Effect of complex fertilizers used in early crop potato culture on loamy sand soil

Efekty stosowania nawozów kompleksowych w uprawie ziemniaka na wczesny zbiór na glebie piaszczysto-gliniastej

Wanda WADAS* and TOMASZ DZIUGIEŁ

Department of Vegetable Crops, Siedlce University of Natural Sciences and Humanities, B. Prusa 14, 08-110 Siedlce, Poland, e-mail *correspondence: wanda.wadas@uph.edu.pl

Abstract

To obtain a high tuber yield of early crop potato good conditions for plant growth must be ensured. Potato has a relatively shallow root system and requires significant nutrient inputs to maintain tuber productivity and quality. The paper presents the results of the research on the effect of complex fertilizers type NPK MgS with and without microelements from the nitrophoska (HydroComplex, Nitrophoska Blue Special and Viking 13) and the amophoska group (Polimag S), and single-nutrient fertilizers on the plant growth and tuber yield of very early potato cultivars ('Aster', 'Fresco', 'Gloria') on loamy sand soil. The field experiment was carried out in mid-eastern Poland (52°03'N, 22°33'E). Potatoes were harvested 75 days after planting (the end of June). The type of fertilizer (single-nutrient or complex fertilizer) slightly affected the growth of potato plants. With the use of complex fertilizers, the assimilation leaf area and leaf area index (LAI) were similar to the application of single-nutrient fertilizers. Of the examined complex fertilizers, Viking 13 (representing the nitrophoska group without microelements) resulted in a smaller increase of assimilation leaf area in comparison with the cultivation without mineral fertilization. The type of fertilizer exerted a greater influence on the plant growth of 'Aster' (Poland) than 'Fresco' (The Netherlands) and 'Gloria' (Germany). The productive effects of complex fertilizers in early crop potato culture on loamy sand soil were comparable with single-nutrient fertilizers. The highest tuber yield was achieved with the application of Nitrophoska Blue Special (from the nitrophoska group with the lowest $N\text{-}NH_4^+$ concentration); the total tuber yield was higher on average by 2.94 t*ha^{-1} (21.0%) and the yield of marketable tuber fraction (diameter above 30 mm) by 2.55 t*ha^{-1} (20.4%) in comparison with the cultivation without mineral fertilization. Although the total tuber yield was a little lower, the share of large tubers (diameter above 51 mm) in the yield was recorded with the use of Polimag S (from the amophoska group and with the most Mg, S, Zn and B concentration of all complex fertilizers applied) and Viking 13 (from the nitrophoska group with Ca). The single-nutrient and complex fertilizers applied in the experiment had no effect on the dry matter, starch or L-ascorbic acid content in potato tubers. Regardless of the type of fertilizer applied, the tuber yield, average weight of one tuber and the share of medium-sized tubers (diameter of 41-50 mm) in the yield of ‘Aster’ were highest. The yield of marketable tuber fraction of the ‘Aster’ was higher than ‘Fresco’ and ‘Gloria’ on average by 3.03 t*ha^{-1} (22.0%) and 4.57 t*ha^{-1} (37.4%), respectively. About 25% of the ‘Gloria’ yield made up of non-marketable tubers (diameter below 30 mm). Tubers of ‘Aster’ contained more dry matter and starch than ‘Fresco’ and ‘Gloria’, however, the content of L-ascorbic acid in tubers of the tested potato cultivars was similar.

Keywords: fertilization of potato, plant growth, tuber yield, tuber quality, cultivar

Streszczenie

Warunkiem uzyskania wysokiego plonu ziemniaków we wczesnym terminie zbioru jest zapewnienie roślinom dobrych warunków wzrostu. Ziemniak ma dość płytki system korzeniowy. Aby uzyskać wysoki plon bulw dobrej jakości należy zapewnić roślinom odpowiednią ilość łatwo dostępnych składników pokarmowych. Celem badań było porównanie wpływu nawozów kompleksowych NPKMgS, z dodatkiem i bez mikroelementów, z grupy nitrofosek (HydroComplex, Nitrophoska Blue Special i Viking 13) i amofosek (Polimag S) oraz nawozów jednoskładnikowych na wzrost roślin i plon bulw bardzo wczesnych odmian ziemniaka (‘Aster’, ‘Fresco’, ‘Gloria’) na glebie piaszczysto-gliniastej. Doświadczenie polowe przeprowadzono w środkowo-wschodniej Polsce (52°03'N, 22°33'E), w ukladzie split-plot w trzech powtórzeniach. Ziemniaki zbierano po 75 dniach od sadzenia (koniec czerwca). Rodzaj stosowanego nawozu (jednoskładnikowy czy kompleksowy) miał niewielki wpływ na wzrost roślin. Przy stosowaniu nawozów kompleksowych powierzchnia asymilacyjna liści i wskaźnik pokrycia liściowego (LAI) byłu podobne jak przy stosowaniu nawozów jednoskładnikowych. Spośród badanych nawozów kompleksowych, Viking 13 (z grupy nitrofosek bez dodatku mikroelementów) powodował najmniejszy przyrost powierzchni asymilacyjnej liści w porównaniu z uprawą bez nawożenia mineralnego. Rodzaj stosowanego nawozu miał większy wpływ na wzrost roślin odmiany ‘Aster’ (odmiana polska), niż odmian ‘Fresco’ (odmiana holenderska) i ‘Gloria’ (odmiana niemiecka). Efekty produkcyjne nawozów kompleksowych w uprawie ziemniaka na wczesny zbiór na glebie piaszczysto-gliniastej były porównywalne z nawozami jednoskładnikowymi. Największy plon bulw uzyskano przy stosowaniu Nitrophoski Blue Special (z grupy nitrofosek, z najmniejszą zawartością $N\text{-}NH_4^+$); plon bulw ogółem był większy średnio o 2,94 t*ha^{-1} (21,0%), a plon bulw frakcji handlowej (o średnicy powyżej 30 mm) o 2,55 t*ha^{-1} (20,4%) w porównaniu z uprawą bez nawożenia mineralnego. Pomimo nieco mniejszego plonu bulw ogółem, udział bulw dużych (o średnicy powyżej 51 mm) w plonie był największy przy stosowaniu Polimagu S (z grupy amofosek, z największą zawartością Mg, S, Zn i B ze wszystkich stosowanych nawozów kompleksowych) i Vikinga 13 (z grupy nitrofosek z dodatkiem Ca). Stosowane w badaniach nawozy nie miały wpływu na zawartość suchej masy, skrobi i kwasu L-askorbinowego w bulwach. Niezależnie od rodzaju zastosowanego nawozu, plon bulw, średnia masa jednej bulwy i udział bulw średniej wielkości (o średnicy 41-50 mm) w plonie odmiany ‘Aster’ był największy. Plon bulw frakcji handlowej odmiany ‘Aster’ był większy niż odmian ‘Fresco’ i ‘Gloria’ średnio o 3,03 t*ha^{-1} (22.0%) i 4.57 t*ha^{-1} (37.4%). Prawie 25% plonu odmiany ‘Gloria’ stanowiły bulwy niehandlowe (o średnicy poniżej 30 mm). Bulwy odmiany ‘Aster’zawierały więcej suchej masy i skrobi niż odmian

