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UTILIZATION OF NITROGEN, PHOSPHORUS AND POTASSIUM FROM COMPLEX FERTILIZERS BY VERY EARLY-MATURING POTATO CULTIVARS

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Abstract. Potato has a relatively shallow root system and requires significant nutrient inputs to maintain tuber productivity and quality. Efficient application of the proper type and amount of fertilizer plays an important role in achieving profitable tuber yield with minimum nutrient loss to the environment. The aim of this study was to compare utilization of nutrients from NPKMgS-type fertilizer complex from the nitrophoska (HydroComplex, Nitrophoska Blue Special, Viking 13) and amophoska group (Polimag S), and single-nutrient fertilizers (ammonium nitrate, superphosphate, potassium sulphate) by very early-maturing potato cultivars (Aster, Fresco, Gloria) on loamy sand soil. Nutrient utilization from fertilizers was calculated as a percentage ratio of the difference between the amount of nutrient uptaken by potato tubers in treatment with particular fertilizers, and nutrient uptake by potato tubers in the control treatment without fertilizers, to the quantity of the nutrient applied in particular fertilizers. With the use of complex fertilizers with microelements from the nitrophoska group, i.e. Nitrophoska Blue Special and HydroComplex, nitrogen, phosphorus and potassium utilization by potato tubers was higher than that obtained using the single-nutrient fertilizers. The use of these fertilizers produced better results for plant growth under well-watered conditions. With the use of complex fertilizers from the nitrophoska group without microelements (Viking 13) and from the ammophoska group (Polimag S), the nutrient utilization was similar or lower than with the application of single-nutrient fertilizers. The highest nutrient uptake along with potato tuber yield was reported with the application of Nitrophoska Blue Special; the nitrogen uptake was higher by 10.05 kg·ha^{-1}, phosphorus by 1.84 kg·ha^{-1}, and potassium by 11.41 kg·ha^{-1} in comparison with single-nutrient fertilizers. When this fertilizer was applied, utilization of nitrogen (21%), phosphorus (9%) and potassium (23%) by very early-maturing potato cultivars was almost twice as high as with single-nutrient fertilizers. The uptake and utilization of nitrogen, phosphorus and potassium by potato tubers depended on the cultivar, and was determined by weather conditions during the potato growing season.

Key words: fertilization, nutrient uptake, nutrient utilization, potato

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INTRODUCTION

Nutrient efficient plants play a major role in increasing crop yields, mainly due to the higher cost of inorganic fertilizer inputs and increasing environmental concerns [Fageria *et al*. 2008]. Nutrient uptake by plants starts with the contact between plant roots and the nutrients in soil due to the large root system. Potato has a relatively shallow root system and requires high inputs of nitrogen, phosphorus and potassium to maintain tuber productivity and quality. Efficient application of the proper type and amount of fertilizer plays an important role in achieving a profitable yield. Mineral fertilizers have a great impact on the nutrient distribution in soil and its bioavailability for plants [Trehan 2009, Pisela and Sala 2012]. It is assumed that nitrogen utilization from fertilizers amounted from about 50-70%, phosphorus 10-15% and potassium 50-60% [Korzeniowska 2009]. Maintaining high crop yields with minimum nutrient losses to the environment is, and will continue to be, a significant challenge to potato producers. Fertilization must ensure high utilization of cultivar production potential under environmental conditions of the cultivation area. In recent years, there has been an increase in the use of complex fertilizers. Complex fertilizers provide crops with essential nutrients in adequate amounts and proportions, and they help reduce or prevent nutrient leaching. The right proportion of nutrients is a prerequisite for satisfactory plant growth. The use of complex fertilizers with microelements in the cultivation of several potato cultivars, belonging to different maturity groups, has caused the greatest increase in tuber yield of a very early-maturing cultivar [Makaraviciute 2003, Marcinkonis *et al*. 2004]. The type of fertilizer (single-nutrient or complex fertilizers) significantly affected growth of very early-maturing potato cultivars. The application of complex fertilizers from the nitrophoska group with microelements resulted in a greater above-ground plant biomass and a higher assimilation leaf area compared with single-nutrient fertilizers [Wadas and Dziugieł 2013]. The nitrogen utilization from fertilizers by early--maturing potato cultivars amounted to about 15-40% [Mazurczyk *et al*. 2005]. Phosphorus utilization by potato tubers from superphosphate ranged from 7-17%, while potassium utilization by potato tubers from potassium salt ranged from 30-80% [Trawczyński 2002, 2005]. Nutrient utilization from fertilizers by potato tubers depends on the cultivar and plant development stage, soil (soil type, pH, humidity), climatic (rainfall and temperature) and agronomic (dose, time and method of fertilizer application) conditions. Potato grown in loamy sand soil had a higher nitrogen uptake than those grown in sandy loam and coarse sand [Trawczyński 2002, 2005, Zebarth *et al*. 2004, Ahmadi *et al*. 2011, Wierzbicka and Trawczyński 2011, Trehan and Singh 2013, Trawczyński and Wierzbicka 2014].

