AGRONOMY SCIENCE
wcześniej – formerly
Annales UMCS sectio E Agricultura

VOL. LXXIX (2) 2024

https://doi.org/10.24326/as.2024.5318

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Morphological and agronomic features of potato cv. Gardena highly resistant to *Phytophthora infestans* (Mont.) de Bary depending on the nitrogen dose

Cechy morfologiczne i agronomiczne ziemniaka odmiany Gardena wysokoodpornej na *Phytophthora infestans* (Mont.) de Bary w zależności od dawki azotu

Abstract. In a 2-year field study, the impact of mineral nitrogen fertilization on the productivity of a new potato cultivar, promising due to the highest resistance to potato late blight among the registered ones, was compared to the proven, widely cultivated Denar cultivar. The study determined morphological features (size and weight of organs), physiological indicators (cover of soil by leaves – LAI. leaf greenness – SPAD) of potato plants during the growing season, yield and quality

Citation: Trawczyński C., Szczepanek M., Boguszewska-Mańkowska D., Pietraszko M., Wszelaczyńska E., Pobereżny J., Gościnna K., Tomaszewska-Sowa M., Lemańczyk G., Lisiecki K., 2024. Morphological and agronomic features of potato cv. Gardena highly resistant to *Phytophthora infestans* (Mont.) de Bary depending on the nitrogen dose. Agron. Sci. 79(2), 35–49. https://doi.org/10.24326/as.2024.5318

characteristics of tubers and optimal level of nitrogen fertilization. Tuber quality was assessed based on the share of tuber size and external defects in the yield structure. Optimal mineral nitrogen fertilization was determined based on the relationship between the increase in tuber yield and the increasing dose of this ingredient. The research took into account two factors: nitrogen dose (0, 50 kg·ha^{-1}, 100 kg·ha^{-1}, 150 kg·ha–1) and cultivar (Gardena and Denar). The increase in the dose of mineral nitrogen fertilization to 150 kg·ha^{-1} resulted in a significant increase in plant height, the weight of the root system, stems, leaves and the share of large tubers in the yield. It was shown that the Gardena cultivar was characterized by greater requirements for mineral nitrogen fertilization, low effectiveness of its use, a higher share of large tubers (diameter above 60 mm) and lower tuber yield than the Denar cultivar. In a year characterized by excess rainfall, plants produced a greater mass of the root system and the mass of the above-ground part, and in a year with an amount of rainfall close to optimal the final yield of tubers and the share of large tubers in the yield were higher.

Keywords: mineral nitrogen, plants features, tuber quality, yield, cultivar, potato

INTRODUCTION

In potato cultivation, a species with high biomass productivity fertilization is one of the main elements of agrotechnics that determines the yield and quality of tubers [Muleta and Aga 2019]. Among the fertilizer ingredients, nitrogen plays the most important role [Maltas et al. 2018], therefore the use of an appropriate dose of mineral nitrogen is of key importance in the development of potato plants [Kumar et al. 2017]. Ultimately, this translates not only into the yield, but also into the nutritional value of the tubers, which among vegetables constitute the largest share in the human diet [Hmelak Gorenjak and Cencič 2013, Pobereżny et al. 2015]. Both over-fertilization with mineral nitrogen and its deficiency cause certain unfavorable consequences for the environment and economic for the producer [Fontes et al. 2010, Giletto and Echeverría 2015]. Inefficient use of nitrogen by plants on the one hand burdens the environment by leaching nitrates into groundwater [Clément et al. 2021]. On the other hand, by reducing the efficiency, i.e. the mass of tubers obtained from a unit of nitrogen used, it may contribute to the increase in production costs, reducing the profit from cultivation [Fontes et al. 2010, Baranowska et al. 2017, Ierna and Mauromicale 2019]. The effectiveness of nitrogen use depends, among others, on the genetic features of the cultivar, which may include the morphological structure of individual organs, the above-ground mass of the plant, as well as the size of the root system, which may additionally be shaped to varying degrees by the weather conditions during the growing season [Swain et al. 2014].

Many years of research on the optimization of mineral nitrogen fertilization have proven significant cultivar diversity of potatoes. Therefore, the selection of varieties may also affect the production efficiency of the nitrogen used [Cohan et al. 2018]. This is important and requires specific arrangements especially in relation to varieties that bring new desirable agronomic features. One such cultivar is Gardena, which among the registered potato varieties has the highest, genetically determined resistance to the fungus *Phytophthora infestans*, the cause of the most dangerous disease of this species, i.e. late blight. Identification of new varieties compared to those proven in cultivation by assessing plant growth during the vegetation period and the quality characteristics of tubers after harvest allows determining their requirements and production suitability [Fontes et al. 2010, Rens et al. 2018]. The aim of the study was to assess morphological and physiological features, yield and tuber quality, as well as the effectiveness of mineral nitrogen fertilization of cv. Gardena compared to cv. Denar common in cultivation, under different doses of mineral nitrogen fertilization.

MATERIALS AND METHODS

Field experiments were carried out in 2020–2021 at the Institute of Plant Breeding and Acclimatization, National Research Institute, Jadwisin Branch (52°47'N, 21°04'E) on Podzolic soil with the particle size composition of light loamy sand, good rye complex, soil valuation class V [IUSS Working Group WRB 2014]. The soil was acidic and had high level in available phosphorus, medium in potassium, manganese, zinc, copper and low in magnesium, iron and boron. The level of organic carbon in the soil was low (Tab. 1).

Table 1. Soil chemical properties (layer of 0–20 cm) before planting of experiment

Years	C organic (g kg^{-1})	pH in KCl	Content in the soil (mg·kg^{-1})*							
			P	K	Mg	Mn	Cu	Zn	B	Fe
2020	9.2	5.0	196	130	27	108	4.0	4.5	0.5	544
2021	7.7	5.0	194	115	22	88	2.5	3.5	0.5	568

* available forms

In a strict field experiment, two factors were analyzed: the dose of mineral nitrogen fertilization: 0, 50 kg·ha^{-1}, 100 kg·ha^{-1}, 150 kg·ha^{-1} and the potato cultivar