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ORIGINAL PAPER

INFLUENCE OF NITROGEN FERTILIZATION ON THE YIELD, QUALITY AND NITROGEN UTILIZATION EFFICIENCY OF EARLY POTATO TUBERS HARVESTED ON TWO DATES*

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Abstract

The aim of the research, conducted in 2012-2014, was to investigate the effect of mineral nitrogen on the total yield and quality of tubers of early varieties harvested 75 days after planting (DAP) and after tuber maturity, as well as to establish fertilization efficiency indices. Nitrogen utilization efficiency was expressed as agronomic efficiency (AE), physiological efficiency (PE) and fertilizer recovery efficiency (FRE) in tubers. Two experimental factors were researched: nitrogen level (0, 50, 100, 150, 200 kg ha^{-1}) and varieties (Altesse and Gwiazda), tested under different weather conditions. The total yield of fresh weight between the nitrogen doses ranged from 20.3 to 26.6 t ha^{-1} when harvested 75 days after planting, and from 31.9 to 45.9 t ha^{-1} when harvested after tuber maturity. Increasing nitrogen doses caused an increase in tuber yield, content of nitrates (V), nitrogen uptake (NUp), but led to a decrease in agronomic (AE) and physiological (PE) efficiency, fertilizer recovery efficiency (FRE) and starch content. The quadratic function parameters proved that the variety Gwiazda needed more nitrogen than the variety Altesse. Between the dates of the harvest, the largest differences were found in relation to the nitrogen uptake with tuber yield. On average for the both varieties, all doses and years, harvest of tubers after maturity resulted in higher AE (by 41 kg kg^{-1}), PE (by 2 kg kg^{-1}) and FRE (by 16%) than when tubers were harvested 75 DAP. The year 2013 was characterized by the highest reduction in the yield of tubers, nitrogen uptake, efficiency of fertilization and fertilizer recovery efficiency by the tested potato varieties on both harvest dates.

Keywords: fertilization indicators, harvest date, nitrogen doses, potato, quality, yield.

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INTRODUCTION

Production of early potatoes is an attractive option which is gaining more interest owing to its profitability and because it allows farmers to use the same fields for other crops in the same year (Nowacki 2012, Baranowska et al. 2017). Another advantage of this production trend is that potatoes can be sold during as well as after the season of their growth. Factors stimulating high yields of early potatoes grown under standard field production systems include: optimal nitrogen fertilization, proper selection of varieties, early planting time and seed germination (Arsenault et al. 2001, Love et al. 2005, Wierzbicka et al. 2008). Nitrogen is a key nutrient in plant production and its use greatly influences the yield and quality of various plant species, including potato (Kumar et al. 2007, Maltas et al. 2018). Inefficient use of nitrogen by plants aggravates surface and groundwater pollution (Milburn et al. 1997, Haverkort et al. 2003, Neeteson et al. 2004, Fotyma 2009, Kopiński 2017). The reason is the low recovery of nitrogen from the fertilizers used, which is even lower when the level of nitrogen fertilization increases (Vos 2009). The effectiveness of nitrogen utilization depends on the genetic traits of a variety, development phase of plants, size of their root system, and on the weather condition during the growing season (Zebarth et al. 2004, Swain et al. 2014). Potato is classified as a plant with high fertilizing requirements, but with low nitrogen utilization (Goffart et al. 2008). According to Vos (2009), fertilizer nitrogen recovery is 45%. In a Dutch experiment, the average nitrogen recovery fraction calculated for tuber yield produced under optimal nitrogen fertilization was 51% (Mackenzie, Taureau 2001). In Canada, nitrogen recovery for tubers ranged from 21 to 62% (Cambouris et al. 2008, Zebrath et al. 2012). In Polish research, nitrogen recovery by early potato cultivars harvested after maturity ranges from 45 to 50% at the lowest nitrogen dose, i.e. 50 kg ha^{-1}, and from 25 to 35% at the highest level of nitrogen fertilization, i.e. 200 kg ha^{-1} (Mazurczyk et al. 2005, Trawczyński, Wierzbicka 2014).

The aim of the research was to investigate the effects of nitrogen fertilization on the yield and quality of early varieties harvested 75 days after planting and after tuber maturity, as well as to establish fertilization efficiency indices.

