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CONTENT OF SOME ELEMENTS IN GRAIN OF SPRING WHEAT CV. ZEBRA DEPENDING ON SOIL TILLAGE SYSTEMS AND CATCH CROPS

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Abstract

The aim of the present study was to evaluate the effect of plough and conservation tillage treatment as well as various catch crops on the chemical composition of the grain of spring wheat grown in monoculture. The study was carried out in 2006‑2008, using an experiment established in 2005. The experimental field was located on medium and heavy mixed rendzina soil. The design of a static two‑factor experiment, set up using the split-plot method in four replications, included the plough tillage system (A) and two conservation tillage methods – with autumn (B) or spring (C) disking of catch crops. The other factor comprised four methods for regeneration of the spring wheat monoculture stand using the following catch crops: undersown red clover (b) and Westerwolds ryegrass (e); lacy phacelia (c) and white mustard stubble crops (d); and the control treatment without catch crops (a). The concentrations of potassium, manganese and sulphur in the spring wheat grain harvested from the ploughed plots were higher than in the conservation tillage treatment. In the plough tillage treatments, grain Mg content was higher than in the conservation tillage variant with spring disking of the catch crops. Conservation tillage had an effect on the increase in phosphorus and copper content in spring wheat grain compared to plough tillage. Zn and Fe content in the grain from the conservation tillage treatments with autumn disking of the catch crops was lower than in that from the plough and conservation tillage treatments with spring incorporation of the catch crops. Iron content in the grain obtained from the treatments with red clover and lacy phacelia was the highest. At the same time, phosphorus content in spring wheat grain was the highest in the control treatments and in the treatment with Westerwolds ryegrass and white mustard. In the plots where a lacy phacelia stubble crop had been sown, zinc and copper content in grain was determined to be the highest. In turn, the highest manganese content was found in the grain from the control treatments, whereas total sulphur content was the highest in the control plots and in the plots with the stubble crops.

Key words: conservation tillage, plough tillage, catch crops, spring wheat, chemical composition of grain.

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ZAWARTOŒÆ WYBRANYCH PIERWIASTKÓW W ZIARNIE PSZENICY JAREJ ODMIANY ZEBRA W ZALE¯NOŒCI OD SYSTEMÓW UPRAWY ROLI ORAZ MIÊDZYPLONÓW

Abstrakt

Celem badañ by³a ocena wp³ywu uprawy p³u¿nej i konserwuj¹cych sposobów uprawy roli oraz ró¿nych miêdzyplonów na sk³ad chemiczny ziarna pszenicy jarej uprawianej w monokulturze. Badania przeprowadzono w latach 2006-2008, wykorzystuj¹c doœwiadczenie za³o¿one w 2005 r. Pole doœwiadczalne by³o po³o¿one na œredniej i ciê¿kiej rêdzinie mieszanej. Schemat statycznego, dwuczynnikowego doœwiadczenia za³o¿onego metod¹ split-plot, w 4 powtórzeniach, uwzglêdnia³ p³u¿ny system uprawy roli (A) oraz 2 sposoby uprawy konserwuj¹cej – z jesiennym (B) lub wiosennym (C) talerzowaniem miêdzyplonów. Drugim czynnikiem by³y 4 sposoby regeneracji stanowiska w monokulturze pszenicy jarej w postaci takich miêdzyplonów, jak: wsiewki miêdzyplonowe koniczyny czerwonej (b) i ¿ycicy westerwoldzkiej (e), miêdzyplony œcierniskowe facelii b³êkitnej (c) i gorczycy bia³ej (d) oraz obiekt kontrolny bez miêdzyplonów (a). Zawartoœæ potasu, manganu i siarki w ziarnie pszenicy jarej z obiektów uprawianych p³u¿nie by³a wiêksza ni¿ z uprawy konserwuj¹cej. W obiektach z upraw¹ p³u¿n¹ zawartoœæ Mg w ziarnie by³a wiêksza ni¿ w wariancie uprawy konserwuj¹cej z wiosennym talerzowaniem miêdzyplonów. Konserwuj¹ca uprawa roli wp³ywa³a na wzrost zawartoœci fosforu i miedzi w ziarnie pszenicy jarej, w porównaniu z upraw¹ p³u¿n¹. Zawartoœæ Zn i Fe w ziarnie z uprawy konserwuj¹cej z jesiennym talerzowaniem miêdzyplonów by³a mniejsza ni¿ z uprawy p³u¿nej i konserwuj¹cej z wiosennym talerzowaniem miêdzyplonów. Zawartoœæ ¿elaza w ziarnie z obiektów z koniczyn¹ czerwon¹ i faceli¹ b³êkitn¹ by³a najwiêksza. Jednoczeœnie zawartoœæ fosforu w ziarnie pszenicy jarej by³a najwiêksza w obiektach kontrolnych, z ¿ycic¹ westerwoldzk¹ oraz z gorczyc¹ bia³¹. Najwiêksz¹ zawartoœæ cynku i miedzi w ziarnie stwierdzono w obiektach, na których wysiewano miêdzyplon œcierniskowy facelii b³êkitnej. Z kolei najwiêksz¹ zawartoœæ manganu stwierdzono w ziarnie z obiektów kontrolnych, natomiast siarki ogólnej z poletek kontrolnych oraz z miêdzyplonami œcierniskowymi.

