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ORIGINAL PAPER

ASSESSMENT OF MINERAL NITROGEN FERTILIZATION OF EARLY POTATO VARIETIES IN INTEGRATED PRODUCTION*

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Abstract

Based on a 3-year field study, the effect of mineral nitrogen fertilization on the yield, selected tuber quality characteristics and fertilization efficiency indicators for early potato varieties grown in the integrated production system were determined. The quality of tubers was assessed according to the percentage share of tuber size and their external defects in the yield structure, starch content, dry matter, nitrates (V), protein and total nitrogen in tubers. The efficiency of fertilization with mineral nitrogen was expressed by the agronomic efficiency (AE), physiological efficiency (PE) and fertilizer recovery efficiency (FRE) by tubers. Two experimental factors were considered: nitrogen dose (0, 50, 100, 150 kg ha^{-1}) and varieties (Bohun, Lady Rosetta, Lawenda, Madeleine, Magnolia). The increase in the dose of mineral nitrogen contributed to a significant increase in the yield structure of tubers with a diameter above 60 mm, the content of nitrates (V), protein, total nitrogen, the uptake of nitrogen and a decrease in nitrogen fertilization efficiency indicators. It was shown that the Lady Rosetta and Lawenda varieties were characterized by higher requirements concerning the optimal nitrogen dose than the other varieties. Nitrogen fertilization efficiency, the content of nitrates (V) and tuber greening were determined mainly by the weather conditions, while the yield, nitrogen content and uptake by tubers were determined by the fertilizing factor, and the remaining tuber quality features were shaped to the greatest extent by the genotype. In a wet year, a significantly higher tuber yield, more large tubers in the structure and higher nitrogen fertilization efficiency were obtained. In years with rainfall deficit, a higher content of total nitrogen, protein, nitrates (V) in tubers and higher nitrogen uptake were found than in a wet year.

Keywords: efficiency indicators, nitrogen dose, potato, tuber quality, yield.

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INTRODUCTION

Due to the large mass of tuber yield produced, the potato requires sufficiently high fertilization (Goffart et al. 2008). Among the elements used in fertilization, nitrogen plays a key role in determining the yield and quality of tubers (Maltas et al. 2018). Due to the highly positive effect of this component, mainly on the volume of tuber yield, mineral nitrogen can be used in excess (Giletto, Echeverría 2015, Muleta, Aga 2019). This may, on the one hand, result in deterioration of tuber quality, for example by increasing the level of nitrates in tubers, and, on the other hand, lead to losses of this component, mainly through leaching into groundwater (Cambouris et al. 2008, Fotyma 2009, Jatav et al. 2017). Considering the above arguments, a system of integrated potato production was introduced in 2014, assuming mainly the reduction of chemical treatment in the cultivation of this species (Nowacki 2012). The principles of using mineral nitrogen in the integrated potato production system rely on many years of research, where it has been demonstrated that the differentiation of the yield size, tuber quality and fertilization efficiency indicators with this component significantly depend on the properties of individual varieties (Nowacki 2013). Optimization in the use of mineral nitrogen taking into account the expected yield size and tuber quality as well as the environmental protection aspect should involve the application of suitable doses for specific potato varieties (Davenport et al. 2005, Fontes et al. 2010, Rens et al. 2018). Differences in potato yielding, shaping the tuber quality and production efficiency indicators, apart from the traits of a variety and the dose of mineral nitrogen, largely depend on the course of the weather during the growing season.

Hence, the aim of the research was to evaluate the yield size, selected tuber quality characteristics and the indicators of the effectiveness of mineral nitrogen application in relation to new potato varieties grown in the integrated production system.

MATERIAL AND METHODS

In controlled field experiments, carried out in 2017-2019 at the Plant Breeding and Acclimatization Institute, National Research Institute, the Jadwisin Branch (52°45′ N, 21°63′ E), the response of early potato varieties to mineral fertilization with nitrogen was determined. The analyzed factors included:

1) mineral nitrogen fertilization doses (4): 0, 50, 100, 150 kg ha^{-1};
2) early potato varieties (5): Bohun, Lawenda (universal type, PB Zamarte Ltd, Poland), Lady Rosetta (universal type to mealy, C. Meijer B.V., The Netherlands), Madeleine (universal type, Agrico B.A., The Nether-

lands), Magnolia (universal type to mealy, PM PB Strzekęcino Ltd., Poland).

The experimental design was a split-plot randomized block with three replications. A plot consisted of four rows at a distance of 0.75 m, with a distance of 0.33 cm between seeds within each row. The size of the field was 14.85 m^2. The number of plants on a plot was 60.

