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EFFECT OF NITROGEN RATE AND STUBBLE CATCH CROPS ON CONCENTRATION OF MACROELEMENTS IN SPRING WHEAT GRAIN

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Abstract

The aim of this study was to determine the effect of different rates of nitrogen fertilizer and stubble catch crops on the content of nitrogen, phosphorus, potassium and magnesium in the grain of spring wheat. Field experiment was carried out in 2005-2008 at Mochełek near Bydgoszcz (53° 13' N, 17° 51' E) on the Alfisols soil classified as a very good rye complex and IIIb quality class. Nitrogen fertilization was applied at the rates of (kg N ha^{-1} $year^{-1}$): 0; 40 (before sowing), 80 (40 kg before sowing and 40 kg in BBCH 31-32 stage), 120 (60 kg before sowing and 60 kg in the BBCH 31 – 32 stage) and 160 (60 kg before sowing and 60 kg in BBCH 31-32 stage and 40 kg in BBCH 45-47 stage). Stubble catch crops (field pea and oilseed radish) were sown in the period from 3 to 11 of August in 2005 to 2007. After 70-77 days of plant growing, the whole biomass was plowed in as green manure. Spring wheat cv. Tybalt was sown following the catch crop,between March 30 to April 11 in 2006 to 2008. Nitrogen fertilization affected the concentrations of N, P and Mg in grain of spring wheat. Every 40 kg increment of nitrogen fertilization per ha resulted in a significant increase in the N content in wheat grain. The concentration of Mg in spring wheat grain was significantly higher when nitrogen fertilization was dosed at 120 or 160 kg per ha than at lower doses. The phosphorus content in grain of wheat grown after field pea catch crop was not related to nitrogen fertilization rates, while after the radish and in the control (without catch crop), it was significantly higher at 120 and 160 kg N per ha than at 40 kg N per ha. No effect of nitrogen fertilization on the K

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concentration in grain of spring wheat was found. Mean values from the three years of the N and Mg content in the grain of spring wheat were significantly influenced by the stubble catch crops. The effect of this factor on the content of macroelements in spring wheat grain was detected only in 2008, which had very low rainfalls during the growth of plants. Under these conditions, the stubble catch crops caused an increase in the content of N and a decrease of P and Mg in grain.

Key words: spring wheat, macroelements, nitrogen, stubble catch crops.

WPŁYW DAWKI AZOTU I MIĘDZYPLONÓW ŚCIERNISKOWYCH NA ZAWARTOŚĆ MAKROELEMENTÓW W ZIARNIE PSZENICY JAREJ

Abstrakt

Celem badań było określenie wpływu dawki azotu i międzyplonów ścierniskowych na zawartość azotu, fosforu, potasu i magnezu w ziarnie pszenicy jarej. Badania polowe wykonano w latach 2005-2008 na glebie płowej, kompleksu żytniego bardzo dobrego, w Mochełku k. Bydgoszczy (53° 13' N, 17° 51' E). Nawożenie azotem stosowano w dawkach (kg ha^{-1}): 0; 40; 80; 120 i 160. Międzyplony ścierniskowe (groch siewny i rzodkiew oleistą) wysiewano w terminie 3-11 sierpnia w latach 2005-2007, i po 70-77 dniach wegetacji przyorywano całą biomasę jako zielony nawóz. Pszenicę jarą cv. Tybalt wysiewano w stanowisku z przyoraną biomasą międzyplonów w latach 2006-2008. Nawożenie azotem wpływało na koncentrację azotu, fosforu i magnezu w ziarnie pszenicy jarej. Każde zwiększenie dawki o 40 kg N ha^{-1} powodowało istotne statystycznie zwiększenie zawartości N. Koncentracja P i Mg w ziarnie pszenicy jarej nawożonej azotem w dawkach 120 lub 160 kg ha^{-1} była istotnie wyższa niż po zastosowaniu niższych dawek. Zawartość P w ziarnie pszenicy uprawianej po rzodkwi oraz bez międzyplonu (obiekt kontrolny) po zastosowaniu 120 i 160 kg N ha^{-1} była wyższa niż w pszenicy nawożonej w ilości 40 kg ha^{-1}. Nie stwierdzono wpływu nawożenia azotem na koncentrację K w ziarnie pszenicy jarej. Międzyplony ścierniskowe powodowały zwiększenie średniej z lat zawartości N oraz zmniejszenie koncentracji Mg w ziarnie. Wpływ międzyplonów ścierniskowych na zawartość makroskładników w ziarnie pszenicy jarej był istotny tylko w 2008 r., charakteryzującym się bardzo małą sumą opadów w okresie wzrostu roślin. W tych warunkach przyorana biomasa międzyplonu ścierniskowego powodowała zwiększenie zawartości N oraz zmniejszenie zawartości Mg i P w ziarnie. Stwierdzono dodatnią korelację między zawartością Mg a koncentracją N i P w ziarnie pszenicy jarej. Zależności te były silniejsze w obiektach kontrolnych niż po międzyplonach ścierniskowych.

