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THE EFFECT OF MULTI-COMPONENT FERTILIZERS ON THE YIELD AND MINERAL COMPOSITION OF WINTER WHEAT AND MACRONUTRIENT UPTAKE

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Abstract

Multi-component fertilizers should be selected based on a thorough analysis of a variety of factors such as plant species, expected yield, nutrient 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. The objective of this study was to determine the effect of multi-component fertilizers, Amofosmag 4 and Amofosmag 3, on winter wheat 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 (NE Poland). The experiment comprised three fertilization treatments in four replications: control treatment (simple fertilizers) and two treatments with mixed multi-component fertilizers, Amofosmag 4 and Amofosmag 3. The tested crop was winter wheat cv. Bogatka.

Winter wheat grain yield was modified by fertilizers and weather conditions. The most beneficial effect was reported for Amofosmag 4, which increased the yield of wheat grain by 7% on average, compared with the remaining treatments. A significantly lower grain yield was noted in the second year of the study characterized by adverse weather conditions. The concentrations of the analyzed macronutrients in winter wheat 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. The only exception was the potassium content of wheat straw, which was significantly higher after the application of multi-component fertilizers. Significant differences were observed in this

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respect between successive years of the study. The highest total uptake of nitrogen, phosphorus and magnesium by winter wheat plants was noted in the Amofosmag 4 treatment, and the highest total uptake of potassium and calcium was observed in the Amofosmag 3 treatment. Amofosmag 4 was found to be the most efficient fertilizer, which suggests that the nutrients contained in multi-component fertilizers are more readily available to plants.

Key words: winter wheat, yield, macronutrients, multi-component fertilizers, uptake.

WPŁYW NAWOZÓW WIELOSKŁADNIKOWYCH NA PLON, ZAWARTOŚĆ I POBRANIE MAKROELEMENTÓW PRZEZ PSZENICE OZIMĄ

Abstrakt

Wybór nawozu wieloskładnikowego musi być poprzedzony wieloetapową analizą czynników, takich jak: gatunek rośliny, oczekiwany plon, zasobność gleby w składniki pokarmowe oraz termin i technika stosowania nawozów. Stosowanie nawozów wieloskładnikowych powinno odbywać się w sposób racjonalny, z uwzględnieniem wysokich i dobrych jakościowo plonów oraz efektywności nawożenia z jednoczesnym wykorzystaniem zalet agrochemicznych nawozów. Celem pracy była ocena skuteczności nawozowej Amofosmagu 4 i Amofosmagu 3 na plon, zawartość i pobranie makroelementów przez pszenicę ozimą oraz efektywność rolniczą. Trzyletnie doświadczenie polowe (2008-2010) przeprowadzono w Ośrodku Dydaktyczno-Doświadczalnym w Tomaszkowie należącym do Uniwersytetu Warmińsko-Mazurskiego w Olsztynie. Doświadczenie, założone metodą losowanych bloków, obejmowało trzy obiekty nawozowe w czterech powtórzeniach: obiekt kontrolny (nawozy jednoskładnikowe) oraz dwa obiekty nawożone nawozami wieloskładnikowymi (Amofosmag 4 i Amofosmag 3). Rośliną testowaną była pszenica ozima odmiany Bogatka. Z badań wynika, że nawożenie Amofosmagiem 4 miało istotny wpływ na zwiększenie plonu ziarna pszenicy ozimej. Zawartość badanych makroelementów w pszenicy w poszczególnych obiektach nawozowych była zbliżona, zastosowane nawozy działały równorzędnie. Wyjątek stanowiła zawartość potasu w słomie, w której istotnie większą koncentrację tego składnika uzyskano pod wpływem nawozów wieloskładnikowych. Zróżnicowanie w składzie mineralnym badanej rośliny wystąpiło między poszczególnymi latami badań. Największe łączne pobranie azotu, fosforu i magnezu przez pszenicę ozimą stwierdzono po zastosowaniu Amofosmagu 4, a potasu i wapnia w obiekcie z Amofosmagiem 3. Największą efektywność rolniczą uzyskano stosując Amofosmag 4. Świadczy to o lepszej przyswajalności składników pokarmowych z nawozów wieloskładnikowych niż jednoskładnikowych.