There is lack of research on the effect of using complex fertilizers in early crop potato culture. The aim of this study was to compare utilization of nutrients from NPKMgS-type fertilizer complex from the nitrophoska and amophoska group, and single-nutrient fertilizers by very early-maturing potato cultivars on loamy sand soil. Fertilization must ensure high utilization of cultivar production potential under environmental conditions of the cultivation area with minimum nutrient losses to the environment.

MATERIAL AND METHODS

Experimental site and design

The experiment was carried out in central-eastern Poland, at the Agricultural Experimental Station of Siedlce University of Natural Sciences and Humanities (52°03' N; 22°33' E) during the three growing seasons from 2005-2007, on loamy sand soil (Table 1). According to the international FAO classification system, the soil was classified as Luvisol. The forecrop for potato was spring triticale. Farmyard manure was applied in autumn, at a rate of 30 t·ha^{-1}, after soil analysis.

Table 1. Selected chemical soil properties at the experimental site during three years of the experiment

Tabela 1. Wybrane właściwości chemiczne gleby w trzyletnim okresie badań

Year Rok	pH in KCl pH w KCl	C_{org} g·kg^{-1}	Available forms of nutrients, mg·kg^{-1} of soil Przyswajalne formy składników pokarmowych, mg·kg^{-1} gleby							
			P	K	Mg	B	Mn	Cu	Zn	Fe
2005	6.85	8.24	141	216	33	0.75	119.0	2.7	7.0	1056
2006	5.00	6.09	89	100	39	0.23	77.3	2.0	6.4	690
2007	5.00	5.51	102	75	34	0.18	79.8	2.3	6.1	670

The field experiment was established as a split-plot design with three replications. The experimental factors were as follows: I – type of fertilizer: control treatment without fertilizer, single-nutrient fertilizers (ammonium nitrate 34%, superphosphate 19%, potassium sulphate 50%), complex fertilizers under trade names HydroComplex (NPKMgS + B, Mn, Zn, F; Yara International ASA Norway), Nitrophoska Blue Special (NPKMgS + B, Zn; COMPO GmbH&Co.KG, Germany), Viking 13 (NPKMgCaS; Yara International ASA, Norway) representing the nitrophoska group, and Polimag S (NPKMgS + B, Cu, Mn, Zn; Zakłady Chemiczne POLICE S.A., Poland) from the amophoska group (Table 2); II – very early-maturing potato cultivar: Aster (Poland), Fresco (The Netherlands) and Gloria (Germany). The examined complex fertilizers and single-nutrient fertilizers were applied in the spring tillage, in amounts equivalent to the recommended rates for the studied cultivars (100 kg N·ha^{-1}). The remaining elements in the single-nutrient fertilizers were applied at rates which guarantee a similar N:P:K proportion as complex fertilizers, i.e. 44 kg P·ha^{-1} and 124.5 kg K·ha^{-1}. In successive years, 4-week pre-sprouted seed potatoes were planted on the 15th, 20th and 18th April, at a spacing of 62.5 × 30 cm, and at a depth of 6-7 cm. The plots were four rows wide and 6 m long. The plot area was 15 m^2 (80 plants per plot). Potatoes were harvested at the tuber physiological maturity stage, on the 25th and 31st July and 8th August in the successive study years. The total and dry matter tuber yield and the content of nitrogen were determined with the Kjeldahl method, phosphorus with the vanadium--molybdenum method, and potassium with the photometric method. The uptake of nitrogen, phosphorus and potassium was calculated with tuber yield and nutrient from utilization of fertilizers by tubers. The uptake of nitrogen, phosphorus and potassium was estimated based on the tuber yield and nutrient content (N, P or K) in the potato tuber. Nutrient utilization from fertilizers was calculated with the difference method using the formula given below:

$$NUT = [(NUP_F - NUP_0)/N_A] \times 100$$

where:

NUT – nutrient (N, P or K) utilization from the particular fertilizer, %,

NUP_F – nutrient uptake by potato tubers in the treatment with a particular fertilizer, $kg \cdot ha^{-1}$,

NUP_0 – nutrient uptake by potato tubers in the control treatment without fertilizers, $kg \cdot ha^{-1}$,

N_A – quantity of nutrient applied in a particular fertilizer, $kg \cdot ha^{-1}$.

Table 2. Chemical composition of complex fertilizers, %
Tabela 2. Skład chemiczny nawozów kompleksowych, %

Fertilizer Nawóz	Chemical composition – Skład chemiczny												
	N_{tot}	NO_3^-	NH_4^+	P	K	Mg	Ca	S	B	Cu	Mn	Zn	Fe
HydroComplex	12.0	5.0	7.0	4.8	14.9	1.5	–	8.0	0.015	–	0.02	0.02	0.35
Nitrophoska Blue Special	12.0	5.5	6.5	5.3	14.1	1.2	–	6.0	0.020	–	–	0.01	+
Polimag S	10.0	–	10.0	3.5	12.4	3.0	–	14.0	0.100	0.1	0.20	0.50	–
Viking 13	13.0	5.3	7.7	5.7	17.4	0.7	2.8	1.4	–	–	–	–	–

Statistical analysis

The results of the experiment were analyzed statistically by means of the analysis of variance (ANOVA) for the split-plot design. The significance of differences was determined by the Tukey's test at $P = 0.05$.

