Article

Not peer-reviewed version

The effect of using elements of sustainable agrotechnology in spring wheat monoculture

Lech Gałęzewski * , Karol Kotwica , Waldemar Kubiak

Posted Date: 14 December 2023

doi: 10.20944/preprints202312.1022.v1

Keywords: crop production; sustainable agricultural technologies; effective microorganisms; harvest residues; catch crop

 doi:10.20944/preprints202312.1022.v1

Article

The Effect of Using Elements of Sustainable Agrotechnology in Spring Wheat Monoculture

Karol Kotwica, Lech Gałęzewski * and Waldemar Kubiak

Department of Agronomy, Faculty of Agriculture and Biotechnology, Bydgoszcz University of Science and Technology, 7 prof. S. Kaliskiego St., 85-796 Bydgoszcz, Poland; lechgalezewski@op.pl (L.G.); karol.kotwica@pbs.edu.pl (K.K.); waldekkubiak@op.pl (W.K)

* Correspondence: lech.galezewski@pbs.edu.pl, lechgalezewski@op.pl; Tel.: +48-523-749-499

Abstract: In sustainable cultivation technologies, the method of managing crop residues and the microbiological activity of the soil supported by the application of effective microorganisms are of particular importance. Therefore, a four-year two-factor experiment was carried out with spring wheat monoculture. Six ways management of organic matter before sowing and tillage (first factor) and the application of microbiological preparations (second factor) were tested - a total - 18 experimental objects. Parameterized: weed infestation, SPAD and LAI indicators, elements of the yield structure and spring wheat yield - all features were significantly determined by the tillage technology used. In most cases, the application of biopreparations does not have a significant impact on the tested features. It was found that the highest yields of spring wheat obtained in the technology: application of EM or UG_{max} microbiological preparations on the shredded straw of the forecrop and mixing it with the soil using a grubber immediately after harvest, sowing of the white mustard catch crop and winter plowing.

Keywords: crop production; sustainable agricultural technologies; effective microorganisms; harvest residues; catch crop

1. Introduction

Agricultural production should expand faster than population growth, without further harm to the environment [1] hence, there is still a search for technologies for the production of food that combine high efficiency with the lowest possible negative impact on the environment. This is particularly important in the case of strategic plant species for feeding humanity, due to the area they occupy. Wheat is one of such species [2,3]. Crop rotation and soil tillage are among key factors impacting cropping system productivity, pest management and soil health [4]. It is widely believed that crop rotation increases yields [5] and ensures sustainable plant production [6,7] combining minimizing environmental impact with high productivity (8). Unfortunately, organizational aspects and limited production space mean that wheat monocultures are still used [9] although this is contrary to sustainable development guidelines and the biodiversity strategy [10].

Sustainable development practices in agriculture include, among others, elements such as: leaving as much plant biomass from crop residues or catch crops in the environment as possible, supporting soil microbiological activity, minimization interference with the soil by reducing tillage [11]. One of the methods of mitigating the negative effects of cereal monoculture is the cultivation of catch crops [12]. Catch crops improve physical, chemical, and biological properties of soil [13, 14]. Likewise, crop residues are an important resource not only as a source of significant quantities of nutrients for crop production but also affecting soil physical, chemical, and biological functions and properties and water and soil quality. When crop residues are returned to the soils, their decomposition can have both positive and negative effects on crop production and the environment [15]. In terms of phytosanitary concerns, leaving crop residues of plants grown in monoculture on the field surface or mixing them with the soil raises doubts. High microbiological activity helps limit the development of pests and plant pathogens and accelerates the decomposition of organic matter. Increasing this activity can be achieved by applying effective microorganisms to the soil [16]. Tillage

 doi:10.20944/preprints202312.1022.v1

is an agrotechnical practice that strongly affects the soil environment. Its effect on soil properties depends on the system and, more specifically, on the degree of soil inversion and loosening. Traditional plow cultivation is associated with many unfavorable environmental consequences, which is the reason for using alternative tillage methods [17]

The hypothesis assumed is that in spring wheat monoculture, various methods of managing post-harvest residues, the use of catch crops and various tillage methods combined with the application of microbiological preparations will be a beneficial alternative to traditional cultivation in which all above-ground biomass is removed from the field and tillage is based on a plow system. In the context of this hypothesis, the aim of the research was to compare the effect of 18 spring wheat cultivation technologies in a 4-year monoculture.

2. Materials and Methods

2.1. Experiment Site

The research was carried out in the years 2010-2014 in Tarnowo Górne (52°55′58″N 18°05′54″E), Kuyavia-Pomerania Voivodeship, Poland. Field experiments were carried out on soil classified by the WRB [24] as Luvisol. The soil grain-size composition was: 0-20cm - 41.4% sand (2–0.05 mm), 52.3% silt (0.05–0.002 mm), 6.3% clay (<0.002 mm).

2.2. Experiment Design

Experiment located for four years in exactly the same place - spring wheat monoculture. The field experiments were carried out in the randomized split-plot design, with four replications. A single plot area was 200 m^2 (8 m x 25 m).

Experimental factors:

Factor A— management of organic matter before sowing and tillage (the text also uses the abbreviation "tillage method" interchangeably):

- straw + post-harvest grubber + winter plowing - A1
- mulch + winter plowing - A2
- mulch + spring plowing - A3
- straw + catch crop + winter grubber + spring grubber - A4
- straw + catch crop + winter plowing - A5
- stubble + post-harvest grubber + winter plowing - A6

Factor B— applying microbiological preparations:

- EM-1 (B1)
- UG_{max} (B2)
- control - without the use of microbiological preparations (B3)

A total of 18 experimental objects. The experiment was carried out in 4 replications - 72 experimental plots. In each of the four years of the experiment, each object was located in exactly the same place - a static experiment.

Explanations:

- straw – in 2010, winter rapeseed straw, in subsequent years spring wheat straw - crushed during harvesting
- straw + post-harvest grubber – crushed straw of forecrop mixed with the soil using a grubber to a depth of 25 cm. Performed immediately after harvesting the forecrop
- grubber – Grubber Lemken Terra Cult vibro
- winter grubber – grubber used in the second decade of November
- spring grubber – grubber applied a week before sowing
- winter plowing – plowing to a depth of 25 cm in the second decade of November – Kverneland EM 100 reversible plow /4 furrow/ with Packomat
- spring plowing – plowing to a depth of 20 cm two weeks before sowing spring wheat
- mulch – shredded forecrop straw left on the soil surface

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 December 2023 doi:10.20944/preprints202312.1022.v1

- catch crop - white mustard sown in the amount of 15 kg·hm^{-2} of seeds in the 2nd-3rd decade of August

- stubble – straw collected and transported outside the field

- EM-1 – application 20.0 dm^{3}·hm^{-2} on crushed straw or stubble, - https://greenland.pl/produkt/preparat-em-1/

- UG$_{max}$ - application of 1.0 dm^{3}·hm^{-2} on crushed straw or stubble, - http://bogdan.agro.pl/

2.3. Precipitation and air temperature

Precipitation and thermal conditions during the field tests were described based on the results of standard meteorological measurements. The sums of monthly precipitation and average monthly air temperatures in the years 1949-2009 are summarized in Table 1. Deviations of monthly rainfall sums and average monthly temperatures in the years of study implementation from the average monthly rainfall sums and average monthly temperatures for the years 1949-2009 are presented in Figures 1 and 2.

Table 1. Sums of monthly precipitation and average monthly air temperatures in the years 1949-2009.