Słowa kluczowe: pszenica ozima, plon, makroelementy, pobranie, nawozy wieloskładnikowe.

INTRODUCTION

Fertilization is the main yield-forming factor, and one of the key indicators of agricultural production intensity and efficiency. Due to the growing demand for agricultural produce and commodities used to produce biofuels, fertilizer use will increase in the coming years (ZALEWSKI 2009). The major advantages of modern fertilizers include easy application and storage, solubility and complex composition. Since the 1990s, there has been a steady increase in the share of multi-component fertilizers in total mineral fertilizer consumption. Numerous fertilizer manufacturers offer a wide variety and range of mixed fertilizers, blends and compound fertilizers so as to meet the farmers' specific needs. In Poland, the driving force behind fertilizer market development is growing awareness among farmers of the importance and profitability of new technological solutions (POTARZYCKI, LEWICKA 2002). A clear advantage of multi-component fertilizers over simple fertilizers is that the former supply a combination of nutrients at a time (GLABISZ et al. 1992). The yield of cereals is determined by their nutritional status at the early stages of growth. The optimum nutrient supply during the critical growth stages enables crops to reach their full yield potential (GAJ 2010). According to CHWIL (2000), rational fertilization of winter wheat is determined by the amounts of primary nutrients supplied, and their relative proportions.

The objective of this study was to determine the effect of mixed multi-component fertilizers, Amofosmag 4 and Amofosmag 3, on winter wheat yield, and the content and uptake of macronutrients, and fertilization efficiency.

MATERIAL 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 wheat (*Triticum aestivum* L. *emend)* cv. Bogatka. The preceding plant was winter triticale. Plot surface area was 10 m^2.

Based on the average levels of available phosphorus in the soil, 350 kg ha^{-1} Amofosmag 3 (NPK Mg 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)

Table 1

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

Year	pH in 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	36

and Amofosmag 4 (NPK Mg 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 pre-sowing: 14 kg N in the form of urea, 23 kg P in the form of triple superphosphate and 43.5 kg K kg ha^{-1} in the form of potash salt 60%.

Samples of winter wheat 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

Air temperatures in 2007 and 2008 were generally higher that the long-term average (Table 2). October and November were colder and drier than the multiannual average. The winter dormancy period of wheat differed significantly from that observed in previous years, and it was characterized by considerably higher temperatures and precipitation levels. Precipitation total in May and June was substantially lower than the multiannual average,

Table 2

Weather conditions in 2008-2010 (data from the Meteorological Station in Tomaszkowo)

Month	Mean monthly temperature (°C)				Precipitation total (mm)			
	2007/ 2008	2008/ 2009	2009/ 2010	1970 - -2000	2007/ 2008	2008/ 2009	2009/ 2010	1970 - -2000
September	12.6	11.8	14.2	12.5	57.9	22.9	25.7	59.0
October	7.5	8.6	5.8	7.8	30.2	82.8	55.7	43.4
November	1.3	4.0	5.0	2.7	33.8	29.4	43.8	47.7
December	0.5	0.1	-1.9	-1.3	27.8	35.1	30.6	36.2
January	0.7	-3.2	-9.0	-2.9	66.2	24.7	19.4	28.8
February	2.5	-2.0	-3.0	-2.4	24.7	31.7	22.5	20.4
March	3.0	1.3	2.1	1.2	52.4	57.9	36.7	26.8
April	7.6	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

which could have adversely affected spike development. August was very wet, which retarded the harvest. In the second year of the study (2008/2009), the distribution of temperatures and rainfalls supported the growth and development of winter wheat. Considerable water deficiency was noted only in April, when rainfall accounted for only 13% of the long-term average, but high water supply in March (two-fold higher than the long period average) as well as high precipitation levels in May and June were sufficient to maintain adequate soil moisture content. July was warm and relatively wet, while August was dry, which contributed to even ripening and kernel plumpness. In 2009/2010, mean monthly temperatures and precipitation totals differed from the long-term averages. A warm and sufficiently wet fall was followed by a harsh and precipitation-deficient winter. Water deficiency in April (rainfall levels two-fold lower than the long-term average) was compensated for by rainfall surpluses in the subsequent months of the growing season, especially May when precipitation total was over 2.5-fold higher than the long period average. 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). Weather conditions could have affected the yield of winter wheat.