Weather conditions

Over the three-year period of the study, the most favorable thermal and moisture conditions for the cultivation of very early-maturing potato cultivars were in the growing season of 2007 (Table 3). The mean monthly temperatures were similar or above the long-term mean. The total precipitation in May and July was slightly above the long-term mean. In 2005, growth and development of plants was hindered by a low air temperature after planting potatoes and drought from mid-June to the end of the growing season. In 2006, it was hampered by mild drought throughout the potato growing season. The total precipitation in June and July was almost 3 times lower than the long-term mean.

Table 3. Mean air temperatures and precipitation totals during the potato growing season
Tabela 3. Średnie temperatury powietrza i sumy opadów atmosferycznych w okresie wegetacji ziemniaka

Year – Rok	Temperature – Temperatura, ºC				Precipitation – Opady, mm			
	April kwiecień	May maj	June czerwiec	July lipiec	April kwiecień	May maj	June czerwiec	July lipiec
2005	8.6	13.0	15.9	20.2	12.3	64.7	44.1	86.5
2006	8.4	13.6	17.2	22.3	29.8	39.6	24.0	16.2
2007	8.6	14.4	18.2	18.9	21.2	59.1	59.0	70.2
Long-term mean Średnia wieloletnia (1981-2000)	8.1	11.2	16.7	19.3	49.6	48.2	67.7	59.6

RESULTS AND DISCUSSION

Of the examined complex fertilizers type NPKMgS, only Nitrophoska Blue Special (from the nitrophoska group with the lowest NH_4^+-N concentration) resulted in a significant increase in the dry matter tuber yield (0.64 Mg·ha^{-1}) in comparison with single-nutrient fertilizers (Table 4).

Table 4. Dry matter tuber yield, Mg·ha^{-1}
Tabela 4. Plon suchej masy bulw, Mg·ha^{-1}

Type of fertilizer Rodzaj nawozu	Cultivar – Odmiana			Year – Rok			Mean Średnia
	Aster	Fresco	Gloria	2005	2006	2007	
Without mineral fertilizers Bez nawożenia mineralnego	4.14	3.54	3.78	3.45	3.03	4.99	3.82
Single-nutrient fertilizers Nawozy jednoskładnikowe	5.21	4.04	4.67	4.13	3.68	6.11	4.64
HydroComplex	5.66	4.48	4.47	3.87	3.67	7.06	4.87
Nitrophoska Blue Special	5.80	5.10	4.96	4.05	4.10	7.70	5.28
Polimag S	5.32	4.30	4.40	4.20	3.38	6.44	4.68
Viking 13	5.00	3.91	4.41	4.08	3.33	5,92	4.44
Mean – Średnia	5.19	4.23	4.45	3.96	3.53	6.37	4.62
$LSD_{0.05}$ – $NIR_{0.05}$ for – dla:							
years – lata				0.16			
type of fertilizer – rodzaj nawozu				0.28			
cultivar – odmiany				0.20			
interaction – interakcji:							
years × type of fertilizer – lata × rodzaj nawozu				0.49			
type of fertilizer × cultivar – rodzaj nawozu × odmiana				ns – ni			

ns – ni – non-significant differences – różnice nieistotne

The productive effect of HydroComplex and Viking 13 (from the nitrophoska group), and Polimag S (from the amophoska group) in very early-maturing potato cultivars growing on loamy sand soil in central-eastern Poland were comparable with the commonly used single-nutrient fertilizers. The beneficial effects of complex fertilizers from the nitrophoska group with microelements (NPKMgS + B, Zn), i.e. Nitrophoska 12 Special and Nirtophoska 15 Perfect, on potato cultivation in semi--coherent soil in north-western Poland were shown in the study carried out by Jabłoński [2006]. Gao *et al.* [2014] reported that NO_3^--N stimulates potato stolon growth more than NH_4^+-N. Both stolon number and stolon length per plant were greater under NO_3^--N treatment. Plants supplied with NO_3^--N produce more tubers and higher tuber yields by improving shoot growth, and thus providing more assimilates after the tuber initiation stage. The yield-increasing effect of fertilizers applied in the experiment depended on the amount of rainfall during the potato growing season. The use of Nitrophoska Blue Special and HydroComplex (from the nitrophoska group with microelements) produced better results with a sufficient water supply for plants [Wadas and Dziugieł 2013]. Under such conditions, fertilizer material easily dissolves in soil water and nutrients are readily available for plant uptake. Ahmadi *et al.* [2011] reported that under non-limiting water conditions, potato plants can take up sufficient amounts of nitrogen, and that could potentially lead to a higher tuber yield on loamy sand soil. A study carried out in Belarus showed that the application of complex fertilizers on soil of different texture,

allows for an increase in the potato tuber yield, improves its quality, and enhances the net return of fertilizers [Pirogovskaya *et al*. 2002]. A study carried out on eastern Lithuanian soils showed that the effect of the NPK complex fertilizer from the nitrophoska group with microelements (Cropcare 10-10-20) on the very early potato tuber yield was higher than that of single-nutrient fertilizers [Marcinkonis *et al*. 2004, Staugaitis *et al*. 2006]. Regardless of the type of fertilizer, the highest dry matter tuber yield was obtained in the warm and moderately wet growing season in 2007 (Table 4). In contrast, the dry matter content in tubers in this year was the lowest [Wadas *et al*. 2012]. The fertilizers applied in the experiment slightly affected the dry matter content in potato tubers. The dry matter content in potato tubers depended to a higher degree on the cultivar [Wadas *et al*. 2012]. The type of fertilizer and cultivar interaction effect on the dry matter tuber yield was not statistically confirmed. Regardless of the type of the fertilizer applied, the dry matter tuber yield of Aster was higher (0.96 and 0.74 $Mg \cdot ha^{-1}$) than the one of Fresco or Gloria (Table 4).