	Month											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
rainfall sums [mm]	21.9	22.3	29.9	31.6	49.1	69.7	79.9	57.5	47.3	35.6	32.6	30.1
average monthly air temperatures	-1.8	-0.5	2.8	7.9	13.9	16.7	18.6	18.5	13.2	8.5	3.1	-1.1

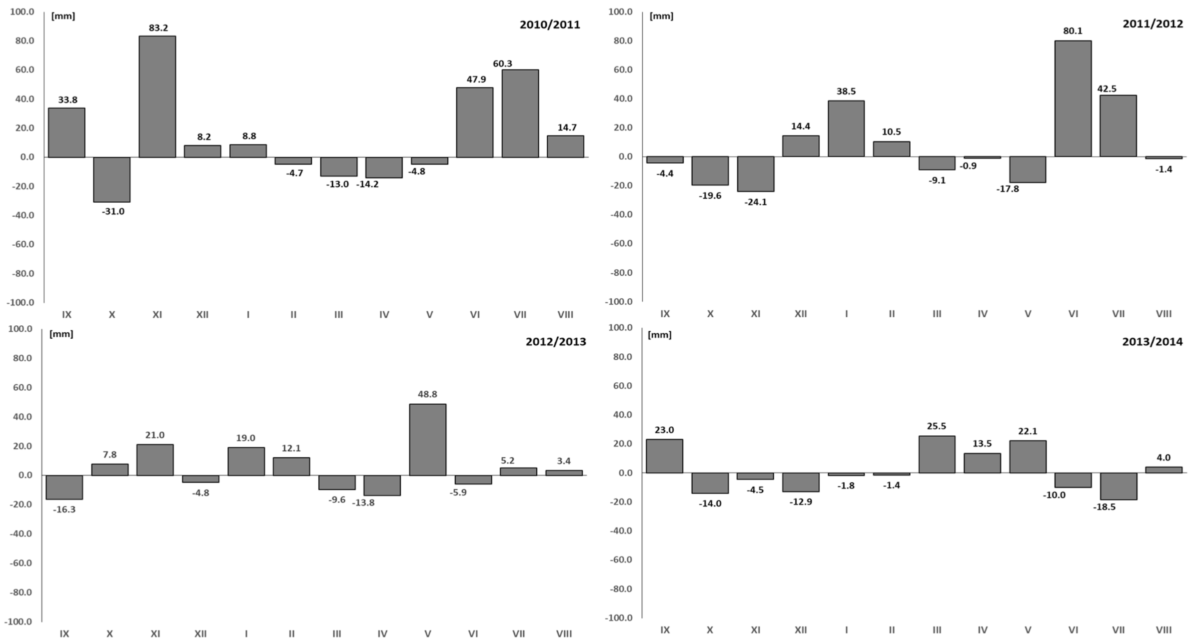

Figure 1. Deviations [mm] of monthly rainfall sums in the years of study implementation from the average monthly rainfall sums for the years 1949-2009.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 December 2023 doi:10.20944/preprints202312.1022.v1

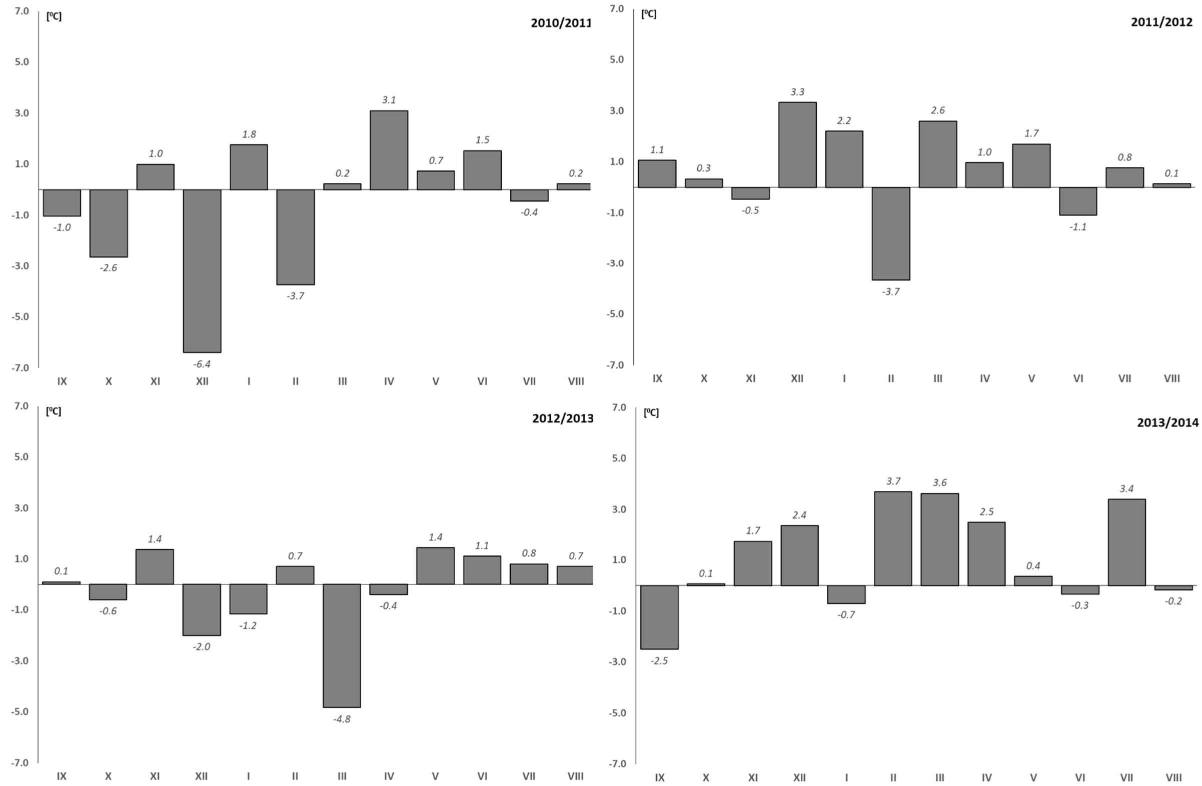

Figure 2. Deviations [⁰C] of average monthly temperatures in the years of study from average monthly temperatures in the years 1949-2009.

The amount of rainfall in the period from September to November in all four years of the study generally did not hinder the correct performance of pre-sowing tillage. They were also beneficial for the rapid growth and biomass production of white mustard grown as a catch crop.

Too little rainfall in February-April was not conducive to quick and uniform emergence of spring wheat. Only 2014 turned out to be relatively favorable in this respect. In 2013, unfavorable rainfall conditions in early spring were combined with the return of heavy frost in the second and third decade of March. This resulted in the need to re-sow spring wheat. The rainfall deficit in April and May in 2011 and 2012 was compensated by the rainfall of the next two months. June and July rainfall totals in 2011 and 2012 exceeded the rainfall needs of wheat. Plants had worse conditions in 2013 and 2014 - severe rainfall deficits in the months of June and July worsened the unfavorable early spring situation. The least favorable (deficit) rainfall distribution for the proper vegetation of spring wheat occurred in the last year of its cultivation, i.e. in 2014.

In all years of the study, after harvest, there were favorable conditions for proper post-harvest tillage, good mixing of shredded straw with the soil and effective application of preparations containing microorganisms.

2.4. Elements of Agrotechnical Practises

Certified seed material of spring wheat variety 'Tybalt' was sown at a density of 450 grains·m^2 in March at a spacing of 10.5 cm, to a depth of 4 cm. The seed material was treated with the Maxim Star dressing (cyproconazole + difluorobenzole) at a dose of 200 g of the preparation ·100 kg^{-1} grain. For sowing, a 4 m cultivation and sowing unit with an active cyclotiler section and a Horsch seeder equipped with disc coulters and kneading rollers was used. During direct sowing, the active sections of the cyclotiler were disconnected.