Słowa kluczowe: pszenica jara, makroelementy, azot, międzyplony ścierniskowe.

INTRODUCTION

Regular supply of soil organic matter, which sustains the right level of biological activity in soil, is necessary to ensure suitable conditions for cultivated plants. In Poland, the total livestock has been over the last thirty years, which has led to a substantial reduction of the soil fertilization with farmyard manure. The average total livestock density in Poland during the last twelve years has been about 45 livestock units (LUs) per 100 ha of agricultural land (Central Statistical Office 2011).

The use of rape and cereal straw for heating purposes is an another unfavorable factor, which deprives farmland from an essential source of organic carbon. Under such conditions, the only meaningful supply of plant nutrients comes from fertilizers. Unfortunately, high doses of mineral nutrients lead to excessive mineralization of soil organic matter. Among fertilizers, nitrogen supplied intensively could be an especially disturbing factor regarding the soil organic matter content (CORRÉ et al. 2000).

One of the management practices aimed at limiting the soil organic matter depletion is the use of stubble catch crops and their biomass as green manure. Some earlier results concerning this solution have suggested that catch crops can significantly affect physical (ZIMNY et al. 2005) and biological (PIOTROWSKA, WILCZEWSKI 2012) soil properties. Additionally, they can stimulate higher yields and better quality of spring cereal grain (WOJCIECHOWSKI 2009). Stubble catch crops improve nitrogen nutrition of plants grown afterwards. The amount of nitrogen taken up by spring cereals during the shooting, earing and grain formation can be increased by 35-50% after plowing into the soil of the biomass of catch crops (THORUP-KRISTENSEN 1994, BERNTSEN et al. 2006). Mineral compounds released from the mineralized biomass are accessible during the whole growing period of cereals, making it possible to improve all important crop features, so that their concentrations in grain can be higher (THORUP-KRISTENSEN 1994, SKINDER, WILCZEWSKI 2004). The fertilizing significance of catch crop biomass depends on the availability of nutrients from the soil resources and on application of mineral fertilizers. Therefore, it is particularly important for crops on the soils less rich in nutrients and humus, or on fields with a low input of fertilizers.

The aim of the research was to assess:

– the influence of stubble catch crops on the nitrogen, phosphorus, potassium and magnesium content in spring wheat grain as dependent on the dosage of nitrogen fertilization applied;
– interrelations among the concentrations of specific components in wheat grain.

Based on previous findings concerning the chemical, physical and biological properties of soil improved by catch crop plowing, a working hypothesis in this study was that the biomass mineralization in spring ensured a better nutrient supply for spring wheat grain.

MATERIAL AND METHODS

A two-factorial, field experiment was carried out between 2005-2008 in order to evaluate the effects of nitrogen fertilization and catch crops on the concentration of macroelements in spring wheat grain. A split-plot experimental design was used. The field experiment was carried out at the

Mochełek (53° 13' N, 17° 51' E), Experimental Station of the University of Technology and Life Sciences in Bydgoszcz, on *Alfisols* formed from sandy loam (Soil Survey Staff 2010). The concentrations of available phosphorus and potassium in soil were very high (111 mg P kg^{-1} and 367 mg K kg^{-1}). The content of total nitrogen and organic carbon was 0.67 and 7.17 g kg^{-1} of dry soil, respectively.