S³owa kluczowe: uprawa konserwuj¹ca, uprawa p³u¿na, miêdzyplony, pszenica jara, sk³ad chemiczny ziarna.

INTRODUCTION

The quality of cereal grain plays an important role in obtaining high quality food product. In recent years, attempts have been made to reduce expenditure related to cereal growing technology. Conservation tillage, while reducing expenditure on soil tillage, at the same time limits water and wind erosion, stimulates biological diversity and increases the content of organic substances and macronutrients in the topsoil (Zimny 1999, Dzienia et al. 2006, Weber 2010). The growing proportion of cereals in the crop structure leads to adverse changes in the soil, the infection of plants with stem base diseases that become more severe over time, and an increased level of weed infestation. This affects grain quality and yield (Woźniak, 2004). Plants sown as catch crops can largely reduce the negative effects of cereal-cropping frequency in crop rotations (Andrzejewska 1999, Kuraszkiewicz 2004). Catch crops influence soil properties as well as the growth and development of the main crop, ultimately affecting yield quality (Kuraszkiewicz 2004, Kwiatkowski, 2009). They can be a significant source of nutrients, including microminerals (£oginow, 1985).

The long-term production use of crop fields may lead to the depletion of reserves of available micronutrients in the plough layer, which results in an insufficient supply of these minerals to crop plants (Wróbel 2000). The uptake of copper, manganese and zinc by the plant root system in soils with a high pH, even when the average soil availability of these elements is moderate, is inferior so that the three elements can become the mineral components reducing the yield amount and quality (Czuba 2000, £abêtowicz, Rutkowska, 2000). An adequate content of micronutrients in grain of high quality wheat is an important trait for the consumer and for the nutritive value of grain as raw product (Ziêba et al. 1992, Stanis£awska-Glubiak et al. 1996, Czuba 2000, Gembarzewski 2000, Kocoñ 2005). Deficiency of both micro– and macronutrients in the plant first of all depresses its resistance to adverse environmental conditions and subsequently decreases the yield and its quality (Stanis£awska-Glubiak, Korzeniowska 2007, Korzeniowska 2008). Gembarzewski (2000) emphasizes that the micronutrient content in yield is important for its nutritive and feeding value. At the same time, Ruszkowska et al. (1996) express the opinion that obtaining high yields for a number of consecutive years entails the need to control the status of micronutrient supply to plants.

The aim of the present study was to evaluate the effect of plough and conservation tillage systems as well as of various catch crops on the chemical composition of grain of spring wheat grown in monoculture on rendzina soil under the conditions prevailing in south-eastern Poland.