The research was carried out on Podzolic soil with the particle size composition of light loamy sand, good rye complex, soil valuation class V (WRB 2014). The soil was characterized by acid reaction, and had high phosphorus content, average amounts of mineral nitrogen, soil organic carbon (SOC) and potassium, and low content of magnesium (Table 1).

Table 1

Soil chemical properties of the field before planting

Year	N min. 0-60 cm (kg ha^{-1})	Soil organic carbon	pH in KCl	Content in the soil (mg kg^{-1})*		
		SOC (g kg^{-1})		P	K	Mg
2017	50	8.4	5.0	88	122	22
2018	60	8.8	5.4	79	104	26
2019	60	6.6	5.2	75	100	22

* available forms

The organic fertilization in the study comprised cut winter triticale straw, incorporated into the soil in an amount of 5 t ha^{-1}. In autumn, the soil was amended with green mass of white mustard stubble intercrop in the amount of 15-16 t ha^{-1}. Mineral fertilization with phosphorus and potassium was carried out in early spring at doses of 26.2 kg P ha^{-1} (enriched superphosphate – 17.4% P) and 99.6 kg K ha^{-1} (potassium salt – 49.8% K). Nitrogen fertilization on plots with a dose up to 100 kg ha^{-1} N was applied in spring before planting tubers, and a supplementary dose 50 kg ha^{-1} N was applied on plots supplied 150 kg ha^{-1} N just before the emergence of potato plants. Nitrogen was used as nitro-chalk - 27% N. Tubers were planted in the third ten days of April and harvested after tuber maturity (the first ten days of September).

The years of research in terms of the course of weather conditions varied considerably. The highest rainfall was recorded in 2017. The sum of precipitation for the entire growing season in 2017 was 55.1 mm higher than the multi-year average. In turn, the air temperature was lower than in the remaining two years. The year 2018 was characterized by less rainfall, lower by 79.2 mm than the multi-year sum, and was the warmest. The least rainfall appeared in 2019. The rainfall for the entire growing season was 135.6 mm lower than the sum of the multi-year period, and the air temp. was 2.3°C higher than the average for the multi-year period. In general, all the years were warm, especially 2018. Based on the Selyaninov's hydrothermal coefficient, 2017 was a wet year while 2018 and 2019 were dry (Table 2).

Table 2

Weather conditions in the research years (Meteorological station in Jadwisin)

Year	Month						
	April	May	June	July	Aug.	Sept.	Sum/Mean
Sum of rainfalls (mm)							
2017	8.9	10.1	107.5	78.8	57.0	140.8	407.1
2018	21.7	43.4	41.0	75.2	60.6	30.9	272.8
2019	1.7	76.6	6.9	33.4	37.0	60.8	216.4
1967-2016	37.0	57.0	75.0	76.0	61.0	48.0	352.0
Mean air temperature (^{o}C)							
2017	7.3	14.1	18.1	18.4	19.4	13.8	15.2
2018	13.2	17.6	19.1	21.2	20.8	15.8	18.0
2019	10.2	13.4	22.7	18.8	20.8	14.7	16.8
1967-2016	7.9	13.7	16.6	18.5	17.9	13.2	14.5
Selyaninov's hydrothermal coefficients (K)*							
2017	0.40	0.23	1.98	1.38	0.95	3.39	1.39
2018	0.54	0.79	0.71	1.14	0.93	0.65	0.79
2019	0.06	1.85	0.1	0.57	0.57	1.38	0.76

* Coefficient value (BAC et al. 1998); K<0.50 severe drought; K: 0.51-0.99 drought; K: 1.00-2.00 wet; K>2.00 very humid.

Weeds were removed mechanically (3 times before the emergence of potato plants) and chemically: one treatment immediately before emergence (Proman 500 SC – at a dose of 4 l ha^{-1}), and the second one after the emergence of potato plants (Titus 25 WG – at a dose of 60 g ha^{-1} + Trend 90 EC at a dose of 0.1 l ha^{-1}). During the growing season, fungicides against potato blight were applied four times (Ekonom 72 WP at 2 kg ha^{-1}, Pyton Consento 450 SC at 2 l ha^{-1}, Infinito 687.5 SC at 1.5 l ha^{-1}, Revus 250 SC at 0.6 l ha^{-1}) and insecticides against Colorado potato beetle were applied three times (Actara 25 WG at 70 g ha^{-1}, Calypso 480 SC at 75 ml ha^{-1} and Apacz 50 WG at 60 g ha^{-1}).