The first experimental factor was nitrogen fertilization applied before and during spring wheat growing period: 0; 40 kg of N (before sowing); 80 kg of N (40 kg before sowing and 40 kg at the BBCH 31-32 stage (LANCASHIRE et al. 1991)); 120 kg N (60 kg before sowing and 60 kg at the BBCH 31-32 stage); 160 kg N (60 kg before sowing, 60 kg at the BBCH 31-32 stage and 40 kg at the BBCH 45-47 stage). The second experimental factor was stubble catch crop treatments: field pea, oilseed radish, and the control without a catch crop. The catch crops were sown after spring barley harvest, from 3 to 11 August in 2005, 2006, 2007, on a plot area of 30 m^2.

Before seeds of catch crops were sown, the soil was ploughed and tilled using a cultivator with a roller. The catch crops were grown without fertilization.

The catch crops were harvested and ploughed between 20 of October and 10 of November. In the spring of the next year, spring wheat (*Triticum aestivum* L.) cv. Tybalt was sown from 30 of March to 1 of April in the years 2006-2008. Mineral fertilization was applied in spring, before soil preparation. Phosphorus and potassium were applied at the doses of 28.4 kg P ha^{-1} and 74.7 kg K ha^{-1}.

Chemical analyses were made after the mineralization of shredded spring wheat grains (wet combustion with perhydrol and sulphuric acid) using the following methods: phosphorus (P) content by the vanadium-molybdenum method, potassium (K) content by the flame photometry method, magnesium (Mg) content by the colorimetric method with titan yellow. The total nitrogen content in grains was determined using the Kjeldahl method (BREMNER, MULVANEY 1982).

The working hypotheses concerning the effect of various nitrogen doses, the stubble catch crops effect as well as the interactions between two experimental factors on the Mg, N, P and K content in wheat grain were verified by analyses of variance in a split-plot mixed model and tests of significance at $P<0.05$. For significant effects from the Anova, means were separated using Tukey's HSD test ($P < 0.05$). Simple correlations between the macronutrient content, grain yields and doses of N fertilizer per ha were calculated using Pearson's coefficient with significance at $P<0.05$. Significant relations between the macronutrient content in wheat grain and a dose of N fertilizer were explained using linear regression equations.

RESULTS AND DISCUSSION

Individual years of the study were highly varied in the total rainfall during the growing time of spring wheat. In 2006, the amount of rainfall was very high from wheat emergence to stem elongation (Table 1). During the further stages, substantial rainfall deficit was observed. In the following year (2007), the total rainfall and its distribution corresponded very well to spring wheat's needs. The worst supply of precipitation at a critical time in the water demand occurred in May and June 2008.

Table 1

Total precipitation and mean air temperature at the experimental station

Month	Year			Mean for 1949-2008
	2006	2007	2008	
Monthly precipitation (mm)				
April	77.0	17.6	38.7	28.0
May	59.9	73.1	11.5	41.7
June	21.8	105.5	15.5	53.5
July	24.2	104.7	58.7	70.8
Total III – VII	182.9	300.7	124.4	194.0
Mean monthly air temperature (^oC)				
April	7.1	8.5	7.6	7.3
May	12.5	13.8	13.2	12.8
June	16.8	18.2	17.6	16.2
July	22.4	18.0	19.2	18.0
Mean III – VII	14.7	14.6	14.4	13.6

The least favourable air temperature was in 2006, due to cool March and early April, which caused a delay in the sowing time of spring wheat. Moreover, in the same year, the grain formation was very poor due to high temperatures in July. The air temperatures were relatively high from April to June 2007 and throughout the growing period of spring wheat in 2008.

The investigated factors significantly influenced the concentrations of macronutrients in the grain of spring wheat. Especially the contents of N and Mg were greatly differentiated. In the three-year experiment (2006-2008), the total N content in spring wheat grain was influenced significantly by the rate of N fertilization (Table 2). No interaction between the rate of N fertilization and the years of investigation with reference to this variable wasa detected. Spring wheat, grown both after catch crops and in the con-

Table 2

Content of nitrogen (N) in grain of spring wheat (g kg^{-1})