Application of complex fertilizers from the nitrophoska group resulted in a similar or higher nitrogen content in tubers compared with single-nutrient fertilizers (Table 5). The highest total nitrogen content was determined in the tubers of potato fertilized with Nitrophoska Blue Special and Viking 13 (from the nitrophoska group without Mn and Fe). The respective increases in nitrogen content amounted to 0.55 and 0.45 $g \cdot kg^{-1}$ of dry matter as compared with single-nutrient fertilizers. The highest increase in the nitrogen content as result of fertilization with Nitrophoska Blue Special and Viking 13 was obtained, respectively, in 2006 with mild drought over the growing season of potato, and in 2007 which was moderately wet. Compared with single-nutrient fertilizers, application of Polimag S (from the amophoska group) increased nitrogen content, on average by 1.44 $g \cdot kg^{-1}$ of dry matter, only in 2007 with most rainfall in the growing season of potato. Phosphorus and potassium content in potato tuber was not significantly modified by the application of the studied fertilizers (Table 5). Of the examined fertilizers, only HydroComplex (from the nitrophoska group with Mn and Fe) resulted in a higher potassium content in comparison with the cultivation without mineral fertilization, the increase was on average 0.86 $g \cdot kg^{-1}$ of dry matter. Both Mn and Fe play a major role in plant nutrition but when applied preplant may oxidize to unavailable forms before plant uptake [Westermann 2005]. Application of Nitrophoska Blue Special and Viking 13 was followed by the highest increase in nitrogen content in tubers, Aster and Gloria cultivars, respectively. The type of fertilizer and cultivar interaction effect on phosphorus and potassium content in tubers were not statistically confirmed. Regardless of the type of the applied fertilizer, Fresco tubers contained more nitrogen than Aster and Gloria. Tubers of the examined very early-maturing potato cultivars had similar phosphorus and potassium contents (Table 5). The most nitrogen was accumulated by potato tubers in 2006, which had the highest precipitation shortages during the potato growing season. In contrast, potassium accumulation in tubers in this year was the lowest. The nitrogen and potassium interaction had a significant effect on vegetative growth and potato tuber yield [Singh and Lal 2012]. The most phosphorus was accumulated by potato tuber in 2007, with most rainfall in the growing season of potato (Table 5).

Table 5. Nitrogen, phosphorus and potassium content in tuber, g·kg^{-1} DM
Tabela 5. Zawartość azotu, fosforu i potasu w bulwach, g·kg^{-1} s.m.

Type of fertilizer Rodzaj nawozu	Cultivar – Odmiana			Year – Rok			Mean Średnia
	Aster	Fresco	Gloria	2005	2006	2007	
Nitrogen – Azot							
Without mineral fertilizers Bez nawożenia mineralnego	11.88	12.98	10.81	10.77	12.66	12.17	11.86
Single-nutrient fertilizers Nawozy jednoskładnikowe	10.94	13.23	11.57	11.58	12.75	11.42	11.91
HydroComplex	12.06	12.62	11.02	10.81	13.19	11.70	11.90
Nitrophoska Blue Special	12.13	13.25	11.99	12.06	13.91	11.41	12.46
Polimag S	10.82	11.40	11.23	10.38	10.92	12.14	11.15
Viking 13	11.67	12.56	12.86	10.96	13.27	12.86	12.36
Mean – Średnia	11.58	12.67	11.58	11.09	12.78	11.95	11.94
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:							
years – lat				0.19			
type of fertilizer – rodzaju nawozu				0.33			
cultivar – odmiany				0.16			
interaction – interakcji:							
years × type of fertilizer – lata × rodzaj nawozu				0.56			
type of fertilizer × cultivar – rodzaj nawozu × odmiana				0.47			
Phosphorus – Fosfor							
Without mineral fertilizers Bez nawożenia mineralnego	2.32	2.34	2.31	2.30	2.17	2.50	2.32
Single-nutrient fertilizers Nawozy jednoskładnikowe	2.36	2.37	2.29	2.27	2.19	2.55	2.34
HydroComplex	2.29	2.43	2.36	2.26	2.27	2.56	2.36
Nitrophoska Blue Special	2.44	2.35	2.33	2.24	2.26	2.62	2.38
Polimag S	2.26	2.35	2.27	2.21	2.29	2.38	2.29
Viking 13	2.28	2.38	2.33	2.24	2.28	2.46	2.33
Mean – Średnia	2.33	2.37	2.32	2.25	2.24	2.51	2.34
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:							
years – lat				0.08			
type of fertilizer – rodzaju nawozu				ns – ni			
cultivar – odmianay				ns – ni			
interaction – interakcji:							
type of fertilizer × cultivar – rodzaj nawozu × odmiana				ns – ni			
Potassium – Potas							
Without mineral fertilizers Bez nawożenia mineralnego	15.23	16.50	16.48	16.35	15.53	16.33	16.07
Single-nutrient fertilizers Nawozy jednoskładnikowe	16.50	16.70	16.30	17.07	15.71	16.72	16.50
HydroComplex	17.15	16.53	17.11	17.66	15.59	17.54	16.93
Nitrophoska Blue Special	16.77	15.72	16.76	16.44	15.69	17.11	16.42
Polimag S	15.95	16.34	16.49	16.35	15.50	16.94	16.26
Viking 13	17.22	16.18	16.26	17.07	15.52	17.07	16.56
Mean – Średnia	16.47	16.33	16.57	16.82	15.59	16.95	16.46
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:							
years – lat				0.45			
type of fertilizer – rodzaju nawozu				0.79			
cultivar – odmiany				ns – ni			
interaction – interakcji:							
type of fertilizer × cultivar – rodzaj nawozu × odmiana				ns – ni			