In the first year of the study (2008), the yield of winter wheat grain ranged from 6.54 to 7.23 t ha^{-1}, and it was significantly affected by the type of fertilizer (Table 3). The highest average yield of winter wheat was noted in the Amofosmag 4 treatment – it was by over 10% higher than in the control and Amofosmag 3 treatment. Wheat straw yield corresponded to grain yield, and it showed no significant changes. In an experiment with spring wheat conducted by NOGALSKA et al. (2010), multi-component fertilizers had a more desirable yield-forming effect than simple fertilizers. In the second

Table 3

Winter wheat 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	6.56	5.30	6.80	6.22	6.69	6.40	7.63	6.91
Amofosmag 4	7.23	5.43	7.35	6.67	7.11	7.09	8.26	7.49
Amofosmag 3	6.54	5.51	7.01	6.33	6.48	7.06	7.87	7.14
Mean for *b*	6.76	5.41	7.05		6.76	6.85	7.92	
$LSD_{p=0.05}$ for *a*	0.33				n.s.*			
b	0.35				0.69			
ab	n.s.*				n.s.*			

Key: *a* – fertilization, *b* – duration of the experiment, *ab* – interaction, n.s. – non-significant difference year of the study (2009), the yield of winter wheat grain varied from 5.30 to 5.51 t ha^{-1}, and it was significantly lower than in 2008 and 2010. Dry April, followed by cold and wet May and June could have reduced the number and size of wheat ears. According to ALARU et al. (2003), cereal grains are highly sensitive to weather conditions. In a study by OLESEN et al. (2009), the average yield of winter cereals ranged from 3.2 to 5.1 t ha^{-1}. In the third year of the experiment (2010), similarly as in the first year, Amofosmag 4 had the most beneficial influence on wheat grain yield, which was found to increase significantly, by around 8% and 4.8%, compared with the control and Amofosmag 3 treatment. The applied fertilizers had no significant effect on wheat straw yield, whereas significant differences were observed in this respect between successive years of the study. Straw yield was significantly higher in 2010 than in 2008 and 2009, which resulted from the highest grain yield in 2010 and favorable weather conditions.

The results of the present study show that Amofosmag 4 caused an approximately 7% and 8% increase (on average) in the yield of wheat grain and straw, respectively, compared with simple fertilizers. In an experiment by CHWIL (2000), winter wheat yield ranged from 5.89 to 7.90 t ha^{-1}. 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 b), and NOGALSKA et al. (2010, 2011).

The results of chemical analyses of winter wheat grain and straw show that the concentrations of the analyzed macronutrients varied insignificantly between treatments (Table 4), while significant differences were found between the years of the study. In the second year, the average nitrogen content of winter wheat grain reached 10.63 g N kg^{-1} d.m., and it was twofold and 1.5-fold lower compared with the third and the first year, respectively. In 2008, the concentrations of phosphorus, potassium and calcium in wheat grain were significantly lower than in the next two years. The magnesium content of wheat grain remained stable throughout the experiment, reaching the highest level in 2010. Similar macronutrient concentrations in wheat grain were reported by RACHOŃ and SZUMIŁO (2009). The findings of other authors (FILIPEK 2001, KRZYWY et al. 2001, NOGALSKA et al. 2010, 2011) indicate that multi-component fertilizers have no significant effect on the mineral composition of cereal grain.