Year	Nitrogen fertilization (kg ha^{-1})	Catch crop			
		field pea	oilseed radish	control	mean
2006-2008	0	19.37 ^{Ad}	18.49 ^{Bd}	17.80 ^{Cd}	18.55 ^{e}
	40	20.14 ^{Acd}	19.66 ^{Bc}	19.16 ^{Cc}	19.65 ^{d}
	80	21.70 ^{Bc}	22.20 ^{Ab}	21.49 ^{Bb}	21.80 ^{c}
	120	22.85 ^{Ab}	22.96 ^{Aab}	22.29 ^{Bb}	22.70 ^{b}
	160	24.06 ^{Aa}	23.84 ^{Ba}	23.92 ^{ABa}	23.94 ^{a}
2006	mean	21.48 ^{A}	21.61 ^{A}	21.60 ^{A}	21.56
2007		21.11 ^{A}	20.61 ^{AB}	19.90 ^{B}	20.54
2008		22.28 ^{A}	22.07 ^{A}	21.29 ^{B}	21.88
Mean		21.62 ^{A}	21.43 ^{B}	20.93 ^{C}	21.33

A, B, C – means marked with the same capital letter constitute a homogenous group across rows
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trol plots, revealed significant increase in the total N content along with an increasing N fertilization rate. The highest concentration of N in grain was obtained when 160 kg N ha^{-1} had ben applied, while a significantly lower N concentration was found in wheat fertilized with 120 kg N ha^{-1}. The lowest N content was observed in grain of wheat unfertilized with N. Based on the linear regression, it was found that an average increase in N content in wheat grain is 0.030, 0.035 and 0.038 g kg^{-1} of dry matter per each kg of this ingredient in the fertilizer applied after field pea and oilseed radish stubble catch crops and in the control, respectively (Figure 1a). Stubble catch crops cultivated for green manure caused a significant increase in the total N content in grain of spring wheat. The effect of field pea on this variable was significantly stronger than oilseed radish. As for this variable, an interaction between the kind of plant species cultivated as stubble catch crops and the years of the investigation was shown. In 2008, both plants cultivated as catch crops influenced the total N content significantly, while in 2007 the N content in the grain of wheat harvested from the control plots was significantly lower than in the field pea treatment. In 2006, no significant impact of catch crops on this variable was noted.

The concentration of total N in wheat grain was relatively high, especially when the grain yield was low and the supply of nitrogen was good supply. Nitrogen fertilization strongly influenced the content of N in grain also in the years with rainfall deficit during the spring wheat vegetation. This significant effect of N fertilization rates on the total N concentration in barley grain is in agreement with numerous research results (Gauer et al. 1992, Walley et al. 2001, Karamanos et al. 2005, Denys et al. 2006). The said impact was especially evident in our study, which resulted from a relatively

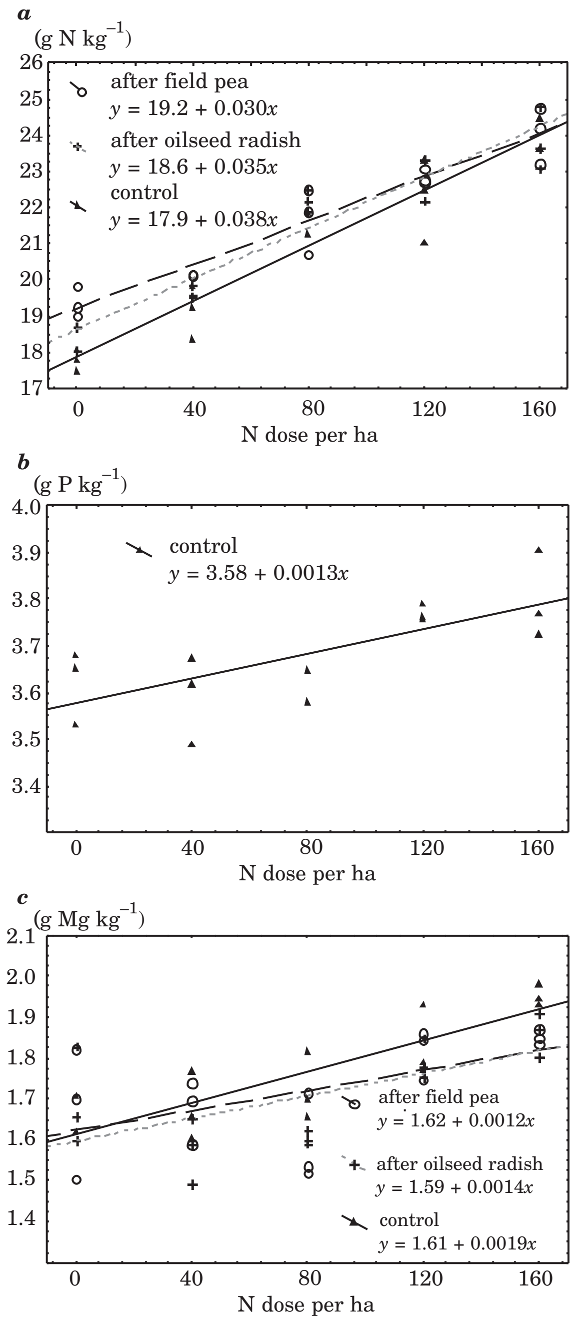

Fig. 1. The dependence of concentration of macroelements in spring wheat grain on a dose of N fertilizer per ha