The dry matter yield was calculated from the fresh matter yield and the dry matter content in tubers. The following chemical composition parameters were determined: the content of starch and nitrates (V) in fresh mass, dry matter and total nitrogen in dry matter. The starch content was determined using the Evers' polarimetric method, namely starch hydrolysis was carried out in a boiling water bath, and protein was precipitated with phosphoric acid, using readings on a Polamat S automatic polarimeter. The content of nitrates (sum III and V) was determined with the colorimetric method based on the Griess reaction. The content of total protein in fresh mass was derived from the equation: total protein (% in fresh mass) = [(% N total in dry mass x % dry mass x 6.25-nitrogen to protein conversion factor)/100].

The dry matter content was assessed by a two-step drying method (60°C and next 105°C). Nitrogen concentrations in tubers were determined with the Kjeldahl's method.

The potato yield response to N fertilization doses was calculated according to the quadratic (1) and linear (2) function:

$$Y = a + bX + cX^2 \text{ (1) and } Y = a + bX \text{ (2)}$$

where: Y – tuber yield, X – nitrogen doses, a – yield at the dose of 0, b – yield increasing per kg of N; c = yield decreasing factor.

The optimal dose of nitrogen (X_{opt}) was calculated according to equation 3:

$$X_{opt} = -b/2c \text{ (3)}$$

Maximal tuber yield (Y_{max}) at X_{opt} was calculated according to equations 4 and 5:

$$Y_{max} = a - \mathrm{i}^2/4c \text{ (4) and } Y_{max} = b \cdot X_{max} + a \text{ (5)}$$

Agronomic efficiency (AE) at X_{opt} was calculated according to equations 6 and 7:

$$\mathrm{AE} = (Y_{max} - Y_0)/X_{opt} \text{ (6) and } \mathrm{AE} = \mathrm{i}_{max}/X_{opt} \text{ (7)}$$

Next, nitrogen uptake with the tuber yield (NUp) was calculated as well as nitrogen utilization efficiency indicators: agronomic efficiency (AE), physiological efficiency (PE), and fertilizer nitrogen recovery in tubers (FRE). The calculated nitrogen use efficiency parameters for potatoes were adopted from Vos (2009) and Zebarth et al. (2008). They were derived from the following formulas:

1. Nitrogen uptake with tuber yield (NUp) according to formula 4:

$$\mathrm{NUp\ (kg\ ha^{-1})} = [(\%\ \mathrm{N\ in\ DM} \cdot \mathrm{DW})/100] \cdot 1000 \text{ (4)}$$

where: DM – dry matter content (%); DW – tuber dry weight (t ha^{-1}).

2. Agronomic nitrogen efficiency (AE) according to formula 5:

$$\mathrm{AE\ (kg\ kg^{-1})} = [(Y_N - Y_0) / \mathrm{N_X}] \cdot 1000 \text{ (5)}$$

As the ratio of difference ($\mathrm{Y_N}$ – tuber yield of dry weight at fertilized plot and Y_0 – tuber yield of dry weight at unfertilized plot and dose of $\mathrm{N_X}$).

3. Physiological nitrogen efficiency (PE) according to formula 6:

$$\mathrm{PE\ (kg\ kg^{-1})} = [(Y_N - Y_0)] / (\mathrm{NUp_N} - \mathrm{NUp_0})] \text{ (6)}$$

As the ratio of difference ($\mathrm{Y_N}$ tuber yield of dry weight at fertilized plot and Y_0 – tuber yield of dry weight at unfertilized plot and NUp by tubers at $\mathrm{N_X}$ minus NUp by tubers at $\mathrm{N_0}$).

4. Fertilizer recovery efficiency in tubers (FRE) was calculated according to formula 7:

$$\mathrm{FRE\ (\%)} = [(\mathrm{N\ uptake\ by\ tubers\ at\ N_X} - \mathrm{N\ uptake\ by\ tubers\ at\ N_0}) / \mathrm{N_X}] \cdot 100 \text{ (7).}$$

Nitrogen uptake with the tuber yield at the fertilized plot (kg ha^{-1}) minus Nitrogen uptake with the tuber yield at the unfertilized plot (kg ha^{-1}) divided by N_X. This parameter is also referred to as nitrogen utilization by potato tubers.

The results of the experiments were statistically analyzed by ANOVA Statisica 13.3. The variance analysis of the studied features (dependent variables) was carried out according to a nitrogen dose, variety and year (independent variables). Comparisons of the means were carried out using the Tukey's test at $p<0.05$ and $p<.01$. The effect of the factors demonstrated by the F – Fisher Snedecor's distribution was presented for all characteristics. Non-linear and linear regression analysis of total yield dry mass depending on the nitrogen fertilization applied was used to determine the optimal nitrogen doses. The evaluation of variance components was carried out to identify the sources of variability of the studied features in the total variability. The percentage share of individual variance components was used to assess the impact of weather conditions in years, the applied nitrogen dose, properties of varieties and their interaction on the variability of the studied components.