Macronutrient uptake was estimated based on the yield and macronutrient content of winter wheat grain and straw. Nitrogen uptake by wheat plants was highest in the third year of the study (186.01 kg N ha^{-1}), after the application of Amofosmag 3. High nitrogen uptake resulted from a high wheat yield and the highest nitrogen content of plants in 2010 (Table 5). Similar results were reported by FOSSATI et al. (1993). Phosphorus uptake levels were comparable in all treatments, and they tended to increase in response to Amofosmag 4. Phosphorus uptake varied considerably between years, reaching the highest level in 2010 (38.1 to 42.9 kg P ha^{-1}) when the

Table 4

Macronutrient content of winter wheat after the application of Amofosmag 4 and Amofosmag 3 (g kg^{-1} d.m.)

Macro-nutrient	Treatment	Grain				Straw			
		2008	2009	2010	mean for *a*	2008	2009	2010	mean for *a*
Nitrogen	NPK	14.00	10.63	20.42	15.01	3.24	3.38	5.27	3.96
	Amofosmag 4	16.90	11.95	20.19	16.34	3.34	3.07	4.52	3.64
	Amofosmag 3	18.45	9.32	20.66	16.14	3.83	2.75	5.26	3.94
Mean for *b*		16.45	10.63	20.42		3.47	3.06	5.01	
$LSD_{p=0.05}$ for	a b *ab*	n.s. 1.527 2.645				n.s. 0.563 n.s.			
Phosphorus	NPK	1.86	4.38	3.72	3.32	0.46	2.10	1.68	1.41
	Amofosmag 4	1.98	4.51	3.96	3.48	0.45	1.78	1.39	1.20
	Amofosmag 3	1.77	4.53	4.22	3.50	0.41	1.54	1.48	1.14
Mean for *b*		1.87	4.47	3.96		0.44	1.80	1.51	
$LSD_{p=0.05}$ for	a *b* *ab*	n.s. 0.312 n.s.				n.s. 0.240 n.s.			
Potassium	NPK	2.77	4.35	4.34	3.82	8.37	8.17	12.99	9.84
	Amofosmag 4	2.65	4.40	4.31	3.78	8.80	11.10	13.86	11.25
	Amofosmag 3	2.47	4.42	4.39	3.76	9.00	10.00	19.11	12.70
Mean for *b*		2.63	4.39	4.34		8.72	9.75	15.32	
$LSD_{p=0.05}$ for	*a* *b* *ab*	n.s. 0.264 n.s.				1.298 1.278 2.214			
Calcium	NPK	0.44	0.45	0.53	0.47	2.37	1.93	3.66	2.65
	Amofosmag 4	0.40	0.50	0.51	0.47	3.02	2.07	3.47	2.85
	Amofosmag 3	0.33	0.53	0.58	0.48	3.61	1.97	3.63	3.05
Mean for *b*		0.39	0.49	0.54		3.00	1.99	3.58	
$LSD_{p=0.05}$ for	*a* *b* *ab*	n.s. 0.081 n.s.				n.s. 0.456 n.s.			
Magnesium	NPK	0.91	0.80	0.91	0.87	0.40	0.54	0.55	0.49
	Amofosmag 4	0.88	0.79	1.02	0.89	0.42	0.55	0.62	0.53
	Amofosmag 3	0.80	0.81	0.97	0.85	0.50	0.51	0.57	0.52
Mean for *b*		0.86	0.80	0.96		0.44	0.53	0.58	
$LSD_{p=0.05}$ for	*a* *b* *ab*	n.s. 0.096 n.s.				n.s. 0.063 n.s.			

Explanations as under Table 3

Table 5

Nutrient uptake by winter wheat grain and straw (kg ha^{-1})