ns – ni – non-significant differences – różnice nieistotne

Potato tuber yield depends on the nutrient uptake. Fertilizers applied in the experiment had a significant effect on nitrogen, phosphorus and potassium uptake with potato tubers (Table 6). The highest nutrient uptake was reported with the application of NPKMgS complex fertilizer Nitrophoska Blue Special (from the nitrophoska group with the lowest NH_4^+-N concentration, and with B and Zn). With the use of this fertilizer, nitrogen uptake with tuber yield was higher on average by 10.05 kg·ha^{-1}, phosphorus by 1.83 kg·ha^{-1}, and potassium by 11.41 kg·ha^{-1}, in comparison with single--nutrient fertilizers. This indicates that the nutrients contained in this fertilizer are more readily available to plants of very early-maturing potato cultivars than single-nutrient fertilizers. With the use of HydroComplex (from the nitrophoska group with Mn and Fe), nitrogen uptake with tuber yield were lower, and the phosphorus and potassium uptake were comparable with Nitrophoska Blue Special. With the use of other complex fertilizers, the nutrient uptake with tuber yield were similar to the application of single--nutrient fertilizers. The highest increase in the nutrient uptake with tuber yield as result of the use of complex fertilizers was obtained in the warm and moderately wet growing season of 2007. Fertilizers applied in the experiment had a greater influence on nitrogen uptake with the tuber yield of Aster and Fresco than Gloria. The type of fertilizer and cultivar interaction effect on phosphorus and potassium uptake were not statistically confirmed. Regardless of the type of the applied fertilizer, nitrogen, phosphorus and potassium uptake with tuber yield of Aster were higher than of Fresco and Gloria (Table 6). Cultivar differences in nutrient uptake with tuber yield may be related to the differences in root systems between the examined very early-maturing potato cultivars. Genotype variation in nutrient uptake from soil is associated with the size of the root system and root morfology [Jungk and Classen 1997, Trehan and Singh 2013].

The type of the applied fertilizers had a significant effect on nitrogen, phosphorus and potassium utilization by potato tubers (Table 7). With the use of NPKMgS fertilizer complex from the nitrophoska group with microelements, i.e. Nitrophoska Blue Special and HydroComplex, utilization of the studied nutrients by potato tubers was significantly higher than that obtained using the single-nutrient fertilizers. When Nitrophoska Blue Special was applied, utilization of nitrogen, phosphorus and potassium by very early--maturing potato cultivars was almost twice as high as with single-nutrient fertilizers. With the use of Viking 13 (from the nitrophoska group without microelements), nitrogen utilization was similar to the application of single-nutrient fertilizers, although utilization of phosphorus and potassium was lower. Although the means from the three years show that nitrogen utilization by potato tubers from Polimag S representing the amophoska group was lower, the phosphorus and potassium utilization were comparable to the single-nutrient fertilizers. Utilization of nitrogen and potassium from fertilizers by potato tubers in this study was generally lower than that reported by other authors [Trawczyński 2002, 2005, Mazurczyk *et al*. 2005, Wierzbicka and Trawczyński 2011, Trawczyński and Wierzbicka 2014]. Nitrogen utilization from fertilizers by early-maturing potato cultivars amounted from about 15% to 40% [Mazurczyk *et al*. 2005]. Weather conditions during the potato growing season are the main factor influencing nitrogen utilization from fertilizers. Drought conditions decreased nitrogen utilization coefficient value [Mazurczyk *et al*. 2005, Trawczyński and Mazurczyk 2014], which was confirmed in the present study. There is an interaction between soil humidity and nitrogen uptake by potato tubers. Under non-limiting water conditions, potato plants take up sufficient amounts of nitrogen, and that could potentially lead to a higher tuber yield. Better nitrogen utilization by the potato was observed in the years with favourable conditions for tuber yield cumulation