MATERIAL AND METHODS

In controlled field experiments, carried out in 2012-2014 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:

   0, 50, 100, 150 kg ha^{-1} for harvest of potato tubers 75 days after planting (first harvest);

   0, 50, 100, 150, 200 kg ha^{-1} for harvest of potato after tuber maturity (second harvest);

2) potato varieties: Gwiazda (edible, universal type, Potato Breeding Zamarte, Poland) and Altesse (edible, salad type, Grocep, Station de Lavergne, France).

The experimental design was a split-plot randomized block in three replications. A plot consisted of four rows spaced 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 light soil classified to Order 5: Soils with clay translocation, Type: Luvisols/Alisols/Stagnosols, Subtype: Stagnic Luvisols (Marcinek et al. 2011). The soil was characterized by acid reaction, with high phosphorus content, and average content of mineral nitrogen, potassium and magnesium. The content of organic carbon in the soil was low (Table 1).

Table 1

Soil chemical properties in the years 2012-2014

Year	N mineral (kg ha^{-1})	C organic (%)	pH in KCl	Content in the soil (mg kg^{-1})*		
				P	K	Mg
2012	45	0.62	5.3	85	107	49
2013	45	0.55	6.0	87	124	48
2014	50	0.50	5.3	77	120	34

* available forms

The organic fertilisation in the study comprised cut winter triticale straw, incorporated into soil in an amount of 5 t ha^{-1}, and in autumn green matter of white mustard stubble intercrop in the amount of 15-16 t ha^{-1}. Mineral fertilisation of phosphorus and potassium was carried out in early spring at doses of 26.2 kg P ha^{-1} (triple superphosphate – 17.4% P) and 99.6 kg K ha^{-1} (potassium salt – 49.8% K). Nitrogen fertilization on plots with a dose of up to 100 kg ha^{-1} N was applied in spring before planting tubers, and on plots supplied doses of 150 and 200 kg ha^{-1} N a supplementary dose 50 and 100 kg ha^{-1} N was delivered just before the emergence of potato plants. Nitrogen was used in the form of ammonium nitrate (nitro-chalk – 27% N). Whole seed potatoes were sprouted in the plastic boxes for 5 weeks. Tubers were planted in the third ten days of April and harvested 75 DAP (the first ten days of July) and harvested after tuber maturity (the third ten days of August).

The weather conditions in the years of the research were determined on the basis of the sum of rainfall and average air temperatures in comparison with the long-term means. In 2012, there was no shortage of precipitation and it was fairly evenly distributed in particular months of plant growth, but the growing season was cooler than in the remaining years. In 2013, the early and late plant growing season was warmer and wetter than the long-term average. The year 2014 was moderately wet, dry in July, and it was the warmest of the analyzed years (Table 2).

Table 2

Weather conditions in the investigation years (the meteorological station in Jadwisin)

Year	Month					
	April	May	June	July	Aug	April-Aug
Sum of rainfalls (mm)						
2012	54.3	52.4	96.6	92.2	87.2	382.7
2013	51.1	130.0	105.4	17.1	97.7	401.3
2014	61.1	41.3	69.8	23.5	79.2	274.9
1967-2011	37.0	56.0	75.0	76.0	60.0	304.0
Mean air temperature (°C)						
2012	7.9	13.9	15.6	15.2	17.4	14.0
2013	6.3	15.7	17.2	18.7	18.2	15.2
2014	10.3	14.1	15.8	21.5	18.2	16.0
1967-2011	7.8	13.6	16.5	18.4	17.7	14.8

Weeds were removed mechanically (before the emergence of potato plants) and chemically (immediately before and after the emergence of potato plants). During the growing season, fungicide against potato blight was applied (once for potato tubers harvested 75 days after planting, and 4 times for potato harvested after tuber maturity). Insecticides were applied (once for the first harvest, and 3 times for the second harvest) in order to control the Colorado beetle.

During the harvest, the total yield of tubers from each plot was determined. Next, 5 kg of tubers were taken as a sample to determine the following chemical composition: 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 (PN-EN ISO 10520, 2002), 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 nitrate content (NO_3) was determined with the colorimetric method based on the Griess reaction, using a mixture of zinc and manganese with reduction of nitrates to nitrites, the dry matter content was assessed by a two-step drying method, and 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 function (1):

$$Y = a + bX + cX^2 \quad (1)$$

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 2:

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

Maximal tuber yield (Y_{max}) at X_{opt} was calculated according to equation 3:

$$Y_{max} = a - b^2/4c \quad (3)$$

Agronomic efficiency (AE) at X_{opt} was calculated according to equation 4:

$$AE\ X_{opt} = (Y_{max} - Y_0)/X_{opt}$$

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:

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

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

2. Agronomic nitrogen efficiency (AE, kg kg^{-1}) according to formula 5:

$$AE;\ (kg\ kg^{-1}) = [(Y_N - Y_0)\ /\ N_X] \quad (5)$$

As the ratio of difference (Y_N – tuber yield of fresh weight at fertilized plot and Y_0 – tuber yield of fresh weight at unfertilized plot and dose of N_X).