In spring, before pre-sowing cultivation, mineral fertilization was applied: N - 60kg·hm^{-2} (ammonium sulphate), P_2O_5 30 kg·hm^{-2} (granulated superphosphate), K_2O - 90 kg·hm^{-2} (potassium

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 December 2023 doi:10.20944/preprints202312.1022.v1

salt). After sowing, nitrogen was applied twice: in the BBCH 32 phase - 60 kgN·hm^{-2} and in the BBCH 51 phase - 60 kg N·hm^{-2}.

Herbicyd Mustang Forte 195 SE (0,8 dm^{3}·hm^{-2} florasulam+aminopyralid+2,4 D) together with the growth regulator Moddus 250 EC (0,8 dm^{3}·hm^{-2} trineksapak etylu), was applied in the BBCH 32 phase. Fungicide protection: Swing Top 183 SC (1,5 dm^{3}·hm^{-2} dimoksystrobina+epoksykonazol) applied in the BBCH 39 phase. Pesticides were applied using a sprayer AMAZONE UX5200 24m

2.5. Samples and Measurements

During the wheat growing season and after harvest, biometric characteristics of plants from all plots were assessed:

- plant density BBCH 11-12 (the results are not presented in the manuscript),
- chlorophyll index SPAD (Yara N-testerTM https://www.yara.my/contentassets/6d5ba39b1a364a33be1e4e6b6b2a2be1/n-tester-instruction-manual.pdf/),
- leaf area index (LAI) (plant canopy analizer Li 2000 (Li Cor, USA). https://licor.app.boxenterprise.net/s/q6hrj6s79psn7o8z2b2s),
- stem length – measured from the soil surface to the end of the ear,
- ear density BBCH 89,
- weight of a thousand grains,
- grains per ear,
- grain yield

2.6. Data Analysis

The dataset of measurements was subjected to statistical analysis. Plant biometrics were subjected to two-ways analysis of variance. This analysis carried out separately for each growing season, and a synthesis was performed for the four years of research in a mixed model (vegetation seasons—random, experimental factors—fixed). A model suitable for Split-plot was used. The first-order factor was the management of organic matter before sowing and tillage, the second-order factor was the use of microbiological preparations. Tukey's post-hoc test ($LSD_{0.05}$) was used to assess the significance of differences between the mean values of each feature.

3. Results and discussion

3.1. significance of the influence of factors

Weather conditions in subsequent years of research were very different in terms of the amount and distribution of rainfall and temperature (Figures 1 and 2). Rainfall, temperature and solar radiation are important climatic factors that determine growth and development differently at different growth stages and ultimately yields. [18]. Variable weather in the years of the study significantly modified the influence of the tillage method on most features of spring wheat (Years x A), and no such relationship was found between variable weather in the years and the application of microbiological preparations (Years x B) (Table 2). ANOVA showed that the tillage method determined all observed features of spring wheat. The application of microbiological preparations only determined the total number of weeds. The interaction of factors A and B was not dependent on variable weather conditions in the years of study. The interactive effect of factors A and B was found in the case of 5 wheat traits, including grain yield.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 December 2023 doi:10.20944/preprints202312.1022.v1

Table 2. Significance of the influence of factors and their interactions on the features of spring wheat plants.

Feature	Years x factor		Factor		Years x factor interaction	factor interaction
	I	II	I	II		
Density of *Echinochloa crus-galli*	+	-	+	-	-	-
Density of *Viola arvensis*	+	-	+	-	-	-
Density of *Stellaria media*	+	-	+	-	-	-
Density of *Chenopodium album*	+	-	+	-	-	-
Density of *Apera spica-venti*	+	-	+	-	-	-
Density of *Avena fatua*	+	-	+	-	-	-
Density of other weed species	-	-	+	-	-	-
Total weed density	+	-	+	+	-	-
Chlorophyll index SPAD (BBCH 32-37)	-	-	+	-	-	-
Chlorophyll index SPAD (BBCH 51-55)	-	-	+	-	-	+
Leaf area index LAI (BBCH 37-39)	-	-	+	-	-	-
Leaf area index LAI (BBCH 49-51)	+	-	+	-	-	-
Leaf area index LAI (BBCH 75-87)	-	-	+	-	-	+
Leaf area index LAI - średnio	-	-	+	-	-	+
Ear density	-	-	+	-	-	-
Grains per ear	+	-	+	-	-	-
Weight of a thousand grains	+	-	+	-	-	-
Grains per ear	-	-	+	-	-	+
Grain yield	+	-	+	-	-	+

(+) – significant impact; (-) – no significant impact; .

3.2. weed infestation

The research showed a significant impact of variable conditions over the years on the influence of tillage methods on the weed infestation of spring wheat by the analyzed weed species and the total number of weeds (Table 3). Therefore, the results of the statistical analysis for these species and total weed infestation are presented for each year and on average over the years of the study.

Leaving shredded straw as mulch on the field surface from harvest until spring plowing (A3) resulted in the highest overall weed infestation (Table 3). The total number of weeds in this method of tillage was significantly, on average over the years, 49.6 pcs.m^{-2} higher than the number of weeds in the other variants of tillage, except for no-plow tillage (A4). The level of weed infestation in spring wheat tillage without plowing (A4), in which straw and catch crop biomass was mixed with the surface layer of soil, turned out to be only slightly, to a statistically insignificant degree, lower than after mulch and spring plowing (A3). The obtained results do not confirm the conclusions of other authors [19, 20] that catch crops (especially white mustard) can be an effective way to reduce the number and weight of weeds in monoculture. However, this discrepancy may be due to the fact that catch crops in the studies in this manuscript occurred in different tillage variants and on this basis it cannot be clearly stated about their protective effect or lack thereof in the context of weed infestation. However, our own results are consistent with other studies [21] in terms of the negative impact (increase in weed infestation) of mulch lying on the field surface. This may be due to the limited effectiveness of herbicides. In our own research, the use of winter plowing in spring wheat agrotechnology contributed to reducing weed infestation. Weed infestation was reduced to the greatest, statistically significant extent, by classic plowing without straw (A6), under the influence of which the total number of weeds per unit area was reduced by more than half, i.e. by 52.9% in relation to the tillage method that most strongly infests spring wheat (A3). The use of winter plowing in other tillage methods in which biomass was plowed (A1, A2, A5) did not result in a significant increase in weed infestation compared to traditional tillage (A6). These results are confirmed by the studies of other authors [22, 23, 24], who noticed that limiting the use of plowing and leaving crop residues causes changes in the botanical composition of weeds and an increase in the number of weeds, forcing increased herbicide protection. However, there is no consensus in the literature in this respect, e.g. Fonteyne et al [25] claims that weed density and biomass were lower in long-term conservation agriculture than in conventional cultivation. The cited authors also claim that the three components of conservation agriculture (no-till, residue retention, and crop rotation) reduced weed biomass, which was lower when all three components were used together. This does not therefore refer to compensation for weed infestation occurring in wheat monoculture.

The tillage method caused significant changes in the weed community (Table 3). In individual years and on average during the research period, *Apera spica-venti* turned out to be the most numerous weed. Indeed, the highest number of individuals of this species was determined in the site where the mulch made of shredded straw was plowed only with spring plowing (A3) and in the conditions of no-plow tillage (A4). Moreover, it was observed that the annual use of spring plowing (A4) promoted an increase in the number of *Apera spica-venti* individuals in subsequent years. The use of other tillage methods significantly reduced the occurrence of *Apera spica-venti*. The number of this species was most effectively reduced by classic tillage - plowing without straw (A6), which reduced its occurrence by an average of 70.4% in the most weedy areas (A3, A4). Relatively numerous weeds in the spring wheat canopy were also *Viola arvensis*, *Chenopodium album* and *Stellaria media*, which, like *Apera spica-venti*, were most numerous under tillage with spring plowing (A3). The use of winter plowing (A6, A1, A2, A5) limited the number of *Chenopodium album* in subsequent years of the study. However, the number of *Stellaria media* increased in subsequent years in each of the six methods of tillage. A similar trend was observed for *Echinochloa crus-gali* and *Avena fatua*. These weeds were relatively few in the spring wheat canopy, but their numbers generally increased in subsequent years of implementing specific methods of farming.