RESULTS AND DISCUSSION

Tuber dry matter yield (DMY), nitrogen uptake (NUp) with the yield and the fertilization efficiency indicates with these parameters differed significantly in relation to the nitrogen dose, the properties of varieties and the course of weather conditions in the years of the study. A significant increase in the tuber yield was recorded up to the dose of 100 kg N ha^{-1} (Table 3). The gradual increase in the DMY to a specific dose of mineral nitrogen and then the decreasing response of the yield to increasing doses of mineral nitrogen confirmed previous findings from numerous studies conducted so far, and the optimal level of fertilization with this component was determined accordingly (Kumar et al. 2007, Fontes et al. 2010, Giletto, Echeverría 2015, Rens et al. 2016). In the current research, some varieties responded with an increase in yield to the highest nitrogen dose. It was found that the response of the Bohun, Magnolia and Madeleine varieties was parabolic and the optimal nitrogen doses were: 104, 120 and 129 kg ha^{-1}, respectively. The Lady Rosetta and Lawenda varieties increased the tuber yield up to a dose of 150 kg ha^{-1} (Figure 1). Greater differentiation in relation to the optimal nitrogen dose for varieties, from 94 to 170 kg N ha^{-1}, were shown by Maltas et al. (2018) and Cohan et al. (2018). Rens et al. (2018) obtained the highest tuber yield under the influence of nitrogen doses from 114 to 138 kg ha^{-1}. This experiment showed that the Bohun variety was characterized by the significantly highest DMY, and the Madeleine variety had the lowest DMY (Table 3). The most favourable year for tuber yield accumulation was 2017, moderately warm and humid. In turn, the signifi-

Table 3

Effect of the experimental factors on the yield of dry matter weight, DMY (t ha^{-1}), nitrogen uptake, NUp (kg ha^{-1}), agronomic efficiency, AE (kg kg^{-1}), physiologic efficiency, PE (kg kg^{-1}) and fertilizer recovery efficiency, FRE (%) by tubers

Treatment	DMY	NUp	AE	PE	FRE
Nitrogen dose					
0	8.46*c*	93.39*d*	-	-	-
50	10.43*b*	124.69*c*	39.44*a*	61.66*a*	62.60*a*
100	11.75*a*	151.29*b*	32.84*b*	54.21*b*	57.90*a*
150	11.65*a*	162.91*a*	21.28*c*	40.77*c*	46.35*b*
Variety					
Bohun	12.08*a*	137.73*bc*	31.47*b*	50.19*bc*	56.75*b*
Lady Rosetta	10.53*c*	145.28*a*	25.90*b*	46.28*c*	53.18*b*
Lawenda	10.57*cb*	139.60*ba*	30.21*b*	46.12*c*	63.70*a*
Madeleine	8.65*d*	110.57*d*	29.00*b*	56.11*ba*	47.90*c*
Magnolia	11.03*b*	132.15*c*	39.35*a*	62.37*a*	58.36*b*
Year					
2017	11.57*a*	121.08*b*	49.80*a*	74.92*a*	66.93*a*
2018	9.54*c*	139.14*a*	26.06*b*	48.06*b*	51.63*b*
2019	10.61*b*	138.99*a*	17.70*c*	33.66*c*	49.37*b*
Significance of the impact					
Nitrogen dose (1)	xx	xx	xx	xx	xx
Variety (2)	xx	xx	xx	xx	xx
Year (3)	xx	xx	xx	xx	xx
(1x2)	x	x	x	x	n.s.
(1x3)	xx	xx	n.s.	x	x
(2x3)	xx	xx	x	xx	x
(1x2x3)	n.s.	n.s.	x	x	x
Share in total variability (%)					
Nitrogen dose (1)	32.3	61.8	18.4	18.5	22.5
Variety (2)	22.7	12.4	6.6	4.8	14.9
Year (3)	12.6	6.2	60.6	72.5	32.6
(1x2)	1.8	1.7	3.4	0.9	5.8
(1x3)	10.3	3.7	0.3	1.0	8.6
(2x3)	19.2	13.3	6.6	1.6	7.4
(1x2x3)	1.0	0.8	4.2	0.7	8.2

xx – highly significant at $\alpha \leq 0.01$; x – significant at $\alpha \leq 0.05$, n.s. – not significant.
Means with the same letter do not differ significantly.