3. Physiological nitrogen efficiency (PE, kg kg^{-1}) according to formula 6:

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

As the ratio of difference (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 N_X minus NUp by tubers at N_0).

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

$$FRE;\ (\%) = [(N\ uptake\ by\ tubers\ at\ N_X - N\ uptake\ by\ tubers\ at\ N_0)\ /N_X]\ x100 \quad (7)$$

Nitrogen uptake with the tuber yield at fertilized plot (kg ha^{-1}) minus Nitrogen uptake with the tuber yield at 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. The variance analysis of the studied features (dependent variables) was carried out according to a nitrogen dose, variety and year (independent variables) separately for each harvesting date. At first harvest, there were 24 plots: 2 varieties x 4 nitrogen doses x 3 years x 3 replications (72 statistical data), and at second harvest, there were 30 plots: 2 varieties x 5 nitrogen doses x 3 years x 3 replications (90 statistical data). Comparisons of the means were carried out using the Tukey's test at $p = 0.05$. The effect of the factors demonstrated by the F – Fisher Snedecor's distribution was presented for all characteristics. Non-linear regression analysis of total yield depending on the nitrogen fertilization applied was used to determine the optimal nitrogen doses.

RESULTS AND DISCUSSION

Significant differences in the yield of tubers, starch and nitrates (V) content were found in relation to varieties, doses and years at each harvesting date. The total yield of fresh weight tubers harvested 75 days after planting (DAP) varied in the dose range of 0 - 150 kg N ha^{-1} from 20.3 to 26.6 t ha^{-1}, and at harvest after tuber maturity from 31.9 to 45.9 t ha^{-1} in the dose range of 0 - 200 kg N ha^{-1} (Table 3). The response of the tuber yield in relation to the increasing level of mineral fertilization with nitrogen was the confirmation of many studies carried out so far (Trawczyński 2004, Kumar et al. 2007, Fontes et al. 2010, Rens et al. 2016, Cohan et al. 2018). In the current research, the tuber yield growth trend was maintained up to the highest dose of mineral nitrogen applied. Statistically confirmed increase in tuber yield at the harvest 75 DAP was obtained for a 50 kg ha^{-1} nitrogen dose, whereas for a matured crop it was detected up to 100 kg N ha^{-1} (Table 3). Precise determination of the optimal level of mineral nitrogen fertilization enables one to analyze tuber yields depending on the dose of this component with the help of a square regression analysis (Trawczyński 2004, Giletto, Echeverría 2015, Cohan et al. 2018, Maltas et al. 2018). The study showed that the varieties were significantly different in demands of the optimal dose of mineral nitrogen (Figure 1). Optimum nitrogen doses for each variety were as follows: Altesse – 97 kg ha^{-1}, Gwiazda – 131 kg ha^{-1} for the first harvest and Altesse – 132 kg ha^{-1}, Gwiazda – 180 kg ha^{-1} for the second harvest, whereas tuber yields at these doses accounted for: 29.1, 25.5, 43.5 and 49.2 t ha^{-1}, respectively (Table 4). Large differences in the optimal nitrogen dose for varieties were demonstrated by Maltas et al. (2018) and Cohan et al. (2018). Optimal nitrogen doses in years ranged from 78 to 194 kg ha^{-1}, and the average for years in the case of Bintje and Laura varieties amounted to 94 and 155 kg N ha^{-1}, respectively (Maltas et al. 2018). In the research of Cohan et al. (2018), optimal nitrogen doses for the total yield of tubers ranged from 130 to 170 kg N ha^{-1} for the five varieties tested. Rens et al. (2018) determined the highest tuber yield following the application of nitrogen doses from 114 to 138 kg ha^{-1}.