low influence of the N rate on the grain yield (data not shown) and, consequently, from a higher availability of this nutrient in soil during the wheat maturation period alongside an increasing N fertilization rate. The uptake of nitrogen with wheat grain and straw crop was low and ranged from 52.2 kg ha^{-1} in the control plots to 87.3 kg ha^{-1} in wheat fertilized with the highest rate of N (data not shown). In some other studies, no significant influence of an N fertilization rate on the content of this nutrient in grain was observed, which was due to a strong influence of N on the grain yield achieved on good soil and with a good water supply (WOJCIECHOWSKI 2009), or under the shortage of rainfall during the wheat ripening period (SOUZA et al. 2004).

The influence of an N fertilization rate on the P concentration in grain of spring wheat depended on stubble catch crops ploughed in entirely in November of the year prior to the sowing time (Table 3). No significant effects of N fertilization rates on the P concentration in grain were found in

Table 3

Content of phosphorus (P) in grain of spring wheat (g kg^{-1})

Year	Nitrogen fertilization (kg ha^{-1})	Catch crop			
		field pea	oilseed radish	control	mean
2006-2008	0	3.687 ^{Aa}	3.650 ^{Aab}	3.622 ^{Abc}	3.653 ^{ab}
	40	3.574 ^{Aa}	3.550 ^{Ab}	3.594 ^{Ac}	3.573 ^{b}
	80	3.600 ^{Aa}	3.599 ^{Aab}	3.625 ^{Abc}	3.608 ^{b}
	120	3.726 ^{Aa}	3.752 ^{Aa}	3.771 ^{Aab}	3.750 ^{a}
	160	3.733 ^{Aa}	3.722 ^{Aa}	3.801 ^{Aa}	3.752 ^{a}
2006	mean	4.022 ^{A}	4.014 ^{A}	3.955 ^{A}	3.997
2007		4.267 ^{A}	4.356 ^{A}	4.284 ^{A}	4.302
2008		2.703 ^{B}	2.594 ^{C}	2.810 ^{A}	2.702
Mean		3.664 ^{A}	3.655 ^{A}	3.683 ^{A}	3.667

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spring wheat grown after the field pea treatment. After the oilseed radish treatment, a significantly lower P content in wheat grain was noted after the application of 40 kg N ha^{-1} compared to 120 kg N ha^{-1} and/or 160 kg N ha^{-1}. The grain of spring wheat harvested from the control plots fertilized with the two lowest rates of N and not fertilized with N had significantly less P than after the application of 160 kg N ha^{-1}. The increasing dosage of N fertilizer in the control caused a higher concentration of P in grain by 0.0013 g kg^{-1} dry matter per each kg of N applied, as demonstrated by the linear regression (Figure 1b).

The stubble catch crops influenced the P concentration in spring wheat grain only in 2008, the year characterized by the water supply unfavourable to plants. In that year, a negative impact of the catch crops, especially oilseed radish, on this variable was noted. In a study by Kraska (2011), the effect of catch crops on the said trait was dependent on the species of plants used for this purpose. The biomass of tansy phacelia negatively affected P levels, while white mustard had no significant effect on P concentrations in wheat grain.

Nitrogen fertilization did not influence significantly the concentration of K in spring wheat grain (Table 4). The stubble catch crop treatments did not affect the content of this nutrient in wheat grain either, although an interaction between the catch crops and years of investigation was demonstrated. In 2006 and 2007, the catch crops did not influence the K concentration in wheat grain, but in 2008 the K content in the grain of wheat grown after oilseed radish was significantly lower than in the control.

