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THE EFFECT OF MULTI-COMPONENT FERTILIZERS ON THE YIELD AND MINERAL COMPOSITION OF WINTER RYE*

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K e y w o r d s: winter rye, yield, macronutrients, multi-component fertilizers, uptake.

A b s t r a c t

The objective of this study was to determine the effect of mixed multi-component fertilizers, Amofosmag 4 and Amofosmag 3, on winter rye yield, and the content and uptake of macronutrients. A three-year field experiment (2008–2010) was carried out in a randomized block design at the Research and Experimental Station in Tomaszkowo, at the University of Warmia and Mazury in Olsztyn. The tested crop was winter rye (*Secale Cereale L.)* cv. Dańkowskie Diament. The obtained results showed that fertilization multi-component fertilizers, especially Amofosmag 3 has the effect of increasing the yield of grain and straw of winter rye as compared to simple fertilizer. The concentrations of the analyzed macronutrients in winter rye grain and straw varied insignificantly between fertilization treatments. Simple and multi-component fertilizers exerted a comparable effect on the mineral composition of the test crop. Significant differences were observed in this respect between successive years of the study. The highest total uptake of nitrogen, potassium and calcium by rye plants was noted in treatments with simple fertilizers, and somewhat higher phosphorus uptake was observed in the Amofosmag 4 treatment. Total magnesium uptake was similar in all treatments.

WPŁYW NAWOZÓW WIELOSKŁADNIKOWYCH NA PLONOWANIE I SKŁAD MINERALNY ŻYTA OZIMEGO

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S ł o w a k l u c z o w e: żyto ozime, plon, makroelementy, nawozy wieloskładnikowe, pobranie.

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Abstrakt

Celem pracy była ocena wpływu nawozów wieloskładnikowych Amofosmagu 4 i Amofosmagu 3 na plon, zawartość i pobranie makroskładników przez żyto ozime. Trzyletnie doświadczenie polowe (2008–2010) przeprowadzono w Ośrodku Dydaktyczno-Doświadczalnym w Tomaszkowie należącym do Uniwersytetu Warmińsko-Mazurskiego w Olsztynie. Rośliną testowaną było żyto ozime odmiany 'Dańkowskie Diament'. Na podstawie otrzymanych wyników stwierdzono, że nawożenie nawozami wieloskładnikowymi, a szczególnie Amofosmagiem 3, miało wpływ na zwiększenie plonu ziarna i słomy żyta ozimego w porównaniu z nawozami jednoskładnikowymi. Zawartość badanych makroelementów w życie w poszczególnych obiektach nawozowych była na ogół zbliżona, zastosowane nawozy działały równorzędnie. Różnice w składzie chemicznym żyta wystąpiły w poszczególnych latach badań. Największe łączne pobranie azotu, potasu i wapnia przez żyto ozime stwierdzono w obiektach z nawozami jednoskładnikowymi, natomiast fosforu – w obiekcie z Amofosmagiem 4. Łączne pobranie magnezu przez żyto było zbliżone we wszystkich obiektach nawozowych.

Introduction

Multi-component fertilizers should be selected based on a thorough analysis of a variety of factors such as the plant species, expected yield, macronutrient availability, time and mode of application. Mixed fertilizers have to be applied in a rational manner, and their rates should be determined in view of crop yield, crop quality and fertilizer efficiency, so as to maximize the benefits of fertilizer use. A wide variety and range of multi-component fertilizers are currently available on the Polish market. The products differ with respect to quality, price, chemical composition and form, including the varying proportions of three primary macronutrients, N, P and K, and secondary nutrients, S, Mg and Ca, which helps consumers make the optimal choice (GRZEBISZ 2000). The use of multi-component mineral fertilizers, supplying a balanced mixture of major nutrients, allows to prevent environmental pollution and address environmental concerns in agricultural ecosystems (ŁABUDA 1994, LIPIŃSKI and BEDNAREK 1998).