Table 3. The influence of the method of tillage for spring wheat on the number of weeds [pcs. m^{-2}] in individual years of research and averages from 2011-2014.

Weed species		Management of organic matter before sowing and tillage						Mean	$LSD_{0,05}$
		A6	A1	A2	A3	A4	A5		
Echinochloa crus-galli	*2011*	3.9	3.3	3.6	3.5	3.3	3.6	3.5	*n.s.***
	2012	2.1b*	3.2ab	3.3ab	3.8a	3.9a	2.7ab	3.2	*1.49*
	2013	3.4b	4.2ab	4.3ab	6.1a	6.0a	4.2ab	4.7	*2.16*
	2014	1.7d	3.4cd	3.6abc	6.8a	5.3ab	2.9cd	4.0	*1.81*
	2011-2014	2.8c	3.5bc	3.7bc	5.0a	4.6ab	3.3c	3.8	*1.24*
Viola arvensis	*2011*	4.8c	6.4bc	7.0b	9.3a	6.6bc	5.7bc	6.6	*2.18*
	2012	7.5b	8.7ab	11.1a	10.0ab	11.0a	9.2ab	9.6	*2.91*
	2013	6.5b	9.8b	11.1b	16.2a	9.1b	8.7b	10.2	*4.90*
	2014	7.0c	8.4c	16.5a	13.4b	8.0c	7.3c	7.0	*2.63*
	2011-2014	6.4c	8.3c	11.4ab	12.2a	8.7bc	7.7c	6.4	*3.01*
Stellaria media	*2011*	2.1d	3.9bc	4.1bc	5.3ab	6.4a	2.3cd	4.0	*1.61*
	2012	3.9b	3.8b	4.1b	4.6b	6.7a	4.9ab	4.7	*2.09*
	2013	4.1c	5.2bc	5.8b	8.6a	7.6a	4.9bc	6.0	*1.50*

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 December 2023 doi:10.20944/preprints202312.1022.v1

	2014	5.3c	6.1c	6.9bc	9.8a	9.4ab	5.7c	7.2	*2.71*
	2011-2014	3.8b	4.7b	5.2b	7.1a	7.5a	4.4b	3.8	*1.80*
Chenopodium album	*2011*	6.8	6.7	7.0	7.4	6.1	7.7	6.9	*n.s.*
	2012	5.8	6.3	5.8	8.5	6.9	7.3	6.8	*n.s.*
	2013	5.1b	5.5b	5.1b	14.9a	10.7a	4.3b	7.6	*4.23*
	2014	5.0c	6.0bc	5.6bc	17.2a	9.6b	5.5c	8.1	*4.08*
	2011-2014	5.7b	6.1b	5.9b	12.0a	8.3b	6.2b	5.7	*3.54*
Apera spica-venti	*2011*	7.8d	13.2bc	10.8cd	17.3a	15.6ab	9.7d	12.4	*3.47*
	2012	7.7d	17.0c	18.4bc	23.5ab	24.9a	13.8c	17.6	*5.69*
	2013	8.9d	14.6c	12.5cd	37.5a	32.6b	10.6cd	19.5	*4.44*
	2014	8.4b	12.5b	14.4b	38.0a	31.7a	10.5b	19.2	*6.60*
	2011-2014	8.2b	14.3b	14.0b	29.1a	26.2a	11.1b	8.2	*10.38*
Avena fatua	*2011*	1.8	2.2	2.3	2.0	2.1	1.4	2.0	*n.s.*
	2012	2.1	2.3	2.3	2.6	3.1	2.8	2.5	*n.s.*
	2013	1.8b	3.2ab	3.2ab	5.0a	4.3a	2.6b	3.3	*2.21*
	2014	1.3b	4.1ab	4.8a	5.6a	5.1a	3.8ab	4.1	*2.86*
	2011-2014	1.7c	2.9ab	3.2ab	3.8a	3.6ab	2.6bc	3.0	*1.09*
Others	*2011-2014*	10.9c	14.0ab	13.7ab	14.7a	13.8ab	12.5bc	10.9	*1.88*
Weeds Total	*2011*	38.1d	47.0bc	47.0bc	57.4a	54.7ab	43.6cd	48.0	*8.82*
	2012	41.1d	55.0c	59.2bc	67.7ab	70.0a	53.8c	57.8	*9.10*
	2013	40.9e	57.8c	55.8cd	105.4a	84.9b	47.5de	65.4	*8.80*
	2014	38.1e	56.0cd	65.7c	104.9a	81.6b	46.9de	65.5	*10.41*
	2011-2014	39.5c	53.9bc	56.9bc	83.9a	72.8ab	48.0c	59.2	*20.28*

* The data marked with different letters (in the lines) were significantly different at p = 0.05, according to Tukey's test.; **not significant.

The application of biopreparations also had an impact on the number of weeds in the conducted research (Figure 3). On average, for the tillage method, the use of the UGmax soil conditioner turned out to be unfavorable in this aspect, which increased the number of weeds to a significant extent compared to the control object. The presented results are not confirmed by other studies performed in similar conditions [26]. The authors of the cited studies claim that the increased weed density due to straw application to the soil was minimized to different extents by the use of effective microorganisms, especially the density of Apera spica-venti, Capsella bursa pastoris, Chenopodium album and all other weeds. Degradation of this straw by the effective microorganisms applied during post-harvest cultivation led to a reduced total weed infestation and reduced density of Apera spica venti, Capsella bursa pastoris, Chenopodium album and all other weeds. It should be added, however, that these results were obtained for the EM preparation, not UG_{max}. Moreover, a different type of tillage was used in the studies cited above. The significantly higher weed infestation obtained after using UG_{max} in our own research cannot be directly compared with the research of other authors due to the fact that it is an average of various tillage methods. This does not change the fact that it is difficult to explain without in-depth analyzes of the causes of the phenomenon why both microbiological preparations had different effects on weed infestation.

 doi:10.20944/preprints202312.1022.v1

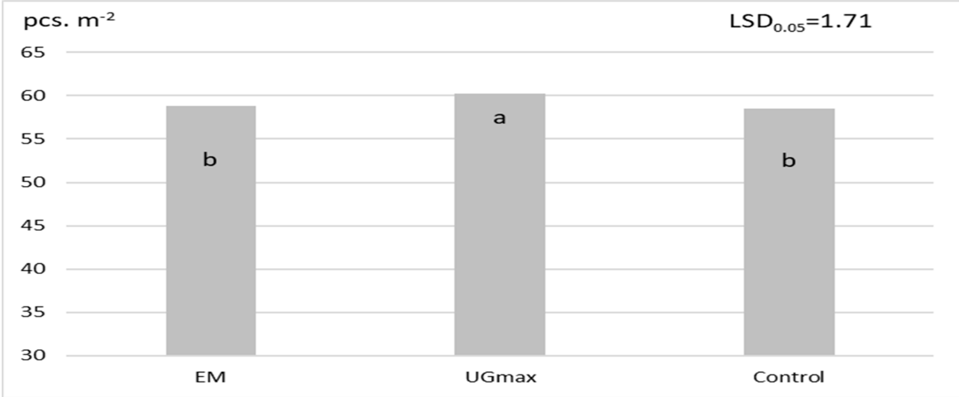

Figure 3. Average total weed density [pcs. m^{-2}] in spring wheat depending on the applied biopreparations (average from 2011-2014).