MATERIAL AND METHODS

The study was carried out in 2006-2008, using an experiment established in 2005 at Bezek Experimental Farm (N: 51^{o} 19', E: 23^{o} 25'), owned by the Lublin University of Life Sciences. The experimental field was located on medium and heavy mixed rendzina soil developed from chalk rock with the grain size distribution of medium silty loam. This soil was characterized by alkaline pH (7.35), a high content of phosphorus (117.8) and potassium (242.4) as well as a very low content of magnesium (19) (the values are expressed in mg kg^{-1} of soil), while the organic carbon content was 24.7 g kg^{-1}. The soil was classified as soil quality class IIIb and defective wheat complex.

The total rainfall from April to August in 2006 was higher than the long-term average, but it was attributable to the heavy rainfall that occurred in August. In 2008, the total rainfall during the analogous period was similar to the long-term norm, whereas in 2007 it was distinctly higher. The mean air temperatures in all those years were higher than the long-term mean (Table 1). In order to make a more complete analysis of the weather conditions, Selyaninov's hydrothermic index (K) was calculated:

$$K = \frac{p}{\Sigma t},$$

where:

P – monthly total rainfall in mm,

Σt – sum of mean daily temperatures for a given month in ^{o}C.

Table 1

Rainfall and air temperatures in April-August in 2006-2008 as compared to the long-term means (1974-2003) according to the Meteorological Station at Bezek

Years	Months					Total
	Apr	May	June	July	Aug	
	rainfall in mm					
2006	25.1	56.7	23.2	26.2	240.9	372.1
2007	12.9	93.6	87.5	130.7	79.9	404.6
2008	47.9	74.2	38.4	93.9	60.9	315.3
Means for 1974-2003	40.1	53.0	77.6	80.3	61.6	312.6
	Temperature in ^{o}C					mean
2006	8.9	13.5	16.7	21.7	18.1	15.8
2007	8.3	15.3	18.6	19.4	18.9	16.1
2008	9.1	12.7	17.4	18.3	19.3	15.4
Means for 1974-2003	7.6	13.6	16.2	17.9	17.5	14.6

The values of Selyaninov's hydrothermic index indicate that a significant water deficit occurred in June and July 2006 (Table 2).

The design of a static two-factor experiment, set up using the split-plot method in four replications, included the plough tillage system (A) and two conservation tillage methods – with autumn (B) or spring (C) disking of the catch crops. The other factor comprised four methods for regeneration of the spring wheat monoculture stand in the form of undersown crops (red clover – b; Westerwolds ryegrass – e) or stubble crops (lacy phacelia – c; white mustard – d). The plots without catch crops were the control treatment (a). The harvest plot area was 30 m^2. Winter wheat grown in this field for 3 years was the forecrop for spring wheat. In 2005, spring wheat and all the catch crops, both the intercrops and stubble crops, were sown

Table 2

Values of Selyaninov's hydrothermic index (K)

Years	Months				
	Apr	May	June	July	Aug
2006	*0.94	1.35	**0.46	**0.39	4.30
2007	*0.52	1.98	1.57	2.17	1.36
2008	1.76	1.88	*0.74	1.65	1.02
Means for 1974-2003	1.76	1.26	1.60	1.45	1.14

*$K < 1.0$ – dry spell
** $K < 0.5$ – drought

and the soil tillage was carried out in accordance with the methodological assumptions, taking this year as the preliminary one.

Plough tillage, preparing the field for spring wheat, started with skimming and harrowing after harvesting the forecrop. Ploughing was done to an average depth before the winter. In the spring, harrowing was performed and, before sowing, both cultivating and harrowing were completed. Phosphorus and potassium fertilizers were introduced during this period; the first portion of nitrogen fertilizers was also applied at the rate of 60 kg N ha^{-1} N in the form of ammonium nitrate. Phosphorus fertilizers were applied at the rate of 30.5 kg P ha^{-1} in the form of triple superphosphate, while potassium fertilizers were incorporated in the spring at 74.7 kg K ha^{-1} in the form of 60% potassium salt. The second dose of nitrogen at the rate of 40 kg ha^{-1} was introduced at the beginning of shooting (BBCH growth stages 30-33). Spring wheat cv. Zebra (technological value E – elite wheat) was sown at the rate of 5 million seeds per ha at a row spacing of 10 cm. Seeds were dressed with the seed dressing Panoctine 350 SL (350 g dm^{-3} guazatine in the form of acetate). Red clover cv. Dajana (20 kg ha^{-1}) and Westerwolds ryegrass cv. Mowester (20 kg ha^{-1}) were sown on the date of spring wheat sowing. Lacy phacelia cv. Stala (20 kg ha^{-1}) and white mustard cv. Borowska (20 kg ha^{-1}) were sown following the harvest of spring wheat and after performing post-harvest treatments.