Table 4

Content of potassium (K) in grain of spring wheat (g kg^{-1})

Year	Nitrogen fertilization (kg ha^{-1})	Catch crop			
		field pea	oilseed radish	control	mean
2006-2008	0	3.302 ^{Aa}	3.210 ^{Aa}	3.340 ^{Aa}	3.284 ^{a}
	40	3.137 ^{Aa}	3.099 ^{Aa}	3.154 ^{Aa}	3.130 ^{a}
	80	3.210 ^{Aa}	3.136 ^{Aa}	3.209 ^{Aa}	3.185 ^{a}
	120	3.320 ^{Aa}	3.134 ^{Aa}	3.227 ^{Aa}	3.227 ^{a}
	160	3.209 ^{Aa}	3.191 ^{Aa}	3.292 ^{Aa}	3.231 ^{a}
2006	mean	3.198 ^{A}	3.108 ^{A}	3.129 ^{A}	3.145
2007		3.796 ^{A}	3.731 ^{A}	3.731 ^{A}	3.753
2008		2.713 ^{AB}	2.623 ^{B}	2.871 ^{A}	2.736
Mean		3.236 ^{A}	3.154 ^{A}	3.244 ^{A}	3.211

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Following the fertilization of spring wheat with nitrogen at the rates of 120 and 160 kg ha^{-1}, as compared to the lower rates of nitrogen fertilization, the concentration of Mg in the grain was significantly higher (Table 5). This effect occurred both in the treatments with the catch crops and on the control plots. Having ananlyzed the effect of N doses on the content of Mg in wheat grain using linear regression, it was found that the average increase was 0.0012, 0.0014 and 0.0019 g kg^{-1} dry matter per each kg of N fertilizer used, respectively after field pea, oilseed radish and in the control (Figure 1c). The stubble catch crops had an adverse effect on the concentration of Mg in grain of spring wheat cultivated afterwards as the main

Table 5

Content of magnesium (Mg) in grain of spring wheat (g kg^{-1})

Year	Nitrogen fertilization (kg ha^{-1})	Catch crop			
		field pea	oilseed radish	control	mean
2006-2008	0	1.676 ^{Ab}	1.695 ^{Abc}	1.650 ^{Ac}	1.674 ^{b}
	40	1.675 ^{Ab}	1.579 ^{Bd}	1.677 ^{Ac}	1.644 ^{b}
	80	1.590 ^{Bb}	1.605 ^{Bcd}	1.725 ^{Ac}	1.640 ^{b}
	120	1.817 ^{Aa}	1.795 ^{Ab}	1.831 ^{Ab}	1.814 ^{a}
	160	1.851 ^{Ba}	1.861 ^{Ba}	1.953 ^{Aa}	1.889 ^{a}
2006	mean	1.650 ^{A}	1.627 ^{A}	1.627 ^{A}	1.634
2007		1.963 ^{A}	1.936 ^{A}	1.959 ^{A}	1.953
2008		1.553 ^{B}	1.558 ^{B}	1.715 ^{A}	1.609
Mean		1.722 ^{B}	1.707 ^{B}	1.767 ^{A}	1.732

A, B, C – means marked with the same capital letter constitute a homogenous group across rows
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crop only in 2008, while in 2006 and 2007 this factor had no influence on the Mg content in wheat grain. This differentiated impact of catch crops in specific years was probably caused by the variable water supply in the spring period during the growth of wheat. The low total rainfall in May and June of 2008, compared to 2006 and 2007, might have reduced the soil enzymatic activity, thus depressing the decomposition of catch crops and the accessability of macrocompounds accumulated in the biomass. In fact, the enzymatic activities involved in the C (β-glucosidase), N (urease) and P cycling (alkaline phosphatase) studied in the experiment were significantly lower in that year compared to 2006 and 2007 (Piotrowska, Wilczewski 2012). Some other results confirmed that soil enzymatic activity is strongly moisture-dependent. Thus, higher soil moisture owing to rainfall enhanced the activity of soil enzymes, specially phosphatase and dehydrogenase, as reported by Akmal et al. (2012). Similar results have been found by Sardans, Penuclas (2005), who observed a strong positive relationship between the activity of soil phosphatases and soil water availability. Frey et al. (1999) reported that moisture influenced soil enzymatic activity indirectly, by enhancing the microbial growth and substrate availability.