The objective of this study was to determine the effect of mixed multi-component fertilizers, Amofosmag 4 and Amofosmag 3, on winter rye yield, and the content and uptake of macronutrients. The applied fertilizers provided the test crop with essential nutrients in optimal proportions.

Materials and Methods

A three-year field experiment (2008–2010) was carried out in a randomized block design at the Research and Experimental Station in Tomaszkowo, at the University of Warmia and Mazury in Olsztyn. The experiment, which comprised three fertilization treatments in four replications: control treatment (simple fertilizers), Amofosmag 4 and Amofosmag 3, was established on proper

brown soil developed from sandy loam, of quality class III b and very good rye complex. The physicochemical properties of soil in each year of the study are presented in Table 1. The tested crop was winter rye (*Secale Cereale L.)* cv. Dańkowskie Diament. The preceding plants were winter triticale. Plot surface area was 10 m^2.

Table 1

Selected physicochemical properties of soil used in the experiment [mg kg^{-1}]

Year	pH w 1 M KCl	Available forms		
		P	K	Mg
2008	6.2	72	207	28
2009	7.0	84	149	35
2010	5.7	70	244	96

Based on the average levels of available phosphorus in the soil, 350 kg ha^{-1} Amofosmag 3 (NPKMg 3:14:20:2 + 22% CaO + 9% SO_3: 10,5 kg N, 21,5 kg P, 58 kg K, 55 kg Ca, 4 kg Mg, 12,5 kg S on pure ingredient basis) and Amofosmag 4 (NPKMg 4:15:15:2 + 24% CaO + 9% SO_3: 12 kg N, 23 P, 43,5 kg K, 60 kg Ca, 4 kg Mg, 12,5 kg S on pure ingredient basis) were applied pre-sowing. The nitrogen rate of 80 kg per ha was supplemented with two doses of ammonium nitrate applied by top-dressing in all treatments, including control. In the control treatment, the following fertilizers were applied presowing: 14 kg N in the form of urea, 23 kg P in the form of triple superphosphate 46% and 43,5 kg K kg ha^{-1} in the form of potash salt 60%.

Samples of winter rye were collected at the stage of full maturity. The grain and straw harvested in each plot was dried and weighed individually. Wet mineralized samples were assayed for the content of: total nitrogen – by the hypochlorite method, phosphorus – by the vanadium-molybdenum method, calcium and potassium – by atomic emission spectrometry (AES), and magnesium – by atomic absorption spectrometry (AAS). The results of chemical analyses were verified statistically by a two-factorial analysis of variance for a randomized block design. The experimental factors were as follows: *a* – fertilization, *b* – duration of the experiment. The least significant difference was assumed at $p = 0.05$.

Results and Discussion

The distribution of air temperatures in the growing season of 2008 differed insignificantly from the long-term average (Table 2). Precipitation total in May and June was substantially lower than the multiannual average for 1970–2000,

which could have reduced the growth rate of winter rye plants. In 2009, mean monthly temperatures were similar to the long-term average. April was very dry, while high precipitation levels were noted in June. According to CHMIELEWSKI (1992), and CHMIELEWSKI and KÖHN (2000), a constant supply of water and moderate temperatures in winter and early spring support the growth and yield of winter cereals (high coefficients of productive tillering). In 2010, air temperatures during the growing season were slightly above the long-term average. Precipitation total in May was over 2.5-fold higher than the long period average for 1970–2000. Weather conditions could have affected the yield of winter rye.

Table 2
Weather conditions in 2008–2010 – data provided by the Meteorological Station in Tomaszkowo

Month	Mean monthly temperature [°C]				Precipitation total [mm]			
	2008	2009	2010	1970–2000	2008	2009	2010	1970–2000
April	7.7	9.4	8.1	6.9	31.4	4.8	18.2	36.1
May	12.3	12.4	12.0	12.7	27.0	52.9	131.9	51.9
June	16.9	14.9	16.4	15.9	32.7	136.9	84.8	79.3
July	18.5	20.4	21.1	17.7	57.7	48.3	80.4	73.8
August	18.4	17.6	19.3	17.2	102.1	19.3	95.3	67.1
September	15.1	14.2	12.0	12.5	22.9	25.7	40.5	59.0