In the conservation tillage treatments (B and C), after the forecrop was harvested in the plots without undersown red clover and Westerwolds ryegrass, grubbing to a depth of 18-20 cm and harrowing were done. Subsequently, lacy phacelia and white mustard were sown, in the same way as in the plough tillage treatment. In treatment (B) the cover crops were disked before the winter, whereas in treatment (C) they were left as mulch for the winter and disking was done in the spring. In the treatments with autumn disking of the catch crops (B), spring tillage was the same as in the plough tillage treatment. In the plots with the other conservation tillage treatment (C), the field was harrowed after disking had been done, and then harrowing was repeated before sowing spring wheat. The wheat crop protection programme included Chwastox Extra 300 SL 3.5 dm^3 ha^{-1} (300 g dm^{-3} MCPA) – (BBCH 23-29), and Alert 375 SC 1 dm^3 ha^{-1} (125 g dm^{-3} flusilazole and 250 g dm^{-3} carbendazim) – (BBCH 26-29).

The elements were determined in collective samples in three replications using the following methods: P – colorimetric method; K – flame photometry; Mg, Cu, Zn, Mn, Fe – atomic absorption spectrometry (AAS); total S – nephelometric method. The results were statistically processed using the analysis of variance. The means were compared using least significant differences (LSD) based on Tukey's test.

RESULTS

Compared to plough tillage, conservation soil tillage had a significant effect on the increase in phosphorus and copper content in spring wheat grain, whereas plough tillage promoted a significantly higher total sulphur content compared to conservation tillage (Table 3). The spring wheat grain from the conservation tillage treatment with spring disking of the catch crops had the lowest potassium content, while a significantly higher content of potassium was found in the grain obtained from the plough and conservation tillage treatments with autumn incorporation of the catch crops. The grain harvested from the ploughed plots was characterized by a significantly higher content of magnesium than that from the conservation tillage treatment in which the catch crops were left for the winter period (Table 3).

The highest zinc and iron content was found in the grain from the plots where conservation tillage with spring disking of the catch crops had been used; the zinc content was significantly lower for the plough tillage treatment, being the lowest when conservation tillage with autumn incorporation of the catch crops had been applied (Table 3). The grain harvested from the plots where conservation tillage with autumn incorporation of the catch crops had been used was characterized by the lowest content of manganese; the grain manganese content was significantly higher in the case of conservation tillage with spring incorporation of catch crop biomass, but the highest content of this mineral was determined in the grain from the plough tillage treatment (Table 3).

The phosphorus content in the spring wheat grain harvested from the plots with Westerwolds ryegrass and white mustard as well as from the control treatment was significantly higher than in the grain from the plots where red clover and lacy phacelia had been sown (Table 4). Catch cropping did not have a significant effect on potassium and magnesium content in spring wheat grain (Table 4). Sowing a lacy phacelia stubble crop increased significantly zinc and copper content in spring wheat grain compared to the other plants sown as catch crops. The grain obtained from the control treatment without catch cropping was characterized by the lowest content of the above elements (Table 4).