[Ahmadi *et al*. 2011, Trawczyński 2010, 2014]. Nitrogen and potassium play an important role in the growth and development of potato crops [Singh and Lal 2012]. Lis and Wierzejska-Bujakowska [2000] reported that from about 35% to 80% of the applied mineral nitrogen remained unutilized in the soil. One of the factors significantly affecting fertilizer nitrogen recovery in Poland is soil pH. Grzebisz *et al*. [2010] showed that acid soils fertilized with Mg can significantly impact nitrogen uptake and utilization. Improvement of the plant Mg nutritional status enables plants to incorporate some of the potentially residual nitrogen into biomass, increasing the biomass yield. Of the examined complex fertilizers type NPKMgS, only Nitrophoska Blue Special resulted in a significant increase in nitrogen uptake and utilization by potato tubers in comparison with the commonly used single-nutrient fertilizers. Potassium utilization from fertilizers is highly diversified depending on the soil and climatic conditions. In the study carried out by Trawczyński [2006], potassium utilization by potato tubers from potassium salt ranged from 30% to 80%. One of the main factors affecting phosphorus and potassium utilization from fertilizers was the content of available forms of these nutrients in the soil. With a high content of available phosphorus and potassium in the soil, utilization of these nutrients from fertilizers is lower, especially with unfavorable weather conditions [Trawczyński 2002, 2005], which was confirmed in the present study. In 2007, with the lowest available phosphorus and potassium content in the soil, and with the most favorable thermal and moisture conditions for the cultivation of very early-maturing potato cultivars, phosphorus and potassium utilization from HydroComplex, Nitrophoska Blue Special (from nitrophoska group with microelements) and Polimag S (from the amophoska group with microelements) was higher than from single-nutrient fertilizers (Table 7). In 2007, as regards the type of the applied fertilizer, phosphorus utilization was 4 times higher, and potassium almost 3 times higher than in 2005, with the highest available phosphorus and potassium content in the soil, despite drought from mid-June to the end of the potato growing season. From the three main plant nutrients (nitrogen, phosphorus and potassium), phosphorus has the lowest utilization coefficient in the first year after fertilizer application due to phosphate absorption, especially on acidic soil. Under the conditions of light and acidic soil, phosphorus utilization from superphosphate by potatoes ranged from 7% to 15% [Trawczyński 2002]. Trehan [2009] reported that recovery of the applied phosphorus by potato crop is not more than 15-20%. Nutrient use efficiency can be improved significantly by exploiting varietal differences in potato.

The uptake and utilization of nitrogen, phosphorus and potassium from fertilizers depended on the potato cultivar (Tables 6 and 7). Nitrogen use efficiency was generally lower for early-maturing cultivars compared to mid-season and late-maturing cultivars [Zebarth *et al*. 2004, Wierzbicka and Trawczyński 2011, Trawczyński and Mazurczyk 2014]. Significant differences in nitrogen utilization efficiency were measured among cultivars of similar maturity [Mazurczyk *et al*. 2005, Trawczyński 2010], which was confirmed in the present study. Nitrogen, phosphorus and potassium utilization by tubers of Aster (Poland), more tolerant to wet conditions, was higher than that of Fresco (The Netherlands) and Gloria (Germany). The variation in nutrient efficiency of different potato cultivars was due to both their physiological use efficiency and nutrient uptake efficiency [Wadas and Łęczycka 2010, Trehan and Singh 2013]. The type of fertilizer and cultivar interaction effect on nitrogen, phosphorus and potassium utilization by potato tubers were statistically confirmed. An appropriate choice of cultivar is very important in early potato production. The cultivar showing high requirements for nitrogen fertilization was characterized by a higher utilization of this component as compared to the cultivar with low requirements [Trawczyński 2010].

Table 6. Nitrogen, phosphorus and potassium uptake with tuber yield, kg·ha^{-1}
Tabela 6. Pobranie azotu, fosforu i potasu z plonem bulw, kg·ha^{-1}