Treatment	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
2008					
NPK	113.51	15.2	74.16	18.73	8.63
Amofosmag 4	145.92	17.5	81.71	24.36	9.34
Amofosmag 3	144.91	14.2	74.39	25.53	8.44
2009					
NPK	77.96	36.6	76.77	14.73	7.69
Amofosmag 4	86.64	37.1	102.58	17.38	8.17
Amofosmag 3	70.67	35.8	94.91	16.81	8.05
2010					
NPK	179.06	38.1	128.62	31.52	10.37
Amofosmag 4	185.72	42.9	146.15	32.43	12.61
Amofosmag 3	186.01	41.2	181.12	32.62	11.27

highest yield of wheat grain and straw was obtained, and the lowest in 2008 (approximately two-fold lower than in 2009 and 2010) when wheat kernels were least abundant in phosphorus. The highest uptake of calcium (except in 2010) and magnesium was noted in the Amofosmag 4 treatment. Potassium uptake by winter wheat plants was highest in the third year of the experiment, in particular after the application of Amofosmag 3, mostly due to a high potassium content of wheat plants, especially straw. Such a trend was also observed with regard to total potassium uptake over three years (Figure 1). The highest total uptake of nitrogen, phosphorus and magnesium was observed in treatments with Amofosmag 4, which may suggest that the nutrients contained in multi-component fertilizers are more readily available to plants. Similar results were reported by NOGALSKA et al. (2010, 2011), who applied mixed fertilizers to spring wheat and spring barley.

Fertilization efficiency, expressed as an increase in wheat grain yield per kg NPK, ranged from 26.30 to 37.41 kg throughout the experiment (Table 6). Amofosmag 4 was found to be most efficient (27.63-37.41 kg wheat grain kg^{-1} NPK, depending on the year). Amofosmag 4 increased grain yield per kg NPK by 3.27 kg (10.7%) and 3.62 kg (11.9%) on average, in comparison to simple fertilizers and Amofosmag 3, respectively. The lowest fertilization efficiency was noted in the second year of the study – a drop by over 20% compared with the first and the third year. Considerable rainfall fluctuations (deficiency in April and surplus from June to September 2009) contributed to a decrease in winter wheat grain yield.

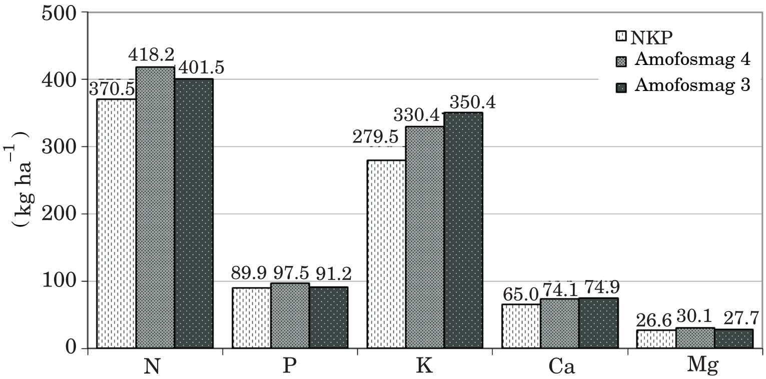

Fig. 1. Total macronutrient uptake by winter wheat over the three-year experiment

Table 6

Fertilization efficiency (kg grain kg^{-1} NPK)

Treatment	Grain			
	2008	2009	2010	mean for *a*
NPK	33.39	26.97	31.66	30.67
Amofosmag 4	36.80	27.63	37.41	33.94
Amofosmag 3	31.22	26.30	33.46	30.32
Mean for *b*	33.80	26.96	34.17	-

CONCLUSIONS

1. Winter wheat grain yield was modified by fertilizers and weather conditions. The most beneficial effect was reported for Amofosmag 4, which increased the yield of wheat grain by 7% on average, compared with the remaining treatments. A significantly lower grain yield was noted in the second year of the study characterized by adverse weather conditions.

2. The concentrations of the analyzed macronutrients in winter wheat 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. The only exception was the potassium content of wheat straw, which was significantly higher after the application of multi-component fertilizers. Significant differences were observed in this respect between successive years of the study.

3. The highest total uptake of nitrogen, phosphorus and magnesium by winter wheat plants was noted in the Amofosmag 4 treatment, and the highest total uptake of potassium and calcium was observed in the Amofosmag 3 treatment. Amofosmag 4 was found to be the most efficient fertilizer, which suggests that the nutrients contained in multi-component fertilizers are more readily available to plants.

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