - Total output per 1 EUR of direct costs; C - Gross margin per 1 tonne of main product; D - Grain selling price to unit cost of production; E - Net income with direct payments per 1 tonne of grain; F - Share of direct payments in net income
Source: Own calculations

the share was even higher and for each tillage system and corresponded to more than 50% of all direct costs. Winnicki et al. [23] achieved similar results. Gross margin is an economic category used for evaluating the profitability of production, and for comparing farms, production systems or production technologies [24]. It is the value of production less direct costs of such production and it allows us to select the crop-growing variant that is the best from the point of view of the economy. The plots where barley was grown by crop rotation, and in particular under the RT system, had a clear advantage in terms of production profitability over other sites. Also, the results achieved by Kovacev et al. [25] confirm the positive impact of tillage technologies limiting the number of treatments on the profitability of crop production. It reduces the consumption of fuel and, as a consequence, decreases the cost of production. In the analyzed experiment, fuel consumption under the RT system, which was characterized by the highest level of profitability, was 32% lower than under the CT system.

Conclusions

In market economy conditions, decisions regarding the selection of a tillage system are primarily based on expenditure and effects. Considering the significance of both production and economic and environmental effects of the production process, the aim of our study was to evaluate different tillage systems used for sowing spring barley in crop rotation and cereal monoculture in terms of their productivity and economic aspects. The analysis of results showed a clear competitive advantage of growing barley in crop rotation over cereal monoculture. This was determined by the production results and, in particular, a significantly higher barley grain yield. From an economic point of view, the advantage was caused by the profitability of production being relatively higher. Among the evaluated tillage systems, the best productivity and economic effects were observed for RT in crop rotation. That system generated the highest yield and the best yield component values. The above-mentioned spring barley growing variant is also recommended with regard to the relatively high values of economic ratios used in the evaluation.

Conflict of Interest

The authors declare no conflict of interest.

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