Table 3

Tuber yield of fresh weight (FW), dry weight (DW), starch and nitrates (V) content

Treatment	Harvest 75 days after planting				Harvest after maturity			
	fresh weight (t ha^{-1})	dry weight (t ha^{-1})	starch (%)	NO_3^- (mg kg^{-1})	fresh weight (t ha^{-1})	dry weight (t ha^{-1})	starch (%)	NO_3^- (mg kg^{-1})
Altesse	26.9*a*	5.0*a*	12.8*a*	34.0*b*	39.7*b*	8.1*a*	14.1*a*	82.0*a*
Gwiazda	22.7*b*	3.8*b*	11.2*b*	54.0*a*	43.6*a*	8.3*a*	12.3*b*	86.0*a*
0	20.3*b*	3.6*b*	11.6*c*	16.0*d*	31.9*c*	6.0*c*	12.4*c*	52.0*d*
50	26.1*a*	4.7*a*	12.2*b*	36.0*c*	40.4*b*	7.9*b*	13.0*b*	63.0*c*
100	26.3*a*	4.7*a*	12.7*a*	59.0*b*	45.1*a*	8.7*a*	13.2*b*	73.0*c*
150	26.6*a*	4.7*a*	11.4*c*	79.0*a*	45.4*a*	8.8*a*	13.7*a*	117.0*b*
200					45.9*a*	8.9*a*	13.3*b*	135. *a*
2012	29.7*a*	5.1*a*	11.7*b*	44.0*a*	55.9*a*	11.1*a*	12.3*b*	62.0*c*
2013	20.8*b*	3.9*b*	11.1*c*	30.0*b*	32.9*c*	6.6*b*	13.8*a*	88.0*b*
2014	23.9*c*	4.2*b*	13.2*a*	50.0*a*	36.1*b*	6.9*b*	13.6*a*	103.0*a*
Mean	24.8	4.4	12.0	45.0	41.7	8.1	13.2	86.0
ANOVA results								
F variety	20.0	38.7	63.1	46.8	28.7	3.2	156.2	23.5
F dose	10.6	9.4	8.2	60.5	52.2	64.4	8.74	1583.4
F year	30.3	14.6	36.8	6.2	382.3	381.7	45.6	1259.5
P > *F* variety	0.0001	0.0001	0.0001	0.0001	0.0001	0.0802	0.0001	0.0901
P > *F* dose	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
P > *F* year	0.0001	0.0001	0.0001	0.0034	0.0001	0.0001	0.0001	0.0001
Significant variety	**	**	**	**	**	n.s.	**	n.s.
Significant dose	**	**	**	**	**	**	**	**
Significant year	**	**	**	*	**	**	**	**

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

In relation to the varieties, it was found that in the first date of harvest the variety Altesse was characterized by a significantly higher tuber yield than the variety Gwiazda, and the opposite dependence was obtained at the second date of harvest. This proved that the variety Altesse accumulated tubers faster than the variety Gwiazda, and was more predisposed to growing for the early harvest. Generally, the yield of fresh weight tubers obtained at the 75 DAP harvest was 16.9 t ha^{-1} and the dry weight was 3.7 t ha^{-1} lower, i.e. by 59.5 and 54.3%, respectively, as compared to the results obtained after tuber maturity. The year 2012, which was characterized by moderate air temperature, sufficient amount of rainfall and the most optimal distribution in individual months of potato plant vegetation, was

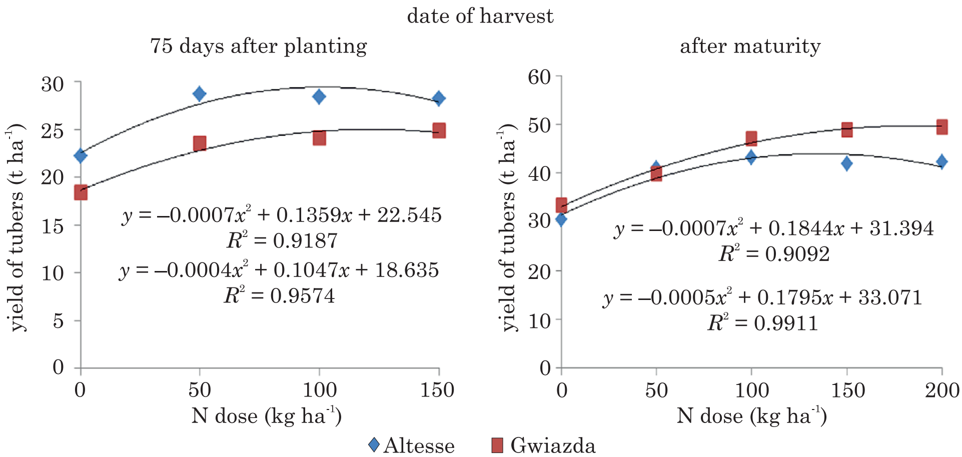

Fig. 1. Influence of nitrogen doses on total yield of potato varieties harvested 75 days after planting and after maturity