‘Fresco’ i ‘Gloria’, natomiast zawartość kwasu L-askorbinowego w bulwach badanych odmian ziemniaka była podobna.

Keywords: jakość bulw, nawożenie ziemniaka, odmiana, plon bulw, wzrost roślin

Introduction

Potato (*Solanum tuberosum* L.) is a very important crop in the world both for consumption as a fresh product and for the processing industry. The production profitability of edible potatoes for early harvest is higher compared with other ways of usage. The growing period for early potatoes is extremely short, only 50-80 days from planting to harvest. To obtain a high marketable tuber yield in such a short period, besides the proper selection of very early-maturing cultivar and pre-sprouted seed potatoes, good conditions for plant growth must be ensured. The most important factor affecting the rapid establishment of the crop canopy is the availability of plant nutrients in the soil. Potato has a relatively shallow root system and requires significant nutrient inputs to maintain tuber productivity and quality. The response of potato to a deficiency of one nutrient may be influenced greatly by the levels of other nutrients (Jenkins and Mahmood, 2003; Alva et al., 2011). Mineral fertilizers have a great impact on the nutrient distribution in the soil and their bioavailability for plants (Pislea and Sala, 2012). The fertilization must be ensure the high utilization of cultivar production potential under the environmental conditions of the cultivar area. A wide variety and range of mineral fertilizers (straight fertilizers, multi-nutrient fertilizers) are currently available on the market. In recent years, there has been an increase in the use of multi-nutrient fertilizers. Straight fertilizers contains only one of the primary nutrients (N, P or K). Multi-nutrient fertilizers supply crops with primary nutrients and micronutrients. Multi-nutrient complex fertilizers have the advantage of having each nutrient in each granule. Complex fertilizers supply a combination of nutrients at a time, in adequate amounts and proportions. New technologies of fertilizers production make it possible to obtain a fertilizer with a ratio of nutrients suited to the specific plant needs (Piwowar, 2011). Complex fertilizers were more economically efficient than a simple mixture of solid mineral fertilizers (Staugaitis et al., 2006; Wadas and Łęczycka, 2010). Many researchers have reported the beneficial effects of using complex fertilizers in potato growing. The use of complex fertilizer in the cultivation of several potato cultivars, belonging to different maturity groups, has caused the greatest increase in the tuber yield of very early-maturing cultivar (Makaraviciute, 2003; Marcinkonis et al., 2004; Jabłoński 2006). Application of new forms of complex fertilizers with the amendments of plant growth promoting substances in years with varing degrees of moisture, on soil of different texture, allows an increase in potato yield and improves the quality as well as enhance the net return on fertilizers (Pirogovskaya et al., 2002). The effect of the complex fertilizer from the nitrophoska group with microelements on the total potato tuber yield was similar to that of single-nutrient fertilizers, but an increase in the marketable yield and starch content was recorded (Marcinkonis et al., 2004). Efficient application of the proper type and amount of fertilizer is an important part of achieving profitable potato tuber yield. Potato plants are very sensitive to N-NH_4^+ toxicity (Britto and Kronzucker, 2002). Mineral fertilizers, through their chemical formulation, can modify the pH of the soil. Generally, fertilizers with high nitrogen content of ammonium origin can acidify soils when they are applied repeatedly (Pisela and Sala, 2012). The rate of crop plant growth is, to some extent, modified by Mg and S application which can significantly impact nitrogen uptake and utilization (Tantawy et al., 2009; Gerendás and Führs, 2013). In early potato production, a lower yield of large-sized tubers produces higher marketable value than a high yield of smaller tubers with non-marketable value. Bari et al. (2001) reported that Zn, S, Mg and B treatment produced a higher percentage of medium-sized and large-sized tubers.

There is a lack of research on the effect of using complex fertilizers in early crop potato culture. The aim of this study was to compare the effect of complex fertilizers type NPK(Mg, S) from the nitrophoska and amophoska group, and single-nutrient fertilizers on the plant growth, tuber yield and quality of early crop potato.

Materials and Methods

Experimental site and season

A field experiment was carried out at the Agricultural Experimental Station of Siedlce University of Natural Sciences and Humanities, in mid-eastern Poland (52°03'N, 22°33'E), during the three growing seasons from 2005-2007, on loamy sand soil with a very high content of available phosphorus, a medium to very high content of potassium, a medium content of magnesium and manganese, a low content of boron, a low to medium content of cooper and iron as well as a medium to high content of zinc (Table 1). The organic carbon content in the soil ranged from 5.5 to 8.2 g*kg^{-1} of soil, pH in 1 mol*dm^{-3} KCl from 5.0 to 6.8. In each year of the study, spring triticale was grown as a potato forecrop. Farmyard manure was applied in autumn, at the rate of 30 t*ha^{-1}.