The influence of the catch crops on the Mg content in spring wheat grain depended on the N fertilization rate. No significant influence of the ploughed catch crop biomass on this variable was shown in the control plots (without N fertilization) and after application of 120 kg N ha^{-1}. The concentration of Mg in the grain of spring wheat fertilized with N at the rates of 80 kg N ha^{-1} and 160 kg N ha^{-1} was significantly lower in the case of plots with preceding catch crops than in control. Earlier studies showed a beneficial impact of ploughed biomass of oilseed radish and common sunflower, grown as stubble catch crops, on the Mg content in wheat grain and a negative influence of sunflower or phacelia biomass on the Mg concentration in wheat straw (WILCZEWSKI, SKINDER 2011).

Significant Pearson's correlation coefficients between the content of nutrients and the spring wheat yield are presented in Table 6. In 2006 and 2007, the N concentration was positively correlated with the grain yield, while in 2008 this relationship was negative. The Mg concentration was correlated with the yield of spring wheat positively in 2007 and negatively in 2008. In 2006, no significant relationship between these variables appeared. Generally positive correlations between concentrations of macronutrients and yield were detected in 2007, while in 2006 and 2008 this tendency was opposite. Such evident differences in the relationships between the analyzed features of spring wheat were attributed to highly varied weather conditions, which affected the yield of wheat grain in individuals years of the investigations.

Table 6

Simple correlation coefficients for the relation between yield of grain of spring wheat and macronutrient content (n=45)

Year	Nutrient			
	N	P	K	Mg
2006	0.67*	-0.03	-0.46*	-0.26
2007	0.83*	0.16	0.07	0.33*
2008	-0.53*	-0.58*	-0.27	-0.74*

* correlation significant at α = 0.05

Based on the linear correlation coefficients between the content of macroelements (N, P, K and Mg) in spring wheat grain, the N dose per ha and wheat grain yield after two catch crops, it was found that the above relationships could appear with different strength on plots with previous stubble catch crops as compared with the control. Significant, positive correlations were found between the Mg and N or P concentrations in wheat grain, stronger in the control treatment than after stubble catch crops (Table 7). There were also the same values of correlations, $r = 0.67$, $P < 0.01$, between the P and K content in wheat grain from plants sown after field pea or oilseed radish. The potassium content did not explain the concentration of Mg in wheat grain and *vice versa*. Meanwhile, the content of N in wheat grain was positively correlated with the concentration of P ($r = 0.73$, $P < 0.01$) but only in the control treatment.

Table 7

Linear correlation coefficients between the content of macroelements in spring wheat grain, N dose per ha and wheat grain yield for each catch crop (n=15)

Correlates	Catch crop treatment	N dose	Grain yield	N	P	K	Mg
N dose	control	-	**	***	**	ns	***
	field pea	-	ns	***	ns	ns	*
	oilseed radish	-	*	***	ns	ns	*
Grain yield	control	0.71	-	***	ns	ns	*
	field pea	0.47	-	ns	ns	ns	ns
	oilseed radish	0.57	-	**	ns	ns	ns
N	control	0.96	0.76	-	**	ns	***
	field pea	0.96	0.47	-	ns	ns	*
	oilseed radish	0.96	0.67	-	ns	ns	*
P	control	0.73	0.26	0.65	-	ns	***
	field pea	0.32	-0.21	0.35	-	**	**
	oilseed radish	0.43	0.03	0.43	-	**	*
K	control	-0.03	-0.41	-0.14	0.04	-	ns
	field pea	-0.003	-0.41	-0.02	0.67	-	ns
	oilseed radish	-0.002	-0.11	-0.01	0.67	-	ns
Mg	control	0.86	0.54	0.83	0.83	-0.04	-
	field pea	0.55	-0.12	0.52	0.67	0.21	-
	oilseed radish	0.63	0.05	0.54	0.65	0.15	-

CONCLUSIONS

1. Nitrogen fertilizer rates influenced the N, P and Mg concentrations but did not affect the content of K in the grain of spring wheat. The content of N was highest at 160 kg N ha^{-1}, while the concentrations of P and Mg were biggest at 120 or 160 kg N ha^{-1}.

2. Overall, the stubble catch crops caused a decrease in the Mg content and an increase in N concentration in spring wheat grain.

3. A linear relationship was found between increasing doses of nitrogen fertilizer and the content of N, P and Mg. These correlations were especially strong with regard to the N content. The relationships between N doses and the concentration of P and Mg were relatively high in control crops, which corresponded to an interaction between N fertilization and stubble catch crops.

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