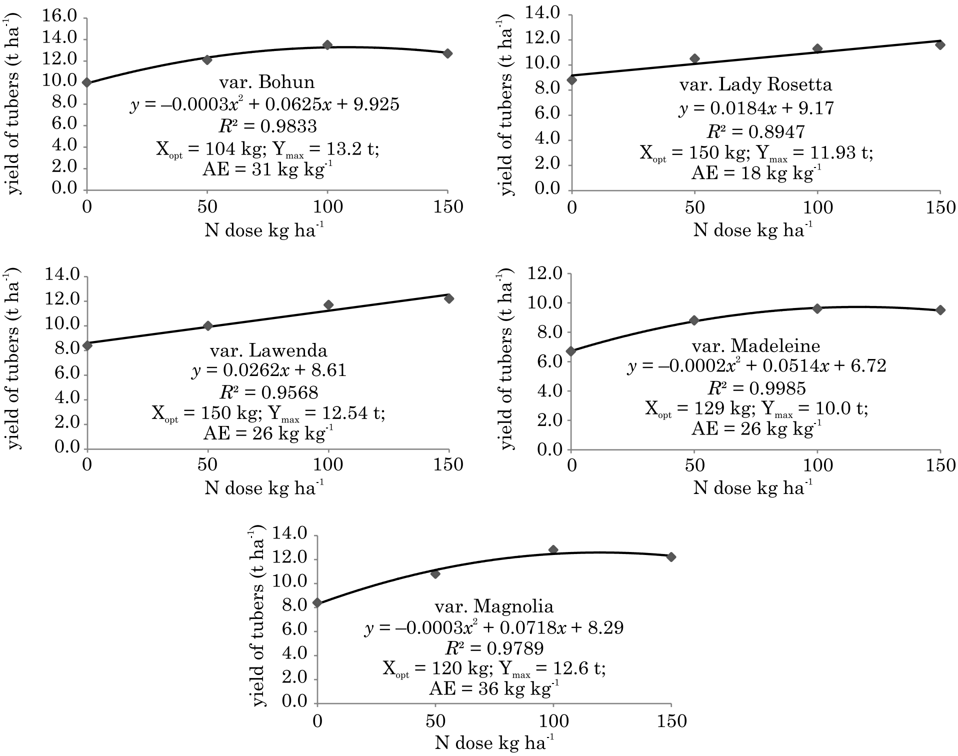

Fig. 1. Influence of N doses on the tuber dry matter yield of varieties

cantly lowest tuber yield was obtained in 2018 (Table 3), which was dry and had the highest air temperature of the three years. The assessment of variables showed that the highest impact on the total variability of DMY was exerted by the level of mineral nitrogen fertilization (32.3%), and the smallest effect was produced by the course of weather conditions in the years (12.6%) – Table 3. The studies conducted so far generally demonstrated the greatest impact of plant-growing conditions on tuber yield accumulation (SAWICKA et al. 2011).

With an increase in mineral nitrogen fertilization, a gradual but significant increase in nitrogen uptake (NUp) was noted. The NUp was higher by 74.4% after applying the dose of 150 kg N ha^{-1} compared to the facility without nitrogen. A similar NUp with the increase in the dose of this component was confirmed by other authors (HAASE et al. 2007, JAMAATI-E-SOMARIN et al. 2009, VOS 2009). In turn, nitrogen uptake in relation to the varieties ranged from 110.57 kg ha^{-1} for Madeleine to 145.28 kg ha^{-1} for Lady Rosetta. It was also shown that a significantly higher NUp from the fertilizers was obtained in years with the shortage of rainfall than in a wet year (Table 4), which resulted from higher accumulation of this element in tubers under drought conditions (Table 4). Lower NUp by tubers in the wet year could