Table 1. Selected soil chemical properties at the experimental site

Years	pH in KCl	C_{org} (g*kg^{-1})	S-total (%)	N-total (%)	Available forms (mg*kg^{-1})							
					P	K	Mg	B	Mn	Cu	Zn	Fe
2005	6.85	8.24	0.013	0.180	141	216	33	0.75	119.0	2.7	7.0	1056
2006	5.00	6.09	0.011	0.054	89	100	39	0.23	77.3	2.0	6.4	690
2007	5.00	5.51	0.012	0.030	102	75	34	0.18	79.8	2.3	6.1	670

Experimental design

The experiment was established in the split-plot design with three replications, including two factors: factor I – type of fertilizer: control object without fertilizers, single-nutrient fertilizers (ammonium nitrate 34%, superphosphate 19%, potassium sulphate 50%), HydroComplex (NPKMgS + B, Mn, Zn, Fe; produced by Yara International ASA Norway), Nitrophoska Blue Special (NPKMgS + B, Zn; produced by COMPO GmbH&Co.KG Germany), Viking 13 (NPKMgS + Ca; produced by Yara International ASA Norway) representing the nitrophoska group and Polimag S (NPKMgS + B, Cu, Mn, Zn; produced by Zakłady Chemiczne POLICE S.A. Poland) from the amophoska group (Table 2), and factor II – potato cultivars: ‘Aster’ (Polish), ‘Fresco’ (The Netherlands), ‘Gloria’ (German) (Table 3). The complex fertilizers and single-nutrient fertilizers were applied in spring, in amounts equivalent to the recommended rates for the cultivars tested (80 kg N*ha^{-1}). The remaining elements in the single-nutrient fertilizers were applied at rates which guarantee an appropriate N:P:K proportion for edible potatoes, i.e. 1:1:1.5.

Table 2. Characteristics of complex fertilizers

Fertilizer	Chemical composition (%)												
	N-total	N-NO_3^-	N-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	-	-	-	-	-

Table 3. Characteristics of potato cultivar

Cultivar	Country of origin	Cooking type	Soil requirements	Water requirements
Aster	Poland	BC	medium – large	medium
Fresco	The Netherlands	B	medium – large	medium – large
Gloria	Germany	B	medium – large	medium – large

In successive years, 4-week pre-sprouted seed potatoes were planted on 15, 20 and 18 April, with row spacing of 0.30 m and 0.625 m between rows. The plots were four rows wide and 6 m long. The plot area was 15 m^2. The average length of sprouts at the time of planting amounted to 15-20 mm. Potato cultivation was carried out according to the rules of correct agronomical practice. After 60 days from planting, the height of plants, assimilation leaf area and leaf area index (LAI) were determined. The measurements were made on four successive plants per plot. The assimilation leaf area was measured by the weight method (Roztropowicz 1999). Potatoes were harvested 75 days after planting (the end of June). The total and marketable tuber yield (diameter above 30 mm), the tuber yield structure, ie. percentage weight of tubers with diameters below 30 mm, 31-40 mm, 41-50 mm, 51-60 mm, above 60 mm, and the average weight of one tuber were determined. The content of dry matter with the oven-drying gravimetric method, starch with the polarimetric method according to Ewers (Mitchell, 1990) and L-ascorbic acid with the titration method with 2,6-dichlorphenolindophenol according to Tillmans (Polish Standard PN-90/A-75101.11) were also determined. Laboratory studies were conducted on samples of 50 different-sized tubers taken from each treatment. Fresh tubers were used in chemical analyses which were conducted immediately after potato harvest.

Statistical analysis

The results of the study were analysed statistically by means of analysis of variance (ANOVA) for the split-plot design . The significance of differences was verified using Tukey's test at $\alpha=0.05$.

Weather conditions

In the three-year period of study, the most favourable thermal and moisture conditions for the cultivation of very early potato cultivars were in the growing season of 2007 (Table 4). The mean monthly temperatures were above the long-term average. Total precipitation in May was slightly above the long-term average.
In 2005, the growth and development of plants was hindered by a low air temperature after potato planting and drought from mid-June to the end of the growing period. In 2006, it was hampered by mild drought throughout the potato growing period. Total precipitation in June was almost three times lower than the long period average.

Table 4. Mean air temperature and precipitation sums in the vegetation period of potato

Specification	Years	Months		
		April	May	June
Temperature (°C)	2005	8.6	13.0	15.0
	2006	8.4	13.6	17.2
	2007	8.6	14.4	18.2
	mean 1981-2000	8.1	11.2	16,7
Rainfalls (mm)	2005	12.3	64.7	44.1
	2006	29.8	39.6	24.0
	2007	21.2	59.1	59.0
	mean 1981-2000	49.6	48.2	67.7
Sielianin's hydrothermal coefficient	2005	0.5	1.6	0.9
	2006	1.2	0.9	0.5
	2007	0.8	1.3	1.1

Hydrothermal coefficient value: up to <0.5 strong drought, 0.51-0.69 drought, 0.70-0.99 mild drought, ≥1 no drought

Results

The fertilizers applied in the experiment significantly affected the growth of plants. The plants were higher on average by 0.058 m with the use of single-nutrient fertilizer. With the application of complex fertilizers they were higher by 0.033 m to 0.055 m in comparison with the control treatment without mineral fertilization (Table 5). The type of fertilizer (single-nutrient or complex fertilizer) had a slight effect on the height of plants. A slightly faster rate of plant growth was observed with the use of complex fertilizers from the nitrophoska group with microelements (HydroComplex and Nitrophoska Blue Special), than with nitrophoska without microelements (Viking 13) and amophoska (Polimag S), but the differences in plant height were not statistically confirmed.

The assimilation leaf area was on average higher by 0.1337 m^2 (36.6%) with the use of single-nutrient fertilizers and by 0.0824 m^2 (22,5%) to 0.1337 m^2 (33.0%) with the application of complex fertilizers compared with the cultivation without mineral fertilization. The value of leaf area index (LAI) was higher by 0.71 (36.4%) and 0.44-0.64 (22.6-32.8%), respectively. With the use of complex fertilizers, the assimilation leaf area and LAI were similar to the application of single-nutrient fertilizers (Table 5). The application of Viking 13 (from the nitrophoska group without microelements) resulted in a smaller increase of assimilation leaf area and LAI in comparison with the other complex fertilizers, but the differences were not statistically confirmed. The type of fertilizer and weather conditions during potato growing season interaction effect on plant growth was not statistically confirmed. The fertilizers applied in the experiment exerted a greater influence on the growth of 'Aster' than 'Fresco' and 'Gloria' (Table 5).

Regardless of the type of fertilizer applied 'Gloria' had a higher assimilation leaf area than 'Aster' and 'Fresco' (Table 5). The LAI for the 'Gloria' was on average 2.64 whereas for the 'Aster' it was smaller on average by 0.21 (8.0%) and for 'Fresco' – by 0.42 (15.9%). The highest differences between cultivars were observed in the very warm and moderately wet growing season in 2007 (Table 6).