Table 3

Chemical composition of spring wheat grain depending on tillage systems
(means for the period 2006-2008)

Specification	Tillage systems			LSD (p = 0.05)
	*A	B	C	
P content in grain (g kg^{-1} DM)	4.32	4.75	4.69	0.118
K content in grain (g kg^{-1} DM)	4.16	4.12	4.06	0.057
Mg content in grain (g kg^{-1} DM)	1.14	1.13	1.10	0.032
Zn content in grain (mg kg^{-1} DM)	26.33	26.22	26.95	0.104
Cu content in grain (mg kg^{-1} DM)	3.98	4.12	4.13	0.040
Mn content in grain (mg kg^{-1} DM)	21.18	19.97	20.86	0.137
Fe content in grain (mg kg^{-1} DM)	32.76	30.42	32.93	0.142
Total S content in grain (g kg^{-1})	1.25	1.20	1.19	0.015

*A – plough tillage
B – conservation tillage with autumn disking of catch crops
C – conservation tillage with spring disking of catch crops

Table 4

Chemical composition of spring wheat grain depending on catch crops
(means for the period 2006-2008)

Specification	Catch crops					LSD (p = 0.05)
	*a	b	c	d	e	
P content in grain (g kg^{-1} DM)	4.78	4.13	4.44	4.69	4.90	0.178
K content in grain (g kg^{-1} DM)	4.12	4.09	4.09	4.13	4.14	**ns
Mg content in grain (g kg^{-1} DM)	1.12	1.13	1.11	1.13	1.14	**ns
Zn content in grain (mg kg^{-1} DM)	25.83	26.30	27.99	26.05	26.32	0.157
Cu content in grain (mg kg^{-1} DM)	3.82	4.12	4.27	4.19	3.98	0.061
Mn content in grain (mg kg^{-1} DM)	21.45	20.24	20.66	20.70	20.30	0.207
Fe content in grain (mg kg^{-1} DM)	31.59	34.44	33.01	31.23	29.90	0.214
Total S content in grain (g kg^{-1})	1.22	1.18	1.24	1.23	1.18	0.023

*a – control without catch crops
b – undersown red clover
c – lacy phacelia stubble crop
d – white mustard stubble crop
e – undersown Westerwolds ryegrass
**ns – non-significant difference

The significantly lowest content of manganese was found in the grain from the treatments with the red clover and Westerwolds ryegrass undersown crops, while this content was significantly higher in the grain from the plots with the lacy phacelia and white mustard stubble crops and the highest in the control treatment (Table 4). The highest iron content was found in the spring wheat grain in the treatment with the red clover intercrop, a significantly lower content in the grain from the plot with the lacy phacelia stubble crop, in the control plots without catch crops, and in the treatment with white mustard. Iron content in the grain from the plots where Westerwolds ryegrass had been undersown was the lowest (Table 4). The lowest grain sulphur content was obtained in the treatments with undersown red clover and Westerwolds ryegrass, while it was significantly higher in the plots with the stubble crops and in the control plots (Table 4).

Among the analyzed elements, the largest amounts of zinc, manganese and iron in spring wheat grain were found in 2008, copper in 2007, and phosphorus in the first year of the study (Table 5). Magnesium and total sulphur content in grain in 2007 and 2008 was significantly higher than in 2006, whereas potassium content was higher in 2006 and 2008 compared to 2007 (Table 5).

Table 5

Chemical composition of spring wheat grain in 2006-2008

Specification	Years			LSD (p = 0.05)
	2006	2007	2008	
P content in grain (g kg^{-1} DM)	5.88	3.69	4.19	0.118
K content in grain (g kg^{-1} DM)	4.16	4.02	4.16	0.057
Mg content in grain (g kg^{-1} DM)	1.03	1.18	1.17	0.032
Zn content in grain (mg kg^{-1} DM)	26.30	24.02	29.18	0.104
Cu content in grain (mg kg^{-1} DM)	3.06	5.68	3.48	0.040
Mn content in grain (mg kg^{-1} DM)	18.38	15.43	28.20	0.137
Fe content in grain (mg kg^{-1} DM)	23.12	30.38	42.60	0.142
Total S content in grain (g kg^{-1})	0.97	1.34	1.33	0.023