3.3. Wskaźnik zieloności liści SPAD

The SPAD index in the BBCH 32-37 phase was lower for all objects than in the BCH 51-55 phase (Table 4). However, in both determination dates, the relationships between the objects in terms of variation in the value of the examined feature were similar. The lowest value of the SPAD index in both dates was recorded in spring wheat in the A3, A2 and A4 tillage variants. In the BBCH 51-55 phase, the SPAD index readings for the remaining tillage variants (A5, A1, A6) turned out to be significantly higher. In the BBCH 32-37 phase, the SPAD index readings on objects A5, A1, A6 were statistically higher in relation to objects A3 and A4.

Table 4. Values of the SPAD index of spring wheat in the BBCH 32-55 phase depending on the variants of agrotechnics and the application of microbiological preparations (average from 2011-2014).

Applying microbiological preparations [B]	Management of organic matter before sowing and tillage [A]						Mean [A]
	A6	A2	A3	A4	A5	A1	
			BBCH 32-37				
Mean [B]	460	434	409	418	460	466	441
$LSD_{0.05}$ dla: A=31.0; B=n.s. B/A=n.s; A/B=n.s.							
			BBCH 51-55				
EM	496	460	440	469	516	515	483
UG	493	460	438	472	523	533	486
Control	507	468	450	451	475	463	469
Mean [B]	499	463	443	464	505	504	479
$LSD_{0,05}$ dla: A=31.9; B=n.s. B/A=41.0; A/B=51.6							

In the BBCH 51-55 phase, a significant relationship was noted between farming methods and the application of biopreparations in shaping the SPAD index (Table 4). SPAD readings in the A5 and A1 tillage variants to which biopreparations were applied were higher than in A5 and A1 without the application of microbiological preparations. No such relationship with the application of biopreparations was found in objects with other tillage methods. It is known that the factor that has the strongest effect on the chlorophyll SPAD index is nitrogen fertilization, while factors such as

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 December 2023 doi:10.20944/preprints202312.1022.v1

tillage and the management of crop residues have a smaller impact [27]. In their research, the cited authors obtained a similar relationship to the results presented in this article - leaving harvest residues significantly reduced the SPAD of spring wheat. However, with regard to tillage, the research is not clear. Our own results are confirmed by other studies conducted in Poland [30], which show that plow tillage gives higher SPAD values in spring wheat than reduced tillage. However, other authors [28, 29] prove that when plowing was used, they obtained lower SPAD values for spring wheat than with other, reduced tillage systems - which does not correspond to own results presented in this manuscript.

3.4. Leaf area index LAI

LAI measured in the spring canopy of wheat had the highest values in the BBCH 49-51 phase and the lowest values in the BBCH 37-39 phase. At no time was there a significant effect of the application of microbiological preparations on LAI. In each of the three measurement dates, and on average for the dates, the LAI index was significantly, in a similar way, differentiated between the objects of individual tilage methods (Table 5). The lowest LAI in the spring wheat canopy occurred in the A4 and A3 variants of tillage. In the BBCH 49-51 phase, the difference in the average value of the LAI A3 and A4 indices in relation to other tillage methods was 0.21. In the further growing season, the difference between the foliage of the spring wheat canopy in objects A4 and A3 and the remaining tillage methods increased and amounted to 0.52 (BBCH 49-51) and 0.38 (BBCH 75-87).

The average value of the LAI index from three measurement dates for most of the analyzed agricultural methods was independent of the use or lack of application of biopreparations. Only in variant A1, the lack of use of biopreparations resulted in a significant reduction in the foliage of the canopy (Table 5).

Table 5. Average values of the LAI index for spring wheat for development phases depending on tillage variants and application of microbiological preparations (average from 2011-2014).

Applying microbiological preparations [B]	**Management of organic matter before sowing and tillage [A]**						**Mean [A]**
	A6	A2	A3	A4	A5	A1	
			BBCH 37-39				
Mean [B]	2.36	2.35	2.16	2.10	2.32	2.31	2.27
LSD_{005} A=0.154; B=n.s. B/A=n.s.; A/B=n.s.							
			BBCH 49-51				
Mean [B]	3.74	3.72	3.25	3.15	3.72	3.68	3.54
LSD_{005} A=0.359; B=n.s. B/A=n.s.; A/B=n.s.							
			BBCH 75-87				
Mean [B]	2.71	2.73	2.34	3.37	2.79	2.68	2.77
LSD_{005} A=0.250; B=n.s. B/A=n.s.; A/B=n.s.							
			BBCH 37-87 (mean)				
EM	2.90	2.99	2.62	2.61	2.93	2.99	2.84
$UG_{max.}$	2.98	2.98	2.49	2.43	3.00	2.97	2.81
Control	2.94	2.84	2.64	2.59	2.92	2.70	2.77
Mean [B]	2.94	2.94	2.58	2.54	2.95	2.89	2.81
LSD_{005} A=0.267; B=n.s. B/A=0.182; A/B=0.323							

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 December 2023 doi:10.20944/preprints202312.1022.v1

3.5. Elements of yield structure

In the conditions of the multi-year experiment, there was no statistically proven impact of the applied biopreparations or their interaction with tillage methods on the number of ears, the number of grains per ear and the weight of one thousand grains. The values of the indicated features were independently influenced by the tillage variants (Tables 2 and 6)

The highest ear density was recorded in spring wheat sown after winter plowing (A1, A2, A5, A6) (Table 6). However, a significantly lower number of ears was found on objects covered with mulch made of shredded forecrop straw until spring plowing (A3). This method of tillage (A3) for wheat contributed to better filling of the ear with grain, a higher weight of a thousand grains and a higher weight of grain per ear compared to other tillage variants. Statistically, such a relationship was confirmed in relation to the differences in the number of grains in the ear between wheat in vawiat A3 in relation to A4, A1 and A2. Generally speaking, in objects where wheat had a larger density of ears, a tendency was observed to have a smaller number of grains per ear and a smaller thousand-grain weight.

The weight of grain per ear was determined by the variants of agrotechnics but also by their interaction with the biopreparations used. The interaction between these factors mainly comes down to the fact that in all agrotechnical variants except variant A1, the application of biopreparations had a small, generally unconfirmed effect on the weight of grain per ear. In the case of the A1 variant, the application of EM and UGmax resulted in a significant increase of 11.7-13.0% compared to the control without the application of biopreparations.

Table 6. Values (average from 2011-2014) of the yield structure elements depending on the tillage variants and the application of microbiological preparations.

Applying microbiological preparations [B]	**Management of organic matter before sowing and tillage [A]**						**Mean [A]**
	(A6)	A2	A3	A4	A5	A1	
Ear density [pcs. m^{-2}]							
Mean [B]	392	402	357	374	392	402	387
LSD$_{0.05}$ A=21.3; B=n.s. B/A=n.s.; A/B=n.s.							
Grains per ear [pcs.]							
Mean [B]	38.5	37.8	40.2	38.4	38.8	38.0	38.6
LSD$_{0.05}$ A=1.746; B=n.s. B/A=n.s.; A/B=n.s.							
Weight of a thousand grains [g]							
Mean [B]	45.2	42.7	46.1	44.3	46.0	43.5	44.6
LSD$_{0.05}$ A=2.35; B=n.s. B/A=n.s.; A/B=n.s.							
Weight of grains per ear [g]							
EM	1.55	1.54	1.62	1.56	1.61	1.61	1.58
UG$_{max}$	1.62	1.58	1.63	1.56	1.61	1.59	1.60
K	1.62	1.59	1.66	1.61	1.60	1.42	1.58
Mean [B]	1.59	1.57	1.64	1.58	1.61	1.54	1.59
LSD$_{0.05}$ A=0.06; B=n.s. B/A=0.13; A/B=1.3							

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 14 December 2023 doi:10.20944/preprints202312.1022.v1

3.6. Grain yield

Spring wheat grain yield was determined by tillage variants (Figure 4) and their interaction with the application of microbiological preparations (Figure 6). However, no independent, statistically confirmable effect of microbiological preparations was not found (Figure 5).