Table 5. Height of plants and assimilation leaf area in relation to the type of fertilizer and cultivar

Specification	Type of fertilizer	Cultivar			
		Aster	Fresco	Gloria	mean
Height of plants (m)	without fertilizer	0.344	0.354	0.389	0.363
	single-nutrient fertilizers	0.431	0.416	0.413	0.420
	HydroComplex	0.436	0.424	0.382	0.414
	Nitrophoska Blue Special	0.416	0.409	0.427	0.418
	Polimag S	0.405	0.354	0.428	0.396
	Viking 13	0.413	0.414	0.407	0.411
	mean	0.408	0.395	0.408	0.404
	$LSD_{0.05}$: type of fertilizer = 0.038, cultivar = ns, type of fertilizer × cultivar = 0.060				
Assimilation leaf area (m^2)	without fertilizer	0.3456	0.3339	0.4178	0.3658
	single-nutrient fertilizers	0.5438	0.4802	0.4744	0.4995
	HydroComplex	0.4963	0.4549	0.5081	0.4864
	Nitrophoska Blue Special	0.4784	0.4362	0.4858	0.4668
	Polimag S	0.4514	0.3364	0.6193	0.4690
	Viking 13	0.4222	0.4577	0.4647	0.4482
	mean	0.4563	0.4166	0.4950	0.4560
	$LSD_{0.05}$: type of fertilizer = 0.0953, cultivar = 0.0536, type of fertilizer × cultivar = 0.1608				
Leaf area index (LAI)	without fertilizer	1.84	1.78	2.23	1.95
	single-nutrient fertilizers	2.89	2.56	2.53	2.66
	HydroComplex	2.65	2.42	2.71	2.59
	Nitrophoska Blue Special	2.55	2.32	2.58	2.48
	Polimag S	2.41	1.78	3.30	2.50
	Viking 13	2.25	2.44	2.48	2.39
	mean	2.43	2.22	2.64	2.43
	$LSD_{0.05}$: type of fertilizer = 0.51, cultivar = 0.28, type of fertilizer × cultivar = 0.86				

Table 6. Height of plants and assimilation leaf area in relation to the cultivar and potato growing season

Specification	Cultivar	Years			
		2005	2006	2007	mean
Height of plants (m)	Aster	0.380	0.314	0.528	0.408
	Fresco	0.333	0.355	0.498	0.395
	Gloria	0.305	0.356	0.562	0.408
	mean	0.340	0.342	0.529	0.404
	$LSD_{0.05}$: years = 0.022, cultivar = ns, years × cultivar = 0.035				
Assimilation leaf area (m^2)	Aster	0.4832	0.3473	0.5384	0.4563
	Fresco	0.3039	0.4056	0.5402	0.4166
	Gloria	0.3915	0.3646	0.7290	0.4950
	mean	0.3928	0.3725	0.6025	0.4560
	$LSD_{0.05}$: years = 0.0544, cultivar = 0.0536, years × cultivar = 0.0928				
Leaf area index (LAI)	Aster	2.57	1.85	2.87	2.43
	Fresco	1.62	2.16	2.88	2.22
	Gloria	2.08	1.94	3.89	2.64
	mean	2.09	1.99	3.21	2.43
	$LSD_{0.05}$: years = 0.29, cultivar = 0.28, years × cultivar = 0.49				

The growth of plants depended to a greater degree on the weather conditions. More favourable conditions for rapid potato plant growth were in the very warm and moderately wet growing season in 2007 (Table 6). In this year, the plants were higher on average by 0.188 m than in the remaining years of the study. The assimilation leaf area and LAI were higher by 0.2199 m^2 and 1.17, respectively.

The productive effects of complex fertilizers, reflected in an increase in the tuber yield in comparison with the cultivation without mineral fertilization, were comparable with commonly used single-nutrient fertilizers (Table 7). The highest tuber yield was reported with the application of Nitrophoska Blue Special (from the nitrophoska group with the lowest $N\text{-}NH_4^+$ concentration). With the use of this fertilizer, the total tuber yield was higher on average by 2.94 $t*ha^{-1}$ (21.0 %) and the yield of marketable tuber fraction by 2.55 $t*ha^{-1}$ (20.4%) in comparison with the cultivation without mineral fertilization. The type of fertilizer and weather conditions during potato growing season interaction effect on tuber yield, and the type of fertilizer and cultivar interaction effect on tuber yield were not statistically confirmed.

Table 7. Tuber yield and average weight of one tuber in relation to the type of fertilizer and cultivar

Specification	Type of fertilizer	Cultivar			
		Aster	Fresco	Gloria	mean
Total tuber yield ($t*ha^{-1}$)	without fertilizer	15.55	13.40	12.84	14.00
	single-nutrient fertilizers	20.05	15.40	13.13	16.19
	HydroComplex	18.79	15.83	14.44	16.36
	Nitrophoska Blue Special	18.77	16.52	15.52	16.94
	Polimag S	17.68	15.77	13.89	15.78
	Viking 13	17.96	16.03	14.43	16.14
	mean	18.17	15.49	14.04	15.90
	$LSD_{0.05}$: type of fertilizer = 2.27, cultivar = 1.04				
Marketable tuber yield ($t*ha^{-1}$)	without fertilizer	14.59	11.70	11.13	12.47
	single-nutrient fertilizers	18.71	13.69	11.62	14.67
	HydroComplex	17.52	14.19	12.72	14.81
	Nitrophoska Blue Special	17.23	14.50	13.32	15.02
	Polimag S	16.22	14.14	12.17	14.18
	Viking 13	16.40	14.28	12.30	14.33
	mean	16.78	13.75	12.21	14.25
	$LSD_{0.05}$: type of fertilizer = 2.43, cultivar = 1.01				
Average weight of one tuber (g)	without fertilizer	37.11	35.08	26.46	32.88
	single-nutrient fertilizers	36.79	37.43	32.91	35.71
	HydroComplex	39.64	34.99	30.27	34.97
	Nitrophoska Blue Special	36.98	35.51	31.33	34.60
	Polimag S	35.81	39.47	33.12	36.13
	Viking 13	37.18	41.61	28.09	35.63
	mean	37.25	37.35	30.36	34.99
	$LSD_{0.05}$: type of fertilizer = ns, cultivar = 2.74				

Regardless of the type of fertilizer applied, the total tuber yield of the ‘Aster’ was higher than that of ‘Fresco’ and ‘Gloria’ on average by 2.68 $t*ha^{-1}$ (17.3%) and 4.13 $t*ha^{-1}$ (29.4%), respectively (Table 7). The yield of marketable tuber fraction was higher on average by 3.03 $t*ha^{-1}$ (22.0%) and 4.57 $t*ha^{-1}$ (37.4%). The highest differences between cultivars were reported in 2005, with the drought from mid-June to the end of the potato growing period (Table 8). In that year, the marketable tuber yield of ‘Aster’, which was more tolerant of wet conditions, was above twice as much as ‘Fresco’ and eight times as much as ‘Gloria’.