DISCUSSION

Phosphorus content in the grain of spring wheat grown using plough tillage was lower by 7.9% to 9.1% compared to both conservation tillage methods. At the same time, phosphorus content in the grain harvested from the plots where red clover had been undersown was lower by 7.0% to 15.7% compared to the other treatments. In the study of Ruszkowska et al. (1993), phosphorus content in spring wheat grain ranging 2.8-4.4 g kg^{-1} was lower than that obtained in the present study. This could have resulted from a good phosphorus supply to spring wheat grown on rendzina soil that was characterized by high phosphorus availability. At the same time, many authors indicate the accumulation of phosphorus in the topsoil under no¯tillage systems (W£ODEK et al. 2003, BLECHARCZYK et al. 2007, WEBER 2010). The content of phosphorus, potassium and magnesium found in spring wheat grain was higher than obtained by KRASKA (2007) in winter wheat grain for wheat crops grown on the same soil.

Conservation soil tillage with spring incorporation of the catch crops promoted higher content of zinc and iron in grain; zinc content was higher by 2.4% to 2.8%, while iron content increased by 0.5% to 8.3% compared to plough and conservation tillage with autumn disking of the catch crops. Moreover, copper content was higher by 3.5% to 3.8% in the grain obtained from both conservation tillage treatments compared to that harvested from the ploughed plots. This could have been attributable to higher availability of these elements in the soil, thereby the possibility of their uptake by wheat in the conservation tillage treatments. ZIMNY (1999) and WEBER (2010) report that conservation tillage promotes higher availability of nutrients in the arable layer compared to plough tillage. At the same time, the introduction of catch crops as a factor mitigating the negative consequences of monoculture cropping of spring wheat increased zinc and copper content in grain compared to the control treatment without catch cropping. Many authors consider catch crops as a source of nutrients, thus increasing nutrient availability in the surface soil layer and thereby improving the level of nutrient supply to plants (ANDRZEJEWSKA 1999, ZIMNY 1999, MA£ECKA et al. 2004, WEBER 2010). Zinc content in the grain of cv. Zebra wheat was lower than that given by GEMBARZEWSKI et al. (1995) in their study in which zinc content ranged from 31 to 38 mg kg^{-1}. SPIAK and WALL (2000) found that zinc content in winter wheat grain was related to the concentration of available forms of this element in the soils. Similarly, STANIS£AWSKA-GLUBIAK et al. (1996) think that changes in micronutrient content in spring wheat grain is conditioned by the level of yield and the richness of the soil in available forms of micronutrients. In turn, in the study of PARYLAK et al. (2000) Cu, Zn and Mn content in wheat grain was not dependent on the availability of these minerals in the soil. Likewise, NOWAK (2000) shows that the type of forecrop and the amount of organic biomass ploughed-in had no effect on micronutrient content in winter wheat grain. However, PARYLAK et al. (2000) found grain zinc concentration to have decreased by 3.8% after the application of green manure. A slightly different correlation was found in the present study. Zinc content in the grain from the catch-cropped treatments was higher by 0.9% to 8.4% compared to the control.

GEMBARZEWSKI (2000) draws attention to copper deficiency in cereal grain. A decrease of copper content in plant products in Poland is a significant threat to the health of humans and animals. Korzeniowska (2008) thinks that copper deficiency in soil can cause a reduction in grain yields by as much as 20% and a decrease in grain copper content. Gembarzewski et al. (1995) report that Polish wheats contain an average of 3.1-3.4 mg of copper per kg of grain. In our study, grain copper content was slightly larger, and in 2007 it was distinctly higher (5.68 mg kg^{-1}), but that was the season in which grain yield was the lowest. After the application of green manure, Parylak et al. (2000) recorded a slight decrease (3.7%) of copper content in wheat grain. In the present study, the introduction of catch crops increased copper content in wheat grain from 4.2% to 11.8% compared to the control without catch cropping.