Table 4

Effect of the experimental factors on the chemical composition of tubers

Treatment	Starch (%)	Nitrates (V) (mg kg^{-1})	Protein (%)	DM (%)	Total N (%)
Nitrogen dose					
0	14.12*c*	28.57*dc*	1.40*d*	20.33*c*	1.10*d*
50	14.85*b*	43.00*c*	1.59*c*	21.25*b*	1.20*c*
100	15.06*a*	62.60*b*	1.82*b*	21.89*a*	1.33*b*
150	14.67*b*	75.51*a*	1.91*a*	21.34*b*	1.43*a*
Variety					
Bohun	13.24*d*	31.02*c*	1.39*c*	19.71*d*	1.13*c*
Lady Rosetta	17.47*a*	49.58*b*	2.21*a*	25.22*a*	1.40*a*
Lawenda	13.72*c*	52.50*b*	1.63*b*	20.05*c*	1.30*b*
Madeleine	12.83*e*	71.80*a*	1.48*c*	18.56*e*	1.28*b*
Magnolia	16.12*b*	57.19*ba*	1.67*b*	22.47*b*	1.19*c*
Year					
2017	15.00*b*	26.21*c*	1.39*b*	21.82*b*	1.02*c*
2018	13.48*c*	78.43*a*	1.77*a*	19.48*c*	1.45*a*
2019	15.54*a*	52.61*b*	1.84*a*	22.31*a*	1.32*b*
Significance of the impact					
Nitrogen dose (1)	x	xx	xx	x	xx
Variety (2)	xx	xx	xx	xx	x
Year (3)	xx	xx	xx	xx	x
(1x2)	n.s.	x	n.s.	n.s.	n.s.
(1x3)	n.s.	x	n.s.	n.s.	n.s.
(2x3)	xx	x	n.s.	x	n.s.
(1x2x3)	x	x	n.s.	x	n.s.
Share in total variability (%)					
Nitrogen dose (1)	2.4	28.4	20.6	3.8	98.3
Variety (2)	67.8	15.2	48.1	68.7	0.3
Year (3)	15.9	39.9	27.5	18.5	1.2
(1x2)	0.9	1.5	1.0	0.9	0.0
(1x3)	0.8	4.8	0.7	1.1	0.0
(2x3)	9.7	6.7	0.7	4.9	0.2
(1x2x3)	2.4	3.4	1.4	2.0	0.0

xx – highly significant at $\alpha \leq 0.01$, x – significant at $\alpha \leq 0.05$, n.s. – not significant.
Means with the same letter do not differ significantly.

also indicate that some of this element was washed out from the root zone to the groundwater (Arriaga et al. 2009, Shrestha et al. 2010). NUp by tubers was mostly determined by fertilization with this element (61.8% share in total variability). Along with an increase in nitrogen doses, an increase in the uptake of this element was noted, but fertilizer recovery efficiency

(FRE) from the fertilizer by tubers decreased. This indicates the decreasing efficiency of absorbing this nutrient from a higher dose of nitrogen (Vos 2009, Cohan et al. 2018, Maltas et al. 2018, Rens et al. 2018). In the fertilization range of 50-150 kg N ha^{-1}, nitrogen recovery ranged from 62.60 to 46.35%. Varieties differed in nitrogen recovery by tubers from 47.90% for Madeleine to 63.70% for Lawenda. Zebarth and Rosen (2007) found that nitrogen recovery by tubers in relation to varieties ranged from 40 to 60%. Zebarth et al. (2004, 2012) showed that varieties and weather conditions in the years shaped the recovery of nitrogen by tubers, which resembles our findings. With the increase of nitrogen dose from 50 to 150 kg N ha^{-1}, the efficiency of 1 kg of applied nitrogen (AE) decreased, from 39.44 to 21.28 kg of tubers. In the wet year 2017, the significantly highest nitrogen AE indicator was achieved, while the lowest one occurred in the year with the highest rainfall deficit. In relation to varieties, the AE indicator ranged from 25.90 to 39.35 kg of tubers per 1 kg of nitrogen applied. The Magnolia variety was characterized by a significantly higher AE indicator than the other varieties (Table 3). At the optimal nitrogen dose, the agronomic efficiency ranged from 18.00 kg of tubers per 1 kg of the applied element for Lady Rosetta to 36.00 kg of tubers for Magnolia (Figure 1). The AE was consistent with the physiological efficiency (PE) in relation to the analyzed factors. PE in relation to mineral nitrogen fertilization ranged from 40.77 to 61.66 kg of tubers, for varieties from 46.12 to 62.37 kg of tubers, and in the years from 33.66 to 74.92 kg of tubers (Table 3). The efficiency indicators (AE and PE) and recovery (FRE) of mineral nitrogen by tubers were shaped to the highest extent by the weather factor (Table 3). Values of mineral nitrogen fertilization efficiency indicators make it possible to determine the profitability of production and, on the other hand, to identify the environmental impact of fertilization with this element (Davenport et al. 2005, Fontes et al. 2010, Maltas et al. 2018).