Table 8. Tuber yield and average weight of one tuber in relation to the cultivar and potato growing season

Specification	Cultivar	Years			
		2005	2006	2007	mean
Total tuber yield ($t*ha^{-1}$)	Aster	16.43	15.73	22.34	18.17
	Fresco	9.09	17.18	20.20	15.49
	Gloria	4.04	12.90	25.17	14.04
	mean	9.86	15.27	22.57	15.90
	$LSD_{0.05}$: years = 1.29, cultivar = 1.04, years × cultivar = 1.80				
Marketable tuber yield ($t*ha^{-1}$)	Aster	15.46	13.65	21.24	16.78
	Fresco	7.23	14.33	19.69	13.75
	Gloria	1.87	11.14	23.63	12.21
	mean	8.18	13.04	21.52	14.25
	$LSD_{0.05}$: years = 1.39, cultivar = 1.01, years × cultivar = 1.75				
Average weight of one tuber (g)	Aster	35.75	33.34	42.67	37.25
	Fresco	22.56	29.88	59.61	37.35
	Gloria	14.72	34.04	42.32	30.36
	mean	24.35	32.42	48.20	34.99
	$LSD_{0.05}$: years = 3.41, cultivar = 2.74, years × cultivar = 4.75				

The weather conditions during potato growing season had a significant effect on the tuber yield. Irrespective of the type of fertilizer applied, the tuber yield was highest in the warm and moderately wet growing season in 2007 (Table 8). In that year, the tuber yield was above twice as much as in comparison with 2005, when the air temperature was the lowest and was accompanied by a deficiency of precipitation from mid-June to the end of the potato growing period.

The type of fertilizer (single-nutrient or complex fertilizer) slightly affected the average weight of one tuber (Table 7). The weight of one tuber depended to a higher degree on the cultivar and weather conditions. The average weight of one tuber of ‘Aster’ and ‘Fresco’ was higher than ‘Gloria’. The highest differences between cultivars were reported in 2005, with the drought from mid-June to the end of the potato growing period (Table 8).

In the warm and moderately wet growing season in 2007, the average weight of one tuber was almost 1.5 times as much as in 2006, with the mild drought throughout the potato growing period, and almost 2 times as much as in 2005, with a low air temperature and drought from mid-June to the end of the potato growing period (Table 8).

The main weight of the yield was made up of tubers with a diameter of 31-40 mm, independent of the type of fertilizer applied and cultivar (Figures 1 and 2). The fertilizers applied in the experiment caused an increase in share tubers with a diameter of 41-50 mm and above 51 mm in the yield, especially in the year 2006, with a mild drought throughout the potato growing period. The highest share of large tubers (diameter above 51 mm) in the yield was found with the use of Polimag S (representing the amophoska group) and Viking 13 (representing the nitrophoska group without microelements). Regardless of the type of fertilizer applied, medium-sized tubers with a diameter of 41-50 mm constituted the highest share of ‘Aster’ yield and large tubers with a diameter above 51 mm constituted the highest share of ‘Fresco’ yield. About 25% of the ‘Gloria’ yield was made up of non-marketable tubers, with a diameter below 30 mm.

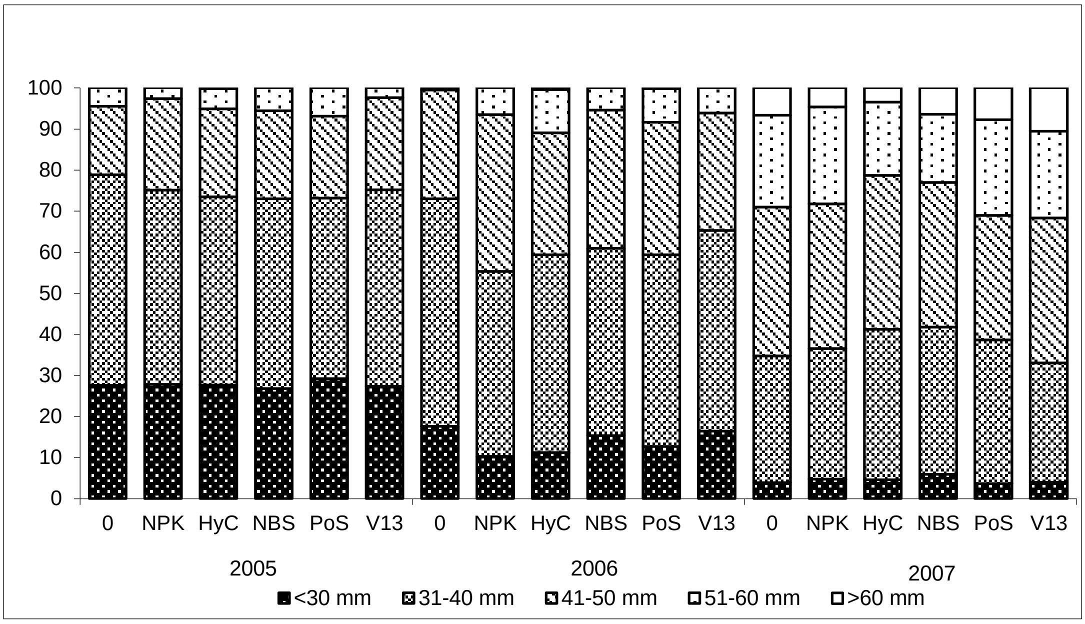

Figure 1. Structure of tuber yield in relation to the type of fertilizer and potato growing season (weight %): 0 – without fertilizer, NPK – single-nutrient fertilizer, HyC – HydroComplex, NBS – Nitrophoska Blue Special, PoS – Polimag S, V13 – Viking 13