On average for years, spring wheat yielded the highest (5.65-5.89 Mg·hm^{-2}) in tillage variants A1, A2, A5 - where winter plowing was used (Figure 4). A similar result (5.50 Mg·hm^{-2}) was obtained for the control object, i.e. with traditional tillage (A6). The highest yield (5.89 Mg·hm^{-2}) was found in varian A5 (straw + catch crop + winter plowing), wheat yielded significantly lower in the facility A3 and A4 - yield lower by 0.95 Mg·hm^{-2} (16.1%) and 0.67 Mg·hm^{-2} (11.3%).

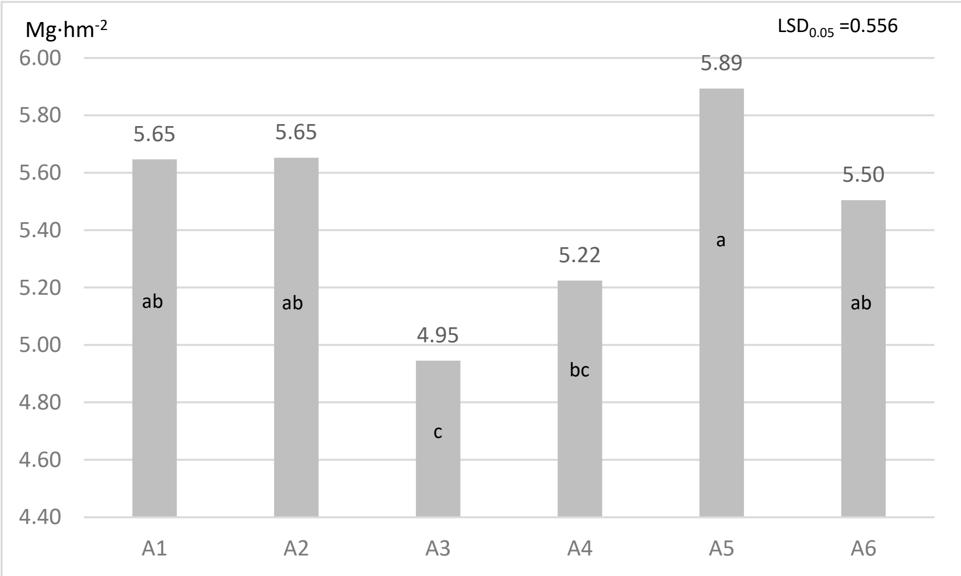

Figure 4. Spring wheat grain yield [Mg·hm^{-2}] depending on management of organic matter before sowing and tillage (average from 2011-2014).

Other studies conducted in Poland [31] confirm that plow tillage resulted in a higher density of ears and the number of grains per ear, which consequently resulted in an increase in spring wheat grain yield compared to conservation tillage. The ears density and grain yield obtained from plots where stubble catch crops were sown were significantly higher than on plots after control plots. The higher yield of spring wheat on the plot after stubble catch crops was largely due to the increased number of ears per unit area. Although the above-mentioned studies were similar to our own results, it should be noted that the spectrum of management of organic matter before sowing and tillage was different. With different climatic conditions for winter wheat in a fallow system, the meta-analysis performed by Adil et al. [32] proves that in dry areas, zero tillage and mulching with straw is the most recommended practice leading to increased water retention and ultimately an increase in yield. In the cited studies, one can see analogies to our own results - as the data indicate (Figure 7), the objects with mulch (A2 and A3) were characterized by the smallest yield fluctuations in the four years of the study. The ambiguity of the impact of crop residue return on wheat yield depending on climatic conditions is confirmed by the meta-analysis of Qi et al. [33] although this is generally a beneficial practice. According to Pawłowski et al. [34], the white mustard intercrop significantly increased the yield of spring wheat in monoculture, and the authors also demonstrated the advantage of traditional, i.e., plowed tillage over non-plowed tillage. This confirms the results presented in this article. This reaction can be attributed to a beneficial effect on the chemical properties of the soil [35].

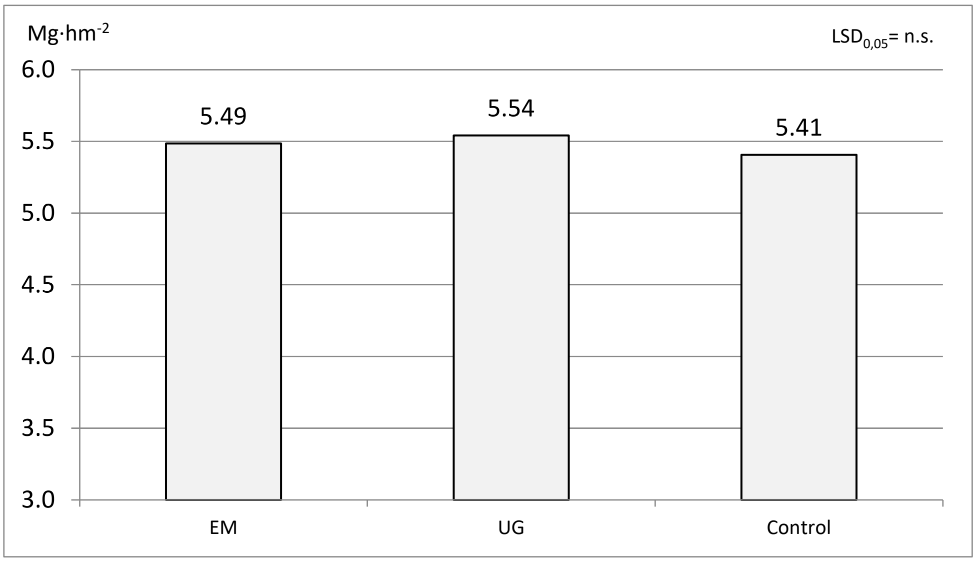

Figure 5. Spring wheat grain yield [Mg·hm⁻²], depending on the application of microbiological preparations in spring wheat monoculture (average from 2011-2014).

For tillage variants A3, A4 and A6, there was no statistically confirmable impact of the application of biopreparations on the yield of spring wheat (Figure 6). The significant role of biopreparations in shaping wheat yield was revealed in variants in which soil cultivation included winter plowing (A1,A2,!5). For those variants in which straw, crushed after harvesting, was mixed with soil with a grubber (A1 and A5), treating stubble with biopreparations turned out to be beneficial, resulting in a significant increase in yield, and both biopreparations gave a similar effect. In variant A2, the biopreparations did not bring the expected, beneficial results; on the contrary, a decreasing tendency in spring wheat yield was noted for the UGmax preparation, statistically confirmed in the case of the EM preparation.

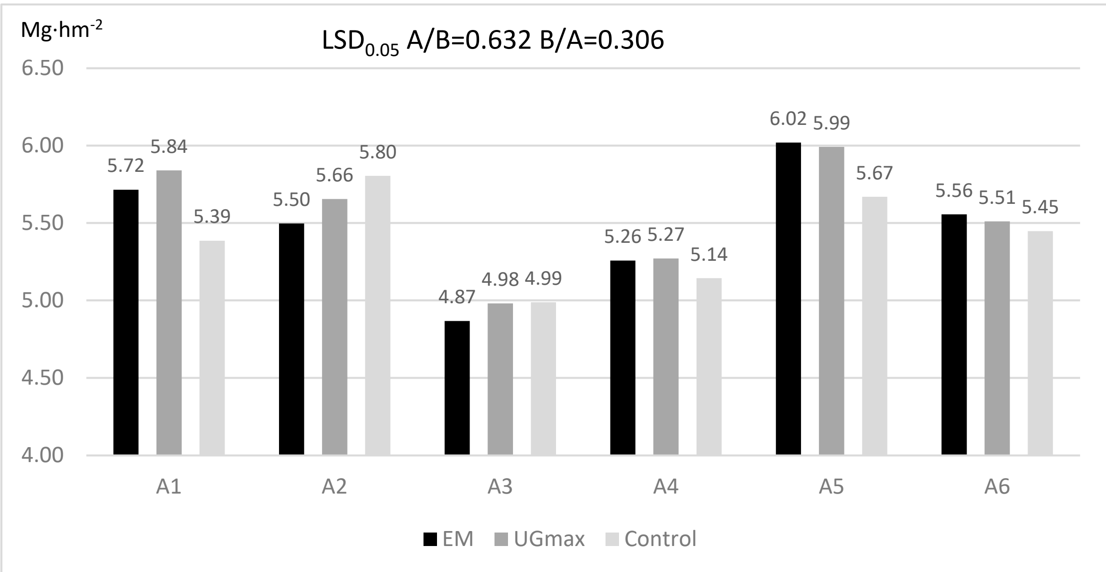

Figure 6. Grain yield [Mg·hm-2] of spring wheat depending on the method of tillage and the application of microbiological preparations.