Type of fertilizer Rodzaj nawozu	Cultivar – Odmiana			Year – Rok			Mean Średnia
	Aster	Fresco	Gloria	2005	2006	2007	
Nitrogen – Azot							
Without mineral fertilizers Bez nawożenia mineralnego	46.55	44.84	40.50	36.53	35.02	60.96	43.96
Single-nutrient fertilizers Nawozy jednoskładnikowe	55.19	54.14	53.49	46.65	46.84	69.33	54.27
HydroComplex	68.74	56.14	48.05	41.15	48.56	83.23	57.64
Nitrophoska Blue Special	68.55	67.06	57.36	47.46	57.18	88.33	64.32
Polimag S	58.33	49.26	49.77	42.37	36.75	78.25	52.46
Viking 13	58.53	49.83	57.80	43.57	44.18	78.41	55.39
Mean – Średnia	59.32	53.55	51.16	42.96	44.76	76.42	54.67
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:							
years – lat				3.03			
type of fertilizer – rodzaju nawozu				5.32			
cultivar – odmiany				3.32			
interaction – interakcji:							
years × type of fertilizer – lata × rodzaj nawozu				9.22			
type of fertilizer × cultivar – rodzaj nawozu × odmiana				9.98			
Phosphorus – Fosfor							
Without mineral fertilizers Bez nawożenia mineralnego	9.70	8.26	8.52	7.96	6.46	12.06	8.83
Single-nutrient fertilizers Nawozy jednoskładnikowe	12.31	9.74	10.90	9.40	8.02	15.52	10.98
HydroComplex	13.08	11.13	10.86	8.71	8.33	18.02	11.69
Nitrophoska Blue Special	14.29	12.43	11.79	9.10	9.25	20.17	12.84
Polimag S	12.06	10.21	9.98	9.20	7.72	15.33	10.75
Viking 13	11.49	9.42	10.38	9.16	7.61	14.51	10.43
Mean – Średnia	12.16	10.20	10.41	8.92	7.90	15.94	10.92
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:							
years – lat				0.71			
type of fertilizer – rodzaju nawozu				1.24			
cultivar – odmiany				0.71			
interaction – interakcji:							
years × type of fertilizer – lata × rodzaj nawozu				2.14			
type of fertilizer × cultivar – rodzaj nawozu × odmiana				ns – ni			
Potassium – Potas							
Without mineral fertilizers Bez nawożenia mineralnego	64.04	56.34	60.75	56.58	44.98	79.56	60.37
Single-nutrient fertilizers Nawozy jednoskładnikowe	85.73	67.33	75.48	69.08	57.74	101.72	76.18
HydroComplex	97.83	74.33	77.39	68.56	57.48	123.52	83.18
Nitrophoska Blue Special	98.29	80.41	84.08	67.08	64.64	131.06	87.59
Polimag S	85.19	70.65	74.47	68.00	53.47	108.84	76.77
Viking 13	87.21	64.82	72.06	69.74	52.94	101.42	74.70
Mean – Średnia	86.38	68.98	74.04	66.51	55.21	107.69	76.47
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:							
years – lat				4.44			
type of fertilizer – rodzaju nawozu				7.77			
cultivar – odmiany				5.01			
interaction – interakcji:							
years × type of fertilizer – lata × rodzaj nawozu				13.46			
type of fertilizer × cultivar – rodzaj nawozu × odmiana				ns – ni			

ns – ni – non-significant differences – różnice nieistotne

Table 7. Nitrogen, phosphorus and potassium utilization by tubers, %
Tabela 7. Wykorzystanie azotu, fosforu i potasu przez bulwy, %

Type of fertilizer Rodzaj nawozu	Cultivar – Odmiana			Year – Rok			Mean Średnia
	Aster	Fresco	Gloria	2005	2006	2007	
Nitrogen – Azot							
Single-nutrient fertilizers Nawozy jednoskładnikowe	8.64	11.52	13.21	10.12	12.04	11.22	11.12
HydroComplex	22.19	13.53	7.55	4.62	13.54	25.11	14.42
Nitrophoska Blue Special	22.00	24.44	16.86	10.93	22.16	30.22	21.10
Polimag S	11.78	6.65	9.27	5.84	1.73	20.14	9.24
Viking 13	11.98	7.21	17.33	7.06	9.16	20.30	12.17
Mean – Średnia	15.32	12.67	12.84	7.71	11.73	21.40	13.61
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:							
years – lat				0.69			
type of fertilizer – rodzaju nawozu				1.28			
cultivar – odmiany				0.96			
interaction – interakcji:							
years × type of fertilizer – lata × rodzaj nawozu				2.21			
type of fertilizer × cultivar – rodzaj nawozu × odmiana				2.52			
Phosphorus – Fosfor							
Single-nutrient fertilizers Nawozy jednoskładnikowe	5.98	3.38	5.46	3.29	3.60	7.94	4.94
HydroComplex	8.45	7.18	5.87	1.89	4.68	14.93	7.17
Nitrophoska Blue Special	10.53	9.55	7.52	2.58	6.41	18.61	9.20
Polimag S	6.78	5.57	4.20	3.53	3.63	9.38	5.51
Viking 13	4.10	2.65	4.27	2.74	2.66	5.62	3.37
Mean – Średnia	7.17	5.67	5.46	2.81	4.20	11.30	6.04
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:							
years – lat				0.29			
type of fertilizer – rodzaju nawozu				0.54			
cultivar – odmiany				0.56			
interaction – interakcji:							
years × type of fertilizer – lata × rodzaj nawozu				0.94			
type of fertilizer × cultivar – rodzaj nawozu × odmiana				1.47			
Potassium – Potas							
Single-nutrient fertilizers Nawozy jednoskładnikowe	17.42	8.48	11.83	10.03	10.25	17.45	12.58
HydroComplex	27.15	14.47	13.48	9.62	10.04	35.44	18.37
Nitrophoska Blue Special	29.13	20.48	19.85	8.93	16.72	43.81	23.15
Polimag S	16.98	11.50	11.02	9.17	6.81	23.52	13.17
Viking 13	17.28	6.42	8.44	9.82	6.02	16.30	10.71
Mean – Średnia	21.59	12.27	12.92	9.51	9.97	27.30	15.60
$LSD_{0.05}$ – $NIR_{0,05}$ for – dla:							
years – lat				0.55			
type of fertilizer – rodzaju nawozu				1.02			
cultivar – odmiany				0.95			
interaction – interakcji:							
years × type of fertilizer – lata × rodzaj nawozu				1.77			
type of fertilizer × cultivar – rodzaj nawozu × odmiana				2.48			