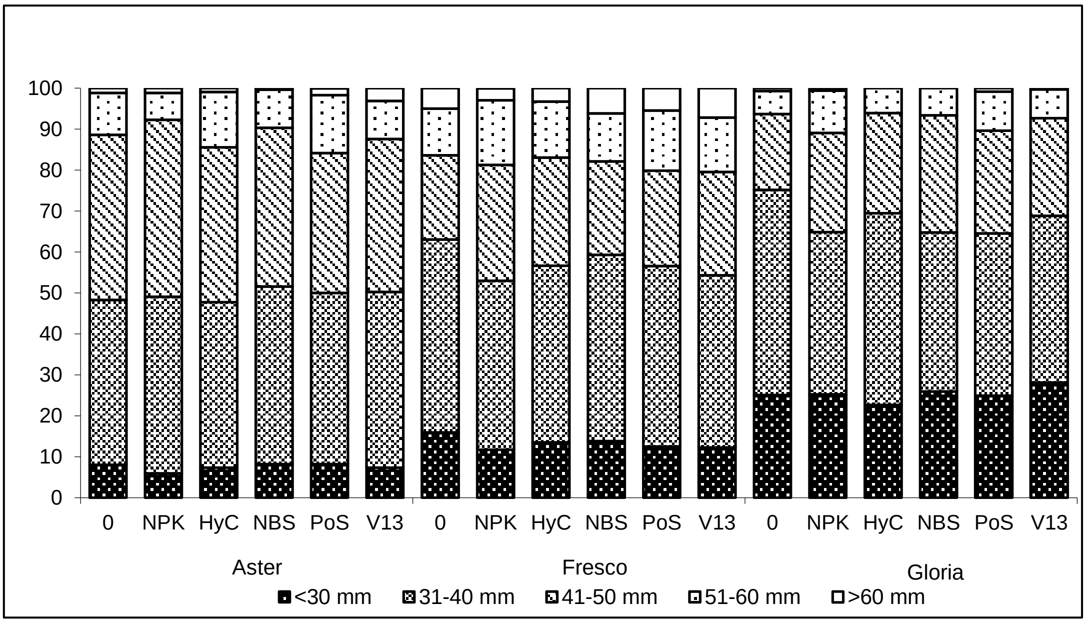

Figure 2. Structure of tuber yield in relation to the type of fertilizer and cultivar (weight %): 0 – without fertilizer, NPK – single-nutrient fertilizer, HyC – HydroComplex, NBS – Nitrophoska Blue Special, PoS – Polimag S, V13 – Viking 13

The fertilizer applied in the experiment had no effect on dry matter, starch and L-ascorbic acid content in potato tubers (Table 9). Of the fertilizers applied, only Nitrophoska Blue Special (from the nitrophoska group with the lowest $N\text{-}NH_4^+$ concentration) slightly increased dry matter and L-ascorbic acid content compared to the cultivation without mineral fertilization.

Table 9. Dry matter, starch and L-ascorbic acid content in tuber in relation to the type of fertilizer and cultivar

Specification	Type of fertilizer	Cultivar			
		Aster	Fresco	Gloria	mean
Dry matter (% f.w.)	without fertilizer	20.59	18.33	19.51	19.48
	single-nutrient fertilizers	19.69	19.42	19.05	19.39
	HydroComplex	20.17	19.47	19.75	19.80
	Nitrophoska Blue Special	20.97	19.60	20.30	20.29
	Polimag S	20.85	19.69	19.53	20.02
	Viking 13	20.01	19.68	19.90	20.20
	mean	20.54	19.36	19.67	19.86
	$LSD_{0.05}$: type of fertilizer = ns, cultivar = 0.63				
Starch (% f.w.)	without fertilizer	12.78	11.12	11.60	11.83
	single-nutrient fertilizers	11.98	11.85	11.11	11.65
	HydroComplex	12.60	11.32	12.32	12.08
	Nitrophoska Blue Special	12.44	11.34	11.73	11.84
	Polimag S	13.07	11.38	12.00	12.15
	Viking 13	12.73	11.70	11.83	12.09
	mean	12.60	11.45	11.76	11.94
	$LSD_{0.05}$: type of fertilizer = ns, cultivar = 0.47				
L-ascorbic acid ($mg*kg^{-1}$ f.w.)	without fertilizer	141.2	133.6	137.2	127.3
	single-nutrient fertilizers	137.8	140.8	138.7	139.1
	HydroComplex	134.3	134.4	141.4	136.7
	Nitrophoska Blue Special	146.0	138.5	142.3	142.3
	Polimag S	143.9	139.6	134.7	139.4
	Viking 13	135.5	142.0	137.8	138.5
	mean	139.8	138.2	138.7	138.9
	$LSD_{0.05}$: type of fertilizer = ns, cultivar = ns				

Table 10. Tuber yield and average weight of one tuber in relation to the cultivar and potato growing season

Specification	Cultivar	Years			
		2005	2006	2007	mean
Dry matter (% f.w.)	Aster	20.55	21.87	19.22	20.54
	Fresco	17.93	20.97	19.19	19.36
	Gloria	18.90	21.31	18.81	19.67
	mean	19.13	21.38	19.08	19.86
	$LSD_{0.05}$: years = 0.86, cultivar = 0.63, years × cultivar = 1.09				
Starch (% f.w.)	Aster	12.89	13.96	10.96	12.60
	Fresco	10.38	13.28	10.70	11.45
	Gloria	11.40	13.33	10.57	11.76
	mean	11.55	13.52	10.74	11.94
	$LSD_{0.05}$: years = 0.59, cultivar = 0.47, years × cultivar = 0.81				
L-ascorbic acid ($mg*kg^{-1}$ f.w.)	Aster	133.2	142.3	143.9	139.8
	Fresco	132.1	138.9	143.5	138.2
	Gloria	130.0	139.3	146.8	138.7
	mean	131.7	140.2	144.7	138.9
	$LSD_{0.05}$: years = 5.6, cultivar = ns, years × cultivar = ns				

The dry matter, starch and L-ascorbic acid content in potato tuber to a higher degree depended on the genetic character of the cultivar and the weather conditions over the growing season (Table 10). Tubers of ‘Aster’ contained more dry matter and starch than ‘Fresco’ and ‘Gloria’. The highest differences between cultivars were reported in 2005, with the drought from mid-June to the end of the potato growing period. Tubers of the studied potato cultivars had similar L-ascorbic acid contents. The most dry matter and starch were accumulated by potato tubers in 2006, which had the lowest rainfall during the growing season. Lowest L-ascorbic acid was accumulated by potato tubers in 2005, when the air temperature was the lowest and accompanied by deficiency of precipitation from mid-June to the end of the potato growing period.