Spring wheat was grown in the same place for four consecutive years. The analysis of variance showed a significant effect of the interaction of years with management of organic matter before sowing and tillage on grain yield (Figure 7). However, there was no relationship indicating a clear reduction in yield with each year of monoculture. While in the second and third year of monoculture yields generally decreased, in the last year (fourth year of monoculture) yields increased significantly and for some objects were the highest during the entire experiment. This indicates that the weather pattern determines the yield to a greater extent than agrotechnical factors.

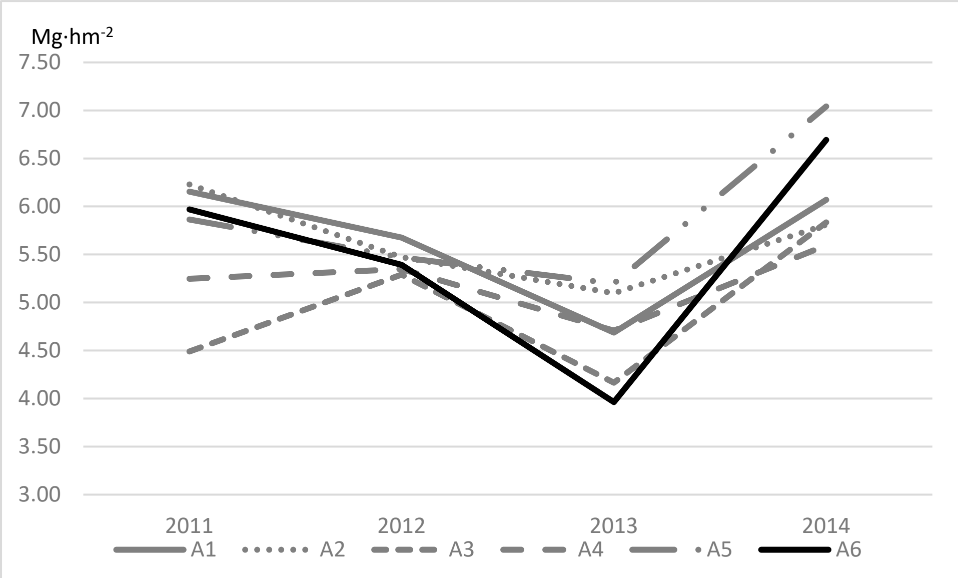

Figure 7. Grain yield [Mg·hm^{-2}] of spring wheat depending on the management of organic matter before sowing and tillage in the years of research.

4. Conclusions

Six methods of management of organic matter before sowing and tillage in combination with the application of microbiological preparations tested in spring wheat momoculture resulted in yield differentiation on average for the four years of research in the range of 4.87 - 6.02 Mg·hm^{-2}. The variability of yields over the years did not reveal the impact of the increasing monoculture period on the reduction of production effects. Management of organic matter before sowing and tillage determined all biometric features of spring wheat and weed infestation - this ultimately translated into yield. The application of microbiological preparations had relatively little importance in shaping individual plant characteristics, but ultimately shaped the yield of spring wheat interactively with organic matter before sowing and tillage. In spring wheat monoculture, it was not always reasonable to implement elements of sustainable cultivation, such as: introducing organic matter into the soil in the form of straw or catch crops or applying microbiological preparations - many variants did not give better results than traditional technology in which no organic matter was introduced into the soil. However, the best technological variant turned out to be: application of EM or UGmax microbiological preparations on the shredded straw of the forecrop and mixing it with the soil using a grubber immediately after harvest, sowing the white mustard catch crop and winter plowing. Completely eliminating plowing or replacing winter plowing with spring plowing had negative effects.

Author Contributions: Conceptualization: K.K.; Methodology: K.K. and L.G.; Investigation: W.K.; Writing - original draft: L.G.; Writing - review & editing: L.G and K.K.; All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data availability: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics statement: Not applicable

Consent to participate: Not applicable

Consent for publication: Not applicable

Conflict of interest: The authors declare no competing interests.