Table 4

Parameters of the quadratic model describing the relationship between tuber yield and nitrogen fertilization doses

Date of harvest	Variety	Ymax ($t\ ha^{-1}$)	Xopt ($kg\ ha^{-1}$)	AE Xopt ($kg\ kg^{-1}$)
75 day after planting	Altesse	29,1	97	68
	Gwiazda	25,5	131	52
After maturity	Altesse	43,5	132	92
	Gwiazda	49,2	180	90

the most favourable for high accumulation of tuber yield, both at the harvest 75 DAP and after maturity. On the other hand, the smallest yield of tubers was obtained in 2013, which could have been caused by excess of precipitation with respect to tubers were harvested 75 DAP, whereas when harvested after maturity, tubers had been affected by a very uneven distribution of precipitation. In 2013, the yield of fresh weight tubers (FW) decreased by 43% at the harvest of 75 DAP, and by 70% at the harvest after maturity, both compared to the year of 2012 (Table 3).

Among the basic quality features of the chemical composition of potato tubers, highly dependent on the genotype, fertilization and course of weather conditions during the growing season, there are starch and nitrates (V). The level of these components mainly determines the nutritional value of tubers (Lin et al. 2004). The study has shown that the variety Altesse was characterized by a significantly higher starch content than the variety Gwiazda, both at the first and second harvest date. Along with the increase in the nitrogen fertilization level, a significant increase in the starch content in tubers to a dose of 100 kg ha^{-1} at 75 DAP was found, and up to a dose of 150 kg ha^{-1} at the harvest after tuber maturity. Previous studies have confirmed the adverse impact on the content of starch in tubers of high doses of nitrogen (Öztürk et al. 2010). Indeed, in the first date of the harvest a set of weather conditions in 2014, when it was sufficiently moist and warm, had the most beneficial effect on the level of starch in tubers. Significantly the smallest starch content in tubers at the harvest 75 DAP was obtained in 2013, which could be attributed to excess rainfall in May and June. At the harvest after maturity of tubers, in 2013 and 2014 a significantly higher level of starch in tubers was obtained than in 2012. Previous studies have shown that a warm growing season promoted the accumulation of starch in tubers (Rymuza et al. 2015). On the basis of the research carried out so far, it was also confirmed that the main factor differentiating the starch content in tubers was weather conditions during the growing season, varietal differences decided less, and in the smallest extent the content of this component depended on the amount of nitrogen (Wierzbicka et al. 2008). Nitrogen fertilization, in turn, had the greatest impact on the level of nitrates (V) in tubers, which was also confirmed by the studies carried out so far (Lachman et al. 2005, Love et al. 2005). The dose of nitrogen fertilization affected the increase in nitrates (V) for 50, 100 and 150 kg N ha^{-1} by 20, 43 and 63 mg kg^{-1} in compare to control (object without of nitrogen) at the harvest 75 DAP and for 50, 100, 150 and 200 kg N ha^{-1} by 11, 21, 65 and 83 mg kg^{-1} in compare to control at the harvest after tuber maturity. The permissible amounts of 200 mg kg^{-1} fresh matter of tubers set by the Regulation of the Ministry of Health (Commision Regulation... 2005) were not exceeded. Other authors proved that nitrates (V) concentration are greater when fertilization exceeds nitrogen requirements to reach maximum tuber yield (Bélanger et al. 2001, 2002). The Gwiazda variety was characterized by a greater tendency to accumulate nitrates in tubers, but significant differences were proven only in relation to the harvest 75 DAP. Moreover, in the first harvest date, the content of nitrates (V) was lower than in tubers assessed after maturity, which was not confirmed by Grudzińska and Zgórska (2008). In addition to nitrogen fertilization, a highly significant impact of weather conditions during the plant growing season on the level of nitrates (V) in tubers was stated. The highest level of nitrates in tubers was found in 2014. Frydecka-Mazurczyk and Zgórska (2000) and Grudzińska and Zgórska (2008) confirmed that dry and warm growing season was conducive to the accumulation of nitrates (V) in tubers.