Discussion

Fertilization is one of the most important agronomical factors affecting plant growth and potato tuber yield. In the initial period after planting, until a foliage surface of approximately 0.02 m^2 is formed, the potato plant extracts the nutritive elements necessary to its growth from the mother tuber in a proportion of 96% and only in a proportion of 4% from the soil, through its radicular system. At the beginning, the assimilation of the nutritive elements from the soil is much reduced, but this process intensifies rapidly, reaching its highest level at the beginning of flowering, when the accumulation of dry substances is the most intense (Nemes et al., 2008). Potato has a relatively shallow root system and requires significant nutrient inputs to maintain tuber productivity and quality. Total biomass production and potato cultivar accumulation depend on the amount of intercepted photosynthetically active radiation. The growth duration and leaf area determine the amount of solar radiation intercepted by the canopy and influences the extent of photosynthesis, evaporation, transpiration, stolon and tuber initiation, final biomass, and partitioning of dry matter into economic yield (Gordon et al., 1997; Kumari, 2012). The leaf area index (LAI) is one of the physiological parameters indicating the performance of crop growth and partitioning of assimilates. The duration of active leaf growth mainly determines potato yield and is a major limiting factor with early-maturing cultivars (Lahlou et al., 2003; Geremew et al., 2007). The LAI value depends not only on the cultivar and plant growth stage, but can also be modified by fertilization, irrigation and other factors (Gordon et al., 1997; Boyd et al., 2002; Jenkins and Mahmood, 2003). In the present study, the type of fertilizer (single-nutrient or complex fertilizer) slightly affected the growth of plants. A slightly faster rate of plant growth was observed with the use of complex fertilizer from the nitrophoska group with microelements, i.e. HydroComplex and Nitrophoska Blue Special, than with nitrophoska without microelements (Viking 13) and amophoska (Polimag S), but the differences were not statistically confirmed. In potato cultivation, some elements like Zn, B, S and Mg can help in increasing the foliage coverage at initial growth stages and in the later stages (Kumar et al., 2008). Bari et al. (2001) observed that the plant height and the highest foliage coverage were recorded in the plot where Zn, B, S and Mg were applied together, which was also confirmed in the present study. The rate of leaf area expansion showed an interaction between genotype and environment, and varied by year (Van Delden et al., 2000). In the present study, the LAI value was higher than 3.0, presumed to be the optimum (Rykaczewska, 2004), only in the very warm and moderately wet growing season in 2007. In the remaining years of the study, the LAI value averaged 2.04. Studies have shown a rapid increase in light interception together with an increase in LAI up to 2.5. The light interception rises, though slowly, until LAI reaches 4.0 (Boyd et al., 2002). According to de la Casa et al. (2011), if potato LAI exceeds 3.0, the intercepted photosynthetically active radiation values change very little, making it very difficult to detect differences due to variations in crop conditions. Regardless of the type of fertilizer applied, ‘Gloria’ had a higher assimilation leaf area than ‘Aster’ or ‘Fresco’.

The productive effects of complex fertilizers in early crop potato culture on loamy sand soil in mid-eastern Poland were comparable with commonly used single-nutrient fertilizers. The highest increase in total and marketable tuber yield in comparison with the cultivation without mineral fertilization was reported with the application of nitrophoska with the lowest N-NH_4^+ concentration, i.e. Nitrophoska Blue Special). Potato plants are very sensitive to NH_4^+ toxicity (Britto and Kronzucker, 2002). Mineral fertilizers, through their chemical formulation, can modify the pH of the soil. Generally, fertilizers with high nitrogen content of ammonium origin can acidify soils when they are applied repeatedly. The microorganisms in the soil convert the nitrogen from ammonium (NH_4^+) to nitric (NO_3^-), thus releasing ions H^+ which acidify the soil (Pislea and Sala, 2012). The high agricultural efficiency of fertilization with Nitrophoska Blue Special was shown in the cultivation of very early-maturing potato cultivars on loamy sand soil in mid-eastern Poland, when potatoes were harvested at the tuber physiological maturity stage. The use of this fertilizer produced better results with sufficient water supply for plants (Wadas and Łęczycka, 2010). The beneficial effects of fertilization with Nitrophoska 12 Special and Nitrophoska 15 Perfect (NPKMgS + B, Zn) on potato cultivation in semi-coherent soil in north-western Poland were shown in the studies carried out by Jabłoński (2006). A study carried out in Belarus showed that the application of new forms of complex fertilizers with the amendments of plant growth promoting substances in years with varying degrees of moisture, on soils of different texture, allows an increase in potato yield and improves the quality as well as enhance the net return on fertilizers (Pirogovskaya et al., 2002). A study carried out on eastern Lithuanian soils showed that the effect of the complex fertilizer from the nitrophoska group, Cropcare (NPKMgS + B, Cu, Fe, Mn, Mo, Zn, Se), on the total potato tuber yield was similar to that of single-nutrient fertilizers, but an increase in the marketable yield and starch content was recorded (Marcinkonis et al., 2004).

The fertilizers applied in the experiment contributed to improved marketable value of the potato yield due to an increase share of medium-sized (diameter 41-50 mm) and large tubers (diameter above 51 mm). In early potato production, a lower yield of large-sized tubers produces higher marketable value than a high yield of smaller tubers with non-marketable value. The highest share of large tubers in the yield was found with the use of Polimag S (representing the amophoska group, and with the most Mg, S, Zn and B concentration) and Viking 13 (representing the nitrophoska group with Ca). The result showed that the Mg, S, Zn and B content of the soil can influence potato tuber size, which was confirmed by other authors (Bari et al., 2001; Sharma et al., 2011). Bari et al. (2001) reported that Zn, S, Mg and B treatment produced a higher percentage of medium-sized and large-sized tubers, which agrees with the present results. The rate of crop plant growth is, to some extent, modified by Mg and S application which can significantly impact nitrogen uptake and utilization. Magnesium is the basic nutrient supporting nitrogen uptake and simultaneously controls the processes responsible for photosynthesis and assimilates production and partitioning among plant parts (Gerendás and Führs, 2013). Sulphur has a direct effect on soil properties as it may reduce soil pH which improves the availability of microelements such as Fe, Zn, Mn and Cu as well as crop yield and its related characteristics (Tantawy et al., 2009). The tuberization signal can be influenced by the Ca level in the soil. The Ca content of the soil can influence both potato tuber number and tuber size and, by increasing soil Ca, the average tuber size may be increased and the tuber number decreased (Ozgen et al., 2003), as was confirmed in the present study.