Financial interests: The authors declare they have no financial interests

References

1. Fróna, D.; Szenderák, J.; Harangi-Rákos, M. The Challenge of Feeding the World. *Sustainability* **2019**, *11(20)*, 5816 DOI: *10.3390/su11205816*
2. Tadesse, W.; Halila, H.; Jamal, M; El-Hanafi, S.; Assefa, S.; Owsis, T; Baum, M. Role of sustainable wheat production to ensure food security in the cwana region. *J. Experimental Biology and Agricultural Sciences* **2017**, *11(20)*, 5816. DOI: 10.18006/2017.5(Spl-1-SAFSAW).S15.S32
3. Johansson, E.; Muneer, F.; Prade, T. Plant Breeding to Mitigate Climate Change—Present Status and Opportunities with an Assessment of Winter Wheat Cultivation in Northern Europe as an Example. *Sustainability* **2023**, *15(16)*, 12349. DOI: 10.3390/su151612349
4. Jalli, M.; Huusela, E.; Jalli, H.; Kauppi, K.; Niemi, M.; Himanen, S.; Jauhiainen, L. Effects of Crop Rotation on Spring Wheat Yield and Pest Occurrence in Different Tillage Systems: A Multi-Year Experiment in Finnish Growing Conditions. *Front. Sustain. Food Syst.* **2021,** *5*. DOI: 10.3389/fsufs.2021.647335
5. Sieling, K.; Stahl, C.; Winkelmann, C.; Christen, O. Growth and yield of winter wheat in the first 3 years of a monoculture under varying N fertilization in NW Germany. *Eur. J. Agron.* **2005**, *22*, 71–84. DOI: 10.1016/j.eja.2003.12.004
6. Mamolos, A.P.; Kalburtji, K.L. Significance of allelopathy in crop rotation. *J. Crop Prod.* **2001**, 4, 197–218. DOI: 10.1300/J144v04n02_06
7. Barbieri, P.; Pellerin, S.; Nesme, T. Comparing crop rotations between organic and conventional farming. *Sci. Rep.* **2017**, *7*,13761. DOI: 10.1038/s41598-017-14271-6
8. Bommarco, R.; Kleijn, D.; Potts, S.G. Ecological intensification: harnessing ecosystem services for food security. *Trends Ecol. Evol.* **2013**, *28*, 230–238. DOI: 10.1016/j.tree.2012.10.012
9. Mukhovi, S.; Jacobi, J. Can monocultures be resilient? Assessment of buffer capacity in two agroindustrial cropping systems in Africa and South America. *Agriculture & Food Security* **2022**, 11(19). DOI: 10.1186/s40066-022-00356-7
10. EU 2020. Biodiversity Strategy for 2030. Available online at https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1590574123338&uri=CELEX:52020DC0380 (Accessed December 07, 2023).
11. Wezel, A.; Casagrande, M.; Celette, F.; Vian, J.F.; Ferrer, A, Peigne, J. Agroecological practices for sustainable agriculture. A review. *Agron. Sust. Develop.* **2014**, *34 (1)*, 1-20. DOI: 10.1007/s13593-013-0180-7ff. ffhal-01234800f
12. Wanic, M.; Żuk-Gołaszewska, K.; Orzech, K. Catch crops and the soil environment – a review of the literature. *J. Elem.* **2019**, *24(1)*, 31-45. DOI: 10.5601/jelem.2018.23.3.1638
13. Leys, A.; Govers, G.; Gillijns, K.; Berckmoes, E.; Takken, I. Scale effects of runoff and erosion loess from arable land under conservation and conventional tillage: The role of residue cover. *J. Hydrol*. **2010**, *390*, 143-154. DOI: 10.1016/j.jhydrol.2010.06.034
14. Gruber, S.; Mohring, J.; Claupein, W. On the way towards conservation tillage-soil moisture and mineral nitrogen in a long-term field experiment in Germany. *Soil Till Res.* **2011,** *115/116*, 80-87. DOI: 10.1016/j.still.2011.07.001
15. Kumar, K.; Goh, K.M. Crop Residues and Management Practices: Effects on Soil Quality, Soil Nitrogen Dynamics, Crop Yield, and Nitrogen Recovery. *Advances in Agronomy* **1999**, *68*, 197-319. DOI: 10.1016/S0065-2113(08)60846-9
16. Pranagla, J.; Ligęza, S.; Smal, H. Impact of Effective Microorganisms (EM) Application on the Physical Condition of Haplic Luvisol. *Agronomy* **2020**, *10(7)*, 1049. DOI: 10.3390/agronomy10071049
17. Jaskulska, I.; Romaneckas, K.; Jaskulski, D.; Gałęzewski, L.; Breza-Boruta, B.; Dębska, B.; Lemanowicz, J. Soil Properties after Eight Years of the Use of Strip-Till One-Pass Technology. *Agronomy* **2020**, *10(10)*, 1596. DOI: 10.3390/agronomy10101596
18. Yu, Q.; Li, L.; Luo, Q.; Eamusa, D; Chena, C.; Shouhua, X.; Wanga, E.; Liu, J.; Nielsena, D.C. Year Patterns of Climate Impact on Wheat Yields. *International Journal of Climatology*. **2014**, *34(2)*, 518-528. DOI:10.1002/joc.3704
19. Kwiatkowski, C.; Harasim, E.; Wesołowski, M. Effects of Catch Crops and Tillage System on Weed Infestation and Health of Spring Wheat. *J. Agr. Sci. Tech*. **2016**, *18*, 999-1012.

20. Gaweda, D.; Kwiatkowski, C.A.; Weed infestation of spring common wheat (Triticum aestivum L.) grown in monoculture depending on the cover crop and weed control method. *Acta Agrobotanica* **2012**, *65(3)*, 119-126.
21. Maclaren, C.; Labuschagne, J.; Swanepoel, P.A. Tillage practices affect weeds differently in monoculture vs. crop rotation. *Soil and Tillage Research* **2021**, *205*, 104795. DOI: 10.1016/j.still.2020.104795
22. Mitchell, J.P.; Carter, L.M.; Reicosky, D.C.; Shrestha, A.; Pettygove, G.S.; Klonsky, K.M.; Marcum, D.B.; Chessman, D.; Roy, R.; Hogan, P.; Dunning, L. A history of tillage in California's Central Valley. *Soil and Tillage Research* **2016**, *157*, 52-64. DOI: 10.1016/j.still.2015.10.015
23. Giller, K.E.; Andersson, J.A.; Corbeels, M.; Kiregaard, J.; Mortensen, D.; Erenstein, O.; Vanlauwe, B. Beyond conservation agriculture. *Front. Plant Sci.* **2015**, 6. DOI: 10.3389/fpls.2015.00870
24. Kirkegaard, J.A.; Convers, M.K.; Hunt, J.R.; Kirkby, Clive, A.; Watt, M.; Rebetzke, G.J. Sense and nonsense in conservation agriculture: Principles, pragmatism and productivity in Australian mixed farming systems. *Agriculture, Ecosystem and Environment* **2014**, *187*, 133-145. DOI: 10.1016/j.agee.2013.08.011
25. Fonteyne, S.; Singh, R.G.; Govaerts, B.; Verhulst, N. Rotation, Mulch and Zero Tillage Reduce Weeds in a Long-Term Conservation Agriculture Trial. *Agronomy* **2020**, *10(7)*, 962. DOI: 10.3390/agronomy10070962
26. Lamparski, R.; Kotwica, K. Effect of the use of pro-ecological treatments and previous crop straw on the weed infestation of winter wheat and spring barley cultivated as short-term monoculture. *Acta Sci. Pol. Agricultura* **2020,** *19(4)*, 201–212. DOI: 10.37660/aspagr.2020.19.4.4
27. Janusauskaite, D.; Feiziene, D.; Feiza, V. The effect of tillage, fertilization and residue management on winter wheat and spring wheat physiological performance. *Acta Physiologiae Plantarum* **2022**, *75*. DOI: 10.1007/s11738-022-03398-3
28. He, J.; Shi, Y.; Zhao, J.; Yu, Z. Strip rotary tillage with subsoiling increases winter wheat yield by alleviating leaf senescence and increasing grain filling. *The Crop Journal* **2020**, *8(2)*, 327-340. DOI: 10.1016/j.cj.2019.08.007
29. Yadav, K.; Rohitashav, S.; Shukla, DK.; Kumar, J.; Nayak, P.; Naresh, R.; Gaurav, K.; Mangaraj, A. Effect of different tillage and nutrient management practices on initial population and SPAD value in wheat (Triticum aestivum L.). *The Pharma Innovation Journal* **2022**; *11(9)*, 408-412.
30. Majchrzak, L.; Skrzypczak, G. The influence of tillage system on physical soil properties and yielding of spring wheat. *Annales UMCS, Agricultura* **2010**, *65(2)*. DOI: 10.2478/v10081-010-0013-1)
31. Kraska, P.; Andruszczak, S.; Kwiecińska-Poppe, E,; Pałys, E. The effect of tillage systems and catch crops on the yield, grain quality and health of spring wheat. *Acta Sci. Pol., Agricultura*, **2014**, *13(1)*, 21-38.
32. Adil, M.; Zhang, S.; Wang, J.; Shah, A.N.; Tanveer, M.; Fiaz, S. Effects of Fallow Management Practices on Soil Water, Crop Yield and Water Use Efficiency in Winter Wheat Monoculture System: A Meta-Analysis. *Front. Plant Sci.* **2022**, *13*. DOI: 10.3389/fpls.2022.825309
33. Qi, G.; Kang, Y.; Yin, M.; Ma, Y.; Bai, Y.; Wang, J. Yield Responses of Wheat to Crop Residue Returning in China: A Meta-Analysis. *Crop Science* **2019**, *59(5).* DOI: 10.2135/cropsci2019.01.0031
34. Pawłowski, L.; Kwiatkowski, C.A.; Harasim, E.; Klikocka-Wiśniewska, O.; Cel, W.; Kujawska, J. Environmental Benefits of Catch Crops Cultivation. *Chemistry-Didactics-Ecology-Metrology* **2021**,*26(1-2)*, 109-121. DOI: 10.2478/cdem-2021-0009
35. Kwiatkowski, C.A.; Harasim, E.; Staniak, M. Effect of catch crops and tillage systems on some chemical properties of loess soil in a short-term monoculture of spring wheat. *Journal of Elementology* **2020**, *25(1)*, 35-43. DOI: 10.5601/jelem.2019.24.2.1837