Nitrogen doses, genotype properties and weather conditions in those years had a significant impact on nitrogen uptake (NUp) and the fertilizer recovery efficiency (FRE). On average, the nitrogen uptake by tubers was twice as large at the second harvest date. The Altesse variety was characterized by significantly higher nitrogen uptake by the tubers at the harvest 75 DAP, but at the harvest after tuber maturity a significantly higher nitrogen uptake was found in the Gwiazda variety. The uptake of nitrogen increased gradually with increasing nitrogen fertilization doses, from 36 kg ha^{-1} in the unfertilized treatment to 65 kg ha^{-1} following the application of 150 kg N ha^{-1} at the first harvest date, and from 69 kg ha^{-1} in the unfertilized treatment to 142 kg ha^{-1} with the application of 200 kg N ha^{-1} in the second harvest date. The nitrogen uptake did not differ significantly between the doses of 100 and 150 kg N ha^{-1} at the harvest 75 DAP and after tuber maturity there was no difference in the N uptake induced by the doses 150 and 200 kg N ha^{-1}. Similar nitrogen uptake affected by increasing application doses has been proven by others (Haase et al. 2007, Jamaati-e-Somarin et al. 2009, Vos 2009). The weather conditions in the study years similarly influenced the uptake of nitrogen by tubers at harvest 75 DAP and after tuber maturity. The smallest uptake of nitrogen by tubers was obtained in 2013, when it was 25 kg ha^{-1} smaller (61%) at the harvest 75 DAP and by 63 kg ha^{-1} smaller (73%) at the harvest of matured tubers when compared to results obtained in 2012, a year characterized by the largest uptake of this component. The lowest uptake of nitrogen by tubers observed in 2013 year, with the highest rainfall in the growing season, could indicate that the nutrient was partially rinsed from the root zone to groundwater, which was emphasized in other studies (Errebhi et al. 1998, Vos, van der Putten 2000, Arriaga et al. 2009, Shrestha et al. 2010). Along with the increase in nitrogen doses, the growth of nitrogen uptake was noted, but at the same time its fertilizer recovery efficiency (FRE) by tubers decreased. This indicated a decreasing efficiency of the nutrient uptake from fertilizers applied to the soil, which was also documented in the literature (Vos 2009, Cohan et al. 2018, Maltas et al. 2018, Rens et al. 2018). In the range of fertilization 50 - 150 kg N ha^{-1}, the recovery efficiency of nitrogen at the first date of harvest ranged from 40 to 19%, and at the second in the range of fertilization doses of 50 - 200 kg N ha^{-1} it varied from 67 to 36%. The tested varieties differed in the recovery of nitrogen from fertilizers only significantly at the first harvesting date, with the Altesse variety being predisposed better. With regard to the recovery of nitrogen by tubers in relation to years of research, convergence has been demonstrated with the uptake of this component. In 2012, the year of the most favourable weather conditions, the recovery of nitrogen by tubers harvested at 75 DAP amounted to 35%, and at the second date of harvest it declined to 54%; in 2013, 16 and 25% were determined, respectively (Table 5). Zebarth and Rosen (2007) stated but fertilizer nitrogen recovery by tubers varied between 40 - 60%.

The yield and nitrogen uptake by the tubers shaped the size of fertilization efficiency indicators: agronomic (AE) and physiological (PE). At the first and second harvest dates, these parameters were significantly differentiated, mainly by a dose of nitrogen fertilization and the weather conditions in the study years. With the increase in the nitrogen dose from 50 to 150 kg N ha^{-1}, on the first harvest date, the agronomic efficiency of 1 kg nitrogen decreased from 117 to 42 kg of tubers (Table 5). However, with the optimal nitrogen dose at the first harvest date, agronomic efficiency was 68 kg of tubers for the Altesse variety and 52 kg of tubers for the Gwiazda variety (Table 4).