The value of edible potato varieties depends on the size of tubers in yield (structure) and the share of tubers with defects. The share of tubers with fractions of more than 35 mm and of tubers without defects are the basic determinants of the commercial yield of tubers. It was found in this study that an increase in the dose of mineral nitrogen led to a decrease in the share of small tubers with a diameter of less than 35 mm and medium-size tubers with diameters of 35-50 and 55-60 mm in the yield structure, while the share of large tubers (with a diameter of more than 60 mm) gradually increased (Table 5). An increase from 58 to 74% in the share of tubers with a diameter over 60 mm in the yield structure within the nitrogen dose range of 0-180 kg ha^{-1} was achieved by Kołodziejczyk (2014). In the current research, the Lady Rosetta variety had the highest share of small and medium tuber fractions, and Lawenda produced the largest share of large tubers. In 2017, the significantly largest share in the yield of large tubers with a diameter above 60 mm was achieved, compared to the remaining years (Table 5). This was mainly because of the favourable course of weather con-

Table 5

Yield structure and share in the yield tubers with defects (% of weight) depending on the study factors

Treatment		Tubers fraction (mm)			External defects of tubers			
	<35	35-50	50-60	>60	D*	G**	C***	sum
Nitrogen dose								
0	5.06*a*	36.83*a*	32.80*a*	25.31*b*	3.67*a*	1.58*a*	1.65*a*	6.90*a*
50	3.79*ba*	29.40*b*	34.92*a*	31.89*b*	4.15*a*	1.67*a*	1.67*a*	7.49*a*
100	2.44*bc*	23.11*c*	31.16*a*	43.29*a*	4.40*a*	2.26a	1.87*a*	8.53*a*
150	2.16*bc*	20.91*c*	30.64*a*	46.29*a*	4.54*a*	2.30*a*	2.68*a*	9.52*a*
Variety								
Bohun	3.98*ba*	25.43*b*	31.37*ba*	39.22*b*	4.34*bc*	2.22*b*	3.09*ba*	9.65*a*
Lady Rosetta	5.42*a*	36.13*a*	35.29*a*	23.16*c*	2.45*d*	1.33*cb*	0.55*ba*	4.33*b*
Lawenda	2.08*c*	16.31*c*	31.72*ba*	49.89*a*	6.73*a*	2.06*b*	2.62*ba*	11.41*a*
Madeleine	2.11*c*	24.12*b*	27.49*b*	46.28*ba*	4.88*ba*	3.46*a*	3.31*a*	11.65*a*
Magnolia	3.23*c*	35.82*a*	35.50*a*	25.45*c*	2.55*dc*	0.71*c*	0.28*b*	3.54*b*
Year								
2017	4.07*a*	24.90*ba*	31.67*a*	39.36*a*	4.07*b*	3.68*a*	0.84*b*	8.59*a*
2018	4.19*a*	30.91*a*	31.81*a*	32.89*b*	3.18*b*	0.74*c*	3.50*a*	7.42*a*
2019	3.83*b*	26.88*b*	33.33*a*	35.96*b*	5.32*a*	1.44*b*	1.56*b*	8.32*a*
Significance of the impact								
Nitrogen dose (1)	xx	xx	n.s.	xx	n.s.	n.s.	n.s.	n.s.
Variety (2)	xx	xx	xx	xx	xx	xx	x	xx
Year (3)	xx	x	n.s.	x	x	xx	x	n.s.
(1x2)	x	x	xx	n.s.	n.s.	x	x	n.s.
(1x3)	x	n.s.	x	n.s.	x	n.s.	n.s.	n.s.
(2x3)	x	xx	x	xx	xx	xx	xx	xx
(1x2x3)	x	x	xx	x	x	xx	xx	x
Share in total variability (%)								
Nitrogen dose (1)	20.2	25.6	6.8	27.2	1.3	2.7	1.3	3.1
Variety (2)	23.8	37.9	25.9	44.6	30.4	21.6	12.4	38.4
Year (3)	17.9	4.2	1.7	3.1	9.3	40.0	9.3	0.8
(1x2)	10.8	6.4	22.0	2.0	3.1	6.1	13.9	4.9
(1x3)	11.2	2.2	11.8	2.0	5.0	1.7	3.8	1.0
(2x3)	6.9	17.6	10.8	17.3	41.9	13.3	38.3	40.7
(1x2x3)	9.3	6.1	21.1	3.8	9.1	14.7	21.1	11.1

xx – highly significant at $\alpha \leq 0.01$, x – significant at $\alpha \leq 0.05$; n.s. – not significant.
Means with the same letter do not differ significantly;
D* – deformations, G** – green, C*** – common scab.