The tuber yield and yield structure were determined by the variety and the pedoclimatic conditions of the experimental years. Regardless of the type of fertilizer applied, the total and marketable tuber yield of 'Aster' (Poland), more tolerant to the wet conditions, was higher than that of 'Fresco' (The Netherlands) and 'Gloria' (Germany). Medium-sized tubers (diameter 41-50 mm) constituted the highest share of 'Aster' yield.

Early-maturing potato cultivars partition a significant amount of dry matter to tubers at a relatively low total plant dry weight, thereby allowing crops to be harvested after comparatively short periods of growth. These cultivars are highly determinate in their growth characteristics, with the production of new leaves ceasing at a relatively early stage (Allen and Scott, 1992). The fertilizers applied in the experiment had no effect on dry matter, starch or L-ascorbic acid in potato tubers. Of the complex fertilizers applied, only Nitrophoska Blue Special (from the nitrophoska group with the most B concentration) contributed to improved tuber quality due to a slightly increased dry matter and L-ascorbic acid content, compared with cultivation without mineral fertilization. These results suggest that the B content of the soil can influence both the dry matter and L-ascorbic acid content in potato tuber and that by increasing soil B the dry matter and L-ascorbic acid content may be increased in early-harvest potato tuber. The ascorbic acid concentration in potato tuber significantly increased by the application of B foliar spray (Mandy and Munshi, 1993). The dry matter, starch and L-ascorbic acid content in potato tuber were determined directly by the cultivar and the pedoclimatic conditions of the experimental years. An appropriate choice of cultivar is very important in early potato production. Regardless of the conditions of potato growth or the type of fertilizer applied, the highest levels of dry matter and starch were accumulated in the tubers of 'Aster', although the content of L-ascorbic acid in tubers of the studied potato cultivars was similar.

In warm and dry years, potato tubers contain more dry matter and starch. The rainfall in the period May-June had no significant effect on the vitamin C (ascorbic acid) content in potato tubers, whereas higher air temperatures in this period favourably stimulated the vitamin C accumulation in the tubers of very early-maturing potato cultivars (Sawicka and Mikos-Bielak, 1995), which was also confirmed in the present study.

Conclusions

Efficient application of the proper type and amount of fertilizer is an important part of achieving profitable potato tuber yield. Fertilization must assure the high utilization of cultivar production potential under the environmental conditions of cultivation area with minimum nutrient losses to the environment. 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. A wide variety and range of complex fertilizers are currently available on the market. They often have a similar composition, but are sold under different trade names, which makes it difficult for the farmer to select best one. Complex fertilizers are more expensive than the equivalent quantity of nutrients achieved by applying equivalent quantities of single-nutrient fertilizers. The results of this study showed that NPKMgS complex fertilizers with and without microelements from the nitrophoska group, i.e. HydroComplex, Nitrophoska Blue Special or Viking 13, and the amophoska group, i.e. Polimag S, can be used in early crop potato culture on loamy sand soil. With the use of complex fertilizers, the assimilation leaf area and leaf area index (LAI) were similar to the application of single-nutrient fertilizers. Of the examined complex fertilizers, Viking 13 (representing the nitrophoska group without microelements) resulted in a smaller increase of assimilation leaf area in comparison with the cultivation without mineral fertilization. The productive effects of complex fertilizers in early crop potato culture were comparable with single-nutrient fertilizers. The highest tuber yield was achieved with the application of Nitrophoska Blue Special (from the nitrophoska group with the lowest $N\text{-}NH_4^+$ concentration); the total tuber yield after 75 days from planting was higher on average by 2.94 $t*ha^{-1}$ (21.0%) and the yield of marketable tuber fraction (diameter above 30 mm) by 2.55 $t*ha^{-1}$ (20.4%). The fertilizers applied in the experiment contributed to improved marketable value of the potato yield due to an increase share of medium-sized (diameter 41-50 mm) and large tubers (diameter above 51 mm). In early potato production, a lower yield of large-sized tubers produces higher marketable value than a high yield of smaller tubers with non-marketable value. Although the total tuber yield was a little lower, the share of large tubers in the yield was recorded with the use of Polimag S (from the amophoska group and with the most Mg, S, Zn and B concentration of all complex fertilizers applied) and Viking 13 (from the nitrophoska group with Ca). The fertilizers applied in the experiment had no effect on the tuber quality. These results allow agricultural practice in the use of fertilizers most economical cost.

The tuber yield more depend on the cultivar than on the type of fertilizer used. An appropriate choice of cultivar is very important in early potato production. The type of fertilizer exerted a greater influence on the plant growth of 'Aster' (Poland) than 'Fresco' (The Netherlands) and 'Gloria' (Germany). Regardless of the type of fertilizer applied, the tuber yield, average weight of one tuber and the share of medium-sized tubers in the yield of 'Aster', more tolerant to the wet conditions, were higher than 'Fresco' and 'Gloria'. The yield of marketable tuber fraction of the 'Aster' was higher on average by 3.03 $t*ha^{-1}$ (22.0%) and 4.57 $t*ha^{-1}$ (37.4%), respectively. About 25% of the 'Gloria' yield made up of non-marketable tubers (diameter below 30 mm). The highest levels of dry matter and starch were accumulated in the tubers of 'Aster', although the content of L-ascorbic acid in tubers of the studied potato cultivars was similar.

Acknowledges

Research supported by the Ministry of Science and Higher Education of Poland. Krystyna Struk, Director of Agricultural Experimental Station, is acknowledged for her valuable technical assistance during the field experiments and during harvest operations. The Authors would like to acknowledge the Reviewers and Editors for their valuable comments and suggestions for this paper.

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