The spring wheat grain from the plough tillage treatments was characterized by a higher content of manganese by 1.5% to 6.1% relative to that from the conservation tillage treatments. At the same time, the use of catch crops promoted a decrease in manganese content in grain from 3.5% to 5.6% relative to the control treatment. The application of green manure in the study of Parylak et al. (2000) also caused a decreasing tendency in the content of this nutrient in wheat grain by 16.6% compared to the results obtained in the stands fertilized with NPK alone. Stanis£awska-Glubiak et al. (1996) found that manganese content in spring wheat grain was dependent on soil pH. When wheat was grown on soil with a slightly acidic pH (6.1), manganese accumulated in the grain as the level of yield increased. In soil with neutral pH (6.7), grain manganese concentration gradually decreased. The low concentration of manganese in the grain determined in the present study, compared to its content reported by Gembarzewski et al. (1995), could have arisen from the fact that the results were obtained in an experiment set up on rendzina soil with alkaline pH.

Undersowing Westerwolds ryegrass resulted in decreased grain iron content from 4.3% to 13.2% compared to the other catch-cropped treatments. In this study, iron content in spring wheat grain was lower than that given by Gembarzewski et al. (1995), which ranged from 47 to 56 mg kg^{-1} depending on wheat grain yield. £abêtowicz and Rutkowska (2000) as well as Kocoñ (2005) report that the uptake of copper, iron, manganese and zinc by the plant root system in soils with a high pH, even with an average availability of these elements in the soil, is worse and they can become the mineral components that reduce yield amount and quality.

Similarly to manganese and potassium, total sulphur content in the wheat grain from the ploughed plots was higher than in that from the conservation tillage treatments. The application of stubble crops promoted higher sulphur content in grain compared to the undersown crops. Motowicka-Terelak et al. (1993) as well as Motowicka-Terelak and Terelak (2000) report that sulphur content in most plants, including crop plants, ranges from 0.5 to 15.0 g kg^{-1}. In wheat grain, this range of sulphur content is between 0.3 and 3.1 g kg^{-1}.

The content of most minerals in spring wheat grain in the last year of the study (2008) was higher than in the first year (2006). This could have resulted from the adverse weather conditions in 2006. Water deficit occurred in June and July, which could have affected the rate of nutrient uptake by the plants. Only grain copper content was the highest in the second year of the study, while for phosphorus this happened in the first year of the study; however, the potassium content was similar in all the analyzed seasons. Catch cropping, which improves chemical properties of soil and consequently the nutrient supply to plants, could have contributed to this outcome. Trzebska-Jeske et al. (1976) also found that Fe, Zn, Mn and Cu content in wheat grain depended on weather conditions prevailing in the successive years of the study. Makarska and Michalak (2003) obtained similar correlations with respect to the chemical composition of spring barley grain. Likewise, investigating the chemical composition of spring wheat grain, Chrzanowska-Dro¯d¯ et al. (1999) found it to be primarily dependent on weather patterns and genetic properties of cultivars, and to a lesser degree on agricultural practices.

CONCLUSIONS

1. Higher potassium, manganese and sulphur content was found in the grain of spring wheat grown using plough tillage compared to the conservation tillage treatments. Magnesium content in the grain from the ploughed plots was higher than in the conservation tillage treatments in which the catch crops had been disked in the spring.

2. Phosphorus and copper content in the grain obtained from the conservation tillage treatments was higher than in the grain from the plough tillage treatments. In turn, zinc and iron content in the grain from the conservation tillage treatments with autumn disking of the catch crops was lower than in the other tillage treatments.

3. Copper and zinc content in the grain of spring wheat grown after the catch crops was higher, while manganese content was lower, compared to the treatments without catch cropping. The highest zinc and copper content was found in the grain of wheat grown after lacy phacelia.

4. Iron content in the grain harvested from the plots with the undersown red clover and the lacy phacelia stubble crop was higher, whereas phosphorus content was lower than in the grain from the other treatments under evaluation.

5. In the grain obtained from the plots with undersown red clover and Westerwolds ryegrass, sulphur content was lower than in the grain from the plots where the stubble crops had been sown.

6. Meteorological conditions in the successive years affected the content of the analyzed elements in spring wheat grain. In the last year of the study, the content of most of these elements in the grain were higher than in the first year.

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