ditions in 2017 and, above all, a sufficient amount of rainfall during the plant growing season. Similar relationships regarding the influence of weather conditions on the tuber yield structure were confirmed BADR et al. (2006) and KOŁODZIEJCZYK (2014). The share of tuber fractions in the yield structure was determined mainly by genotypic traits (Table 5). Among the assessed defects, the largest share was composed of deformed tubers, on average from 2.45 to 6.73%, a smaller share comprised greening tubers, from 0.71 to 3.68%, and the smallest share consisted of tubers infected with common scab, from 0.28 to 3.50% (Table 5). The Lady Rosetta variety had the lowest share of deformed tubers, and the Magnolia variety had the lowest share of greening and scab infested tubers. Significantly more deformed tubers in the yield were found in the year with the most severe shortage of rainfall, greening tubers were more common in the wettest year, and tubers infected with common scab appeared most numerously in the dry year with the highest air temperature in the growing season. Similar dependencies were confirmed by LUTOMIRSKA and JANKOWSKA (2012). The most deformed and infested tubers with common scab were found to correlate with the interaction of varieties and years, whereas the greening of tubers depended more on the weather conditions.

The content of nutrients in tubers was highly dependent on the examined factors. The main ones in this respect are starch and nitrogen compounds, both with a beneficial nutritional effect, i.e. protein, and with an anti-nutritional effect, i.e. nitrates (LIN et al. 2004). Under the influence of the nitrogen dose of 150 kg ha^{-1}, there was a significant reduction in the starch content in tubers compared to the dose of 100 kg ha^{-1} N (Table 4). The studies conducted so far have confirmed the unfavourable effect of high nitrogen doses on the starch content in tubers (ÖZTÜRK et al. 2010, WIERZBICKA 2012). The greatest differentiation of the starch content in tubers, from 12.83% (Madeleine variety) to 17.47% (Lady Rosetta variety), was demonstrated in relation to the varieties. The course of weather conditions such as the highest rainfall deficit in one of the years contributed to the significantly highest starch content in tubers, which coincides with results obtained by RYMUZA et al. (2015) and WIERZBICKA (2012). The current study has shown that the genotype determined the starch content in tubers to the greatest extent (67.8%) – Table 4. According to WIERZBICKA et al. (2008), the main factor differentiating the starch content in tubers was the weather during the growing season.

Mineral nitrogen fertilization and weather conditions during the growing season had a greater impact on the level of nitrates (V) in tubers than the genotype factor, which confirms the results provided by LACHMAN et al. (2005). Mineral nitrogen fertilization differentiated the content of nitrates (V) from 28.57 to 75.51 mg kg^{-1} (Table 4). This was a fairly low level of nitrates in tubers compared to the one shown elsewhere (ŻOŁNOWSKI 2013), which could have been explained by the fact that the experimental plots were set up on light soil, in the integrated production system, without the use of manure. In the dry years, the level of this component was 2-3 times higher than in the wet one. GRUDZIŃSKA and ZGÓRSKA (2008) confirmed that the dry and hot plant growing season favoured the accumulation of nitrates (V) in tubers. In relation to the genotype factor, the greatest differences were noted between the Bohun variety, with the significantly lowest content of nitrates (V) in tubers, and the Madeleine variety, with the highest accumulation of these compounds in tubers. The research showed the convergence of the nitrate (V) content in tubers with the level of protein and total nitrogen in relation to the analyzed factors (Table 4). In general, the experimental factors differentiated the protein content from 1.35% to 2.19%, while the total nitrogen content varied from 1.02% to 1.45%, and these values are comparable to those obtained in the previous research (TRAWCZYŃSKI, WIERZBICKA 2016). BURGOS et al. (2009) reported higher protein values in tubers, from 2.07 to 3.51%. This research also revealed a similar dry matter content in tubers as obtained previously, which depended on a genotype and fertilizing factor (WIERZBICKA, TRAWCZYŃSKI 2012).

CONCLUSIONS

1. Mineral nitrogen fertilization up to a dose of 150 kg ha^{-1} had a significantly positive effect on the share of large tubers (with a diameter above 60 mm) in the yield structure, the content of nitrates (V), protein, total nitrogen and the uptake of this component with the tuber yield.

2. The greatest differences between the varieties were demonstrated in relation to the yield structure, especially the share of tubers with a diameter above 60 mm and tubers with appearance defects, mainly deformed ones.

3. Based on the dependence of tuber yield on the level of mineral nitrogen fertilization, the optimal dose of mineral nitrogen for the tested varieties varied from 104 to 150 kg ha^{-1}.

4. Mineral nitrogen fertilization was the most important determinant of the total nitrogen content in tubers and its uptake with yield, while varieties determined dry matter and starch content in tubers, and weather conditions in the years determined the agronomic and physiological efficiency indicators of fertilization with nitrogen.

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