ns – ni – non-significant differences – różnice nieistotne

CONCLUSIONS

Efficient application of a proper type and amount of fertilizer plays an important role in achieving profitable potato tuber yield with minimum nutrient losses to the environment. The results of this study showed that the NPKMgS complex fertilizers from the nitrophoska group with microelements, i.e. Nitrophoska Blue Special or HydroComplex, can be successfully used to fertilize very early-maturing potato cultivars on loamy sand soil. The use of these fertilizers produced better results with sufficient water supply for plants. Under well-watered conditions, fertilizer material easily dissolves in soil water, and the nutrients are readily available for plant uptake. The effects of fertilization with NPKMgS complex fertilizers from the nitrophoska group without microelements (Viking 13) and from the amophoska group (Polimag S) were worse. Of the examined complex fertilizers, only Nitrophoska Blue Special (from the nitrophoska group with the lowest NH_4^+-N concentration) resulted in a higher dry matter tuber yield, on average by 0.64 Mg·ha^{-1}, compared with the single-nutrient fertilizers. The use of Nitrophoska Blue Special and Viking 13 resulted in an increase in the nitrogen content in tubers. Compared with the cultivation without mineral fertilization, the potassium content increased as a result of HydroComplex application. Fertilizers applied in the experiment had no effect on the phosphorus content in tubers. The highest nutrient uptake with tuber yield were reported with the application of Nitrophoska Blue Special (from the nitrophoska group with the lowest NH_4^+-N concentration, and with B and Zn); nitrogen uptake was higher by 10.05 kg·ha^{-1}, phosphorus by 1.84 kg·ha^{-1}, and potassium by 11.41 kg·ha^{-1} in comparison with single--nutrient fertilizers. With the use other complex fertilizers, the nutrient uptake with tuber yield was similar to the application of single-nutrient fertilizers. With the use of complex fertilizers from the nitrophoska group with microelements, i.e. Nitrophoska Blue Special and HydroComplex, nutrient utilization by potato tubers was higher than that obtained using the single-nutrient fertilizers. When other complex fertilizers were applied, the nutrient uptake and utilization was similar or lower to the application of single-nutrient fertilizers. The uptake and utilization of nitrogen, phosphorus and potassium by tubers depended on the potato cultivar, and was conditioned by weather conditions during the potato growing season.

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WYKORZYSTANIE AZOTU, FOSFORU I POTASU Z NAWOZÓW KOMPLEKSOWYCH PRZEZ BARDZO WCZESNE ODMIANY ZIEMNIAKA

Streszczenie. Ziemniak ma dość płytki system korzeniowy, dlatego, aby utrzymać produktywność i jakość bulw, wymaga dostarczenia znacznej ilości składników pokarmowych. Efektywne stosowanie odpowiedniego rodzaju i ilości nawozu jest bardzo ważne dla uzyskania opłacalnego plonu przy niewielkiej stracie składników do środowiska. Celem badań było porównanie wykorzystania składników pokarmowych z nawozów kompleksowych NPKMgS z grupy nitrofosek (HydroComplex, Nitrophoska Blue Special, Viking 13) i amofosek (Polimag S) i nawozów jednoskładnikowych (saletra amonowa, superfosfat pojedynczy, siarczan potasu) przez bardzo wczesne odmiany ziemniaka (Aster, Fresco, Gloria). Wykorzystanie składników z nawozów określono metadą różnicową – jako stosunek różnicy ilości składników pobranych przez bulwy ziemniaka na obiektach z danym nawozem i na obiekcie kontrolnym bez nawożenia mineralnego do ilości składnika zastosowanego w danym nawozie. Przy stosowaniu nawozów kompleksowych z grupy nitrofosek z mikroelementami, tj. Nitrophoski Blue Special i HydroComplexu, wykorzystanie azotu, fosforu i potasu przez bulwy ziemniaka było większe niż przy stosowaniu nawozów jednoskładnikowych. Stosowanie tych nawozów dawało lepsze efekty w warunkach dobrego zaopatrzenia roślin w wodę. Przy stosowaniu nawozów kompleksowych z grupy nitrofosek bez mikroelementów (Viking 13) i z grupy amofosek (Polimag S) wykorzystanie składników było podobne lub mniejsze jak z nawozów jednoskładnikowych. Najwięcej składników pokarmowych pobranych z plonem bulw stwierdzono przy stosowaniu Nitrophoski Blue Special (z grupy nitrofosek z najmniejszą ilością NH_4^+-N); pobranie azotu było większe o 10,05 kg·ha^{-1}, fosforu o 1,84 kg·ha^{-1}, a potasu o 11,41 kg·ha^{-1} w porównaniu z nawozami jednoskładnikowymi. Przy stosowaniu tego nawozu wykorzystanie azotu (21%), fosforu (9%) i potasu (23%) przez bardzo wczesne odmiany ziemniaka było prawie dwa razy większe jak z nawozów jednoskładnikowych. Pobranie i wykorzystanie azotu, fosforu i potasu zależało od odmiany i było uwarunkowane warunkami pogodowymi w okresie wegetacji ziemniaka.

Słowa kluczowe: nawożenie, pobranie skadników, wykorzystanie składników, ziemniak

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