In 2008, the yield of winter rye grain ranged from 5.64 to 6.73 t ha^{-1}, and it was significantly affected by the type of fertilizers (Table 3). The highest average yield of winter rye grain was noted in the Amofosmag 3 treatment. Straw yield was not significantly influenced by the fertilizers applied in the study. In experiments conducted by SADOWSKI and RYCHCIK (2010), and SKUODIENĖ and NEKROŠIENĖ (2009), the average winter rye yield reached 5.47 t ha^{-1} and 3.82 t ha^{-1}, respectively. In the second year of the study, the yield of winter rye grain varied from 5.96 to 5.97 t ha^{-1}, which was the lowest level noted throughout the experimental period. Precipitation total in April was very low, which could have reduced the number and size of rye ears. The experimental factors had no significant effect on straw yield. As demonstrated by CHMIELEWSKI and KÖHN (2000), and ALARU et al. (2003), cereal grains are highly sensitive to weather conditions. In the third year of the experiment (2010), Amofosmag 3 had the most beneficial influence on rye grain yield, which was found to increase by around 6%, compared with the control treatment. Rye straw yield was affected by the applied fertilizers to a lower degree. In a study by OLESEN et al. (2009), the average yield of winter cereals ranged from 3.2 to 5.1 t ha^{-1}.

Table 3

Winter rye yield after the application of Amofosmag 4 and Amofosmag 3 [t ha^{-1}]

Treatment	Grain				Straw			
	2008	2009	2010	mean for *a*	2008	2009	2010	mean for *a*
NPK	5.64	5.96	7.09	6.23	7.06	8.28	8.71	8.02
Amofosmag 4	5.96	5.94	7.23	6.38	7.58	7.81	8.98	8.12
Amofosmag 3	6.73	5.97	7.49	6.73	9.28	7.64	9.37	8.76
Mean for *b*	6.11	5.96	7.27		7.97	7.91	9.02	
$LSD_{p = 0.05}$ for *a*	0.30				n.s.			
b	0.32				0.75			
ab	n.s.				0.73			

Explanation: *a* – fertilization, *b* – duration of the experiment, *ab* – interaction, n.s. – non-significant difference

The results of the present study show that Amofosmag 3 caused an approximately 8% and 9% increase (on average) in the yield of rye grain and straw, respectively, compared with simple fertilizers. An increase in the yield of different cereal species in response to the application of mixed fertilizers was also reported by ZAWARTKA and SKWIERAWSKA (2004), and NOGALSKA et al. (2010, 2011), whereas in an experiment by WINIARSKI et al. (2002) the yield-forming effects of multi-component and simple fertilizers were comparable.

Rye is grown as a food plant for human consumption and animal feed, therefore its macronutrient and micronutrient content is equally important as yield (BEDNAREK et al. 2006). In 2008, the nitrogen content of winter rye grain ranged from 10.62 to 11.50 g kg DM. A lower nitrogen content of rye kernels was observed in 2009, and the highest nitrogen concentrations in rye grain (15.28 g kg^{-1} DM) were noted in 2010. The applied fertilizers had no significant effect on changes in the nitrogen levels in rye grain. In a study by GROMOVA and POLACK (1995), the average nitrogen content of rye grain was 23.70 g kg^{-1} DM. Nitrogen concentrations in winter rye straw were significantly affected by the type of fertilizers and the year of the study. A significantly lower nitrogen content of rye straw (on average) was reported following the application of Amofosmag 3. In 2008, rye grain contained significantly less phosphorus and potassium than in 2009 and 2010. In the second and third year of the experiment, rye kernels were more abundant in phosphorus and potassium (statistically significant differences). Multi-component fertilizers had no significant effect on changes in the concentrations of phosphorus and potassium in rye straw. The calcium content of winter rye grain was not determined by the type of fertilizers. Differences between treatments were minor, and the highest calcium concentrations in the test crop were noted in 2010. Both mixed

Table 4
Macronutrient content of winter rye after the application of Amofosmag 4 and Amofosmag 3 [g kg^{-1} d.m.]