Table 5

Nitrogen uptake, NUp tubers (kg ha^{-1}), agronomic efficiency, AE (kg kg^{-1}), physiological efficiency, PE (kg kg^{-1}) and fertilizer recovery efficiency, FRE (%)

Treatment	Harvest 75 days after planting				Harvest after maturity			
	NUp	AE	PE	FRE	NUp	AE	PE	FRE
Altesse	58*a*	78*a*	54*a*	32*a*	111*b*	117*a*	49*a*	40*a*
Gwiazda	50*b*	68*a*	41*b*	24*b*	116*a*	108*a*	49*a*	39*a*
N0	36*c*				69*d*			
N50	56*b*	117*a*	55*a*	40*a*	102*c*	169*a*	58*a*	67*a*
N100	60*a*	59*b*	46*ba*	25*b*	121*b*	116*b*	52*a*	53*ba*
N150	65*a*	42*b*	38*b*	19*b*	134*ba*	89*cb*	43*b*	43*b*
N200					142*a*	75*c*	40*b*	36*c*
2012	66*a*	79*a*	63*a*	35*a*	149*a*	153*a*	52*a*	54*a*
2013	41*c*	45*b*	39*b*	16*b*	86*c*	60*c*	45*a*	25*c*
2014	56*b*	95*a*	40*b*	33*a*	105*b*	125*b*	50*a*	40*b*
Mean	54	72	47	28	113	113	49	44
ANOVA results								
F variety	41.6	1.6	13.7	12.8	4.4	1.1	0.1	0.2
F dose	106.1	32.1	7.8	10.1	103.2	23.4	11.8	40.4
F year	133.6	13.7	11.4	14.3	215.1	41.2	2.9	21.3
P > *F* variety	0.0001	0.2083	0.0001	0.0001	0.0398	0.3016	0.7356	0.6637
P > *F* dose	0.0001	0.0001	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001
P > *F* year	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0639	0.0001
Significant variety	**	n.s.	**	**	*	n.s.	n.s.	n.s.
Significant dose	**	**	*	**	**	**	**	**
Significant year	**	**	**	**	**	**	n.s.	**

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

At harvest, after maturity of tubers supplied nitrogen in the dose range of 50 - 200 kg N ha^{-1}, the agronomic efficiency ranged from 169 to 75 kg of tubers per 1 kg of nitrogen. In relation to the optimal nitrogen dose, the agronomic efficiency was 92 kg of tubers for the Altesse variety and 90 kg of tubers for the Gwiazda variety (Tables 4, 5). Smaller differences between doses were found in the mass of tubers obtained due to the uptake of nitrogen collected. The physiological efficiency at the harvest 75 DAP ranged from 55 to 38 kg, and at the harvest after maturity from 58 to 40 kg of dry matter tubers. Lower efficiency of nitrogen use in early maturing varieties compared to late maturing has been demonstrated by others (Zebarth et al. 2004, 2012). In 2013, with the highest amount of rainfall and the highest air temperature in May and June, at the harvest 75 DAP, significantly the lowest agronomic efficiency was obtained. In turn, in 2012, with approximately identical long-term means of precipitation but lower air temperature in May and June as compared to the other years, the significantly highest indicator of physiological efficiency of nitrogen was stated. At the harvest after tuber maturity, the highest indicator of agronomic efficiency was achieved in 2012. On the other hand, the physiological efficiency indicator was not significantly different between the years when tubers were harvested after maturity. The research emphasizes that the values of mineral nitrogen fertilization efficiency indicators are of key importance because, on the one hand, they allow one to determine the profitability of production, and on the other hand they help to determine the environmental effects of fertilization with this component (Davenport et al. 2005, Cambouris et al. 2008, Fontes et al. 2010, Maltas et al. 2018).

CONCLUSIONS

1. An increase of fertilization up to a dose of 150 kg N ha^{-1} (at the harvest 75 DAP) and 200 kg N ha^{-1} (at the harvest after tuber maturity) had a significantly negative effect on starch content and nitrogen fertilization efficiency indicators, while it had positive effect on the content of nitrates (V) and nitrogen uptake with tuber yield.

2. At the harvest after tuber maturity, from 4.3 to 109.3% higher values of the assessed indicators were obtained in relation to the harvest 75 days after planting.

3. The tested varieties differed significantly in the obtained tuber yield, starch content and nitrogen uptake at both harvesting dates, while the recovery efficiency of nitrogen by tubers only when harvested 75 days after planting. The variety of Gwiazda was characterized by greater requirements in relation to the optimal nitrogen dose than the variety of Altesse.

4. 4. The vegetation period, with the most uneven distribution of precipitation (2013) was characterized by the highest reduction the yield of tubers, nitrogen uptake, efficiency fertilization and recovery of nitrogen by the tested potato varieties in both harvest dates.

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