	Treatment	Grain				Straw			
		2008	2009	2010	mean for *a*	2008	2009	2010	mean for *a*
Nitrogen	10.62	10.62	8.98	15.95	11.85	3.16	3.46	6.65	4.42
	10.20	10.20	9.62	14.85	11.55	3.46	3.42	5.11	3.99
	11.50	11.50	8.66	15.06	11.74	3.21	3.17	3.87	3.41
Mean for *b*		10.77	9.08	15.28		3.27	3.35	5.21	
$LSD_{p = 0.05}$ for *a*		n.s.				0.582			
b		1.012				0.520			
ab		n.s.				1.009			
Phosphorus	1.92	1.92	4.92	3.77	3.53	1.17	2.07	1.95	1.73
	1.99	1.99	5.51	3.66	3.72	1.08	2.13	1.98	1.73
	1.88	1.88	2.71	3.38	2.65	1.00	2.19	2.01	1.74
Mean for *b*		1.93	4.38	3.60		1.08	2.13	1.98	
$LSD_{p = 0.05}$ for *a*		0.244				n.s.			
b		0.240				0.177			
ab		0.422				n.s.			
Potassium	3.07	3.07	5.47	4.24	4.25	15.15	11.90	13.55	13,52
	3.30	3.30	5.62	4.10	4.34	12.65	12.90	13.27	12,94
	2.82	2.82	5.57	4.10	4.16	11.32	12.72	11.32	11,78
Mean for *b*		3.06	5.55	4.14		13.04	12.50	12.71	
$LSD_{p = 0.05}$ for *a*		n.s.				n.s.			
b		0.285				n.s.			
ab		n.s.				n.s.			
Calcium	0.58	0.58	0.54	0.71	0.61	5.26	3.22	3.86	4.11
	0.60	0.60	0.47	0.69	0.58	4.05	2.82	3.54	3.47
	0.51	0.51	0.46	0.74	0.57	4.58	2.42	3.44	3.48
Mean for *b*		0.56	0.49	0.71		4.63	2.82	3.61	
$LSD_{p = 0.05}$ for *a*		n.s.				0.254			
b		0.051				0.280			
ab		n.s.				0.440			
Magnesium	0.77	0.77	0.84	0.94	0.85	0.37	0.43	0.44	0.41
	0.81	0.81	0.89	0.96	0.88	0.36	0.45	0.37	0.39
	0.72	0.72	0.84	0.95	0.83	0.41	0.44	0.32	0.39
Mean for *b*		0.76	0.85	0.95		0.38	0.44	0.37	
$LSD_{p = 0.05}$ for *a*		n.s.				n.s.			
b		0.060				0.054			
ab		n.s.				n.s.			

Explanations as in Table 3

fertilizers contributed to a slight, but significant decrease in the calcium content of straw, compared with simple fertilizers. The magnesium content of winter rye remained stable throughout the experiment, and it was not significantly affected by the applied fertilizers. There were differences in

magnesium levels between the years of the study. The highest magnesium content of rye grain and straw was reported in 2010 and 2009, respectively. The results of chemical analyses of winter rye grain and straw show that the concentrations of the analyzed macronutrients varied between the years of the study, and that they were determined by weather conditions rather than by the applied fertilizers. The findings of other authors (FILIPEK 2001, TRAWCZYŃSKI and GRZEŚKIEWICZ 2006, NOGALSKA et al. 2010, 2011) indicate that multi-component fertilizers have no significant effect on the macronutrient content of test crops.

Macronutrient uptake was estimated based on the yield and macronutrient content of winter rye grain and straw. Nitrogen uptake by rye plants varied throughout the experimental period, and it reached the highest level in the third year of the study. Nitrogen uptake was correlated with rye yield and the percentage content of nitrogen in plants (Table 3 and Table 4). Phosphorus uptake levels were comparable in all treatments, and they tended to increase in response to Amofosmag 4. Phosphorus uptake varied considerably between years, due to differences in rye yield and the percentage content of macronutrients in plants. Potassium uptake by winter rye plants was highest in the third year of the experiment, in particular after the application of simple fertilizers. The highest calcium uptake was noted in the first year of the study, mostly due to a high calcium content of rye straw (Table 5). Magnesium uptake by rye plants was comparable in all treatments, regardless of the fertilizers applied. Differences in magnesium uptake were observed only between the years of the study. The highest total uptake of nitrogen, potassium and calcium was noted in treatments with simple fertilizers, and somewhat higher phosphorus uptake was observed in the Amofosmag 4 treatment (Figure 1). Total magnesium uptake was similar in all treatments. Partially different results were reported by NOGALSKA et al. (2010, 2011).

Table 5

Nutrient uptake by winter rye grain and straw [kg ha^{-1}]

Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
2008					
NPK	82.19	19.08	124.2	40.40	6.95
Amofosmag 4	87.01	20.04	115.3	34.26	7.54
Amofosmag 3	107.17	21.93	124.0	45.93	8.64
2009					
NPK	82.16	46.45	131.1	29.87	8.56
Amofosmag 4	83.77	49.35	134.1	24.81	8.79
Amofosmag 3	75.91	32.90	130.4	21.22	8.37
2009					
NPK	171.0	41.85	148.0	38.71	10.49
Amofosmag 4	153.2	44.24	130.2	36.76	10.26
Amofosmag 3	149.0	40.66	136.7	37.77	10.10

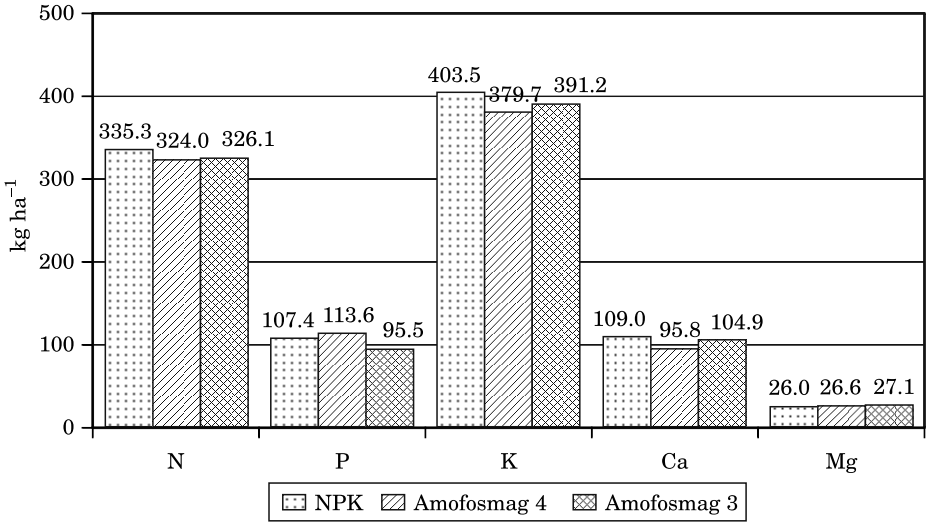

Fig. 1. Total macronutrient uptake by winter rye over a three-year experimental period

Conclusions

1. The most beneficial effect was reported for Amofosmag 3 which increased the yield of winter rye grain by 8% on average, compared with the control treatment.

2. The concentrations of the analyzed macronutrients in winter rye grain and straw varied insignificantly between fertilization treatments. Simple and multi-component fertilizers exerted a comparable effect on the mineral composition of the test crop. Significant differences were observed in this respect between successive years of the study.

3. The highest total uptake of nitrogen, potassium and calcium by rye plants was noted in treatments with simple fertilizers, and somewhat higher phosphorus uptake was observed in the Amofosmag 4 treatment. Total magnesium uptake was similar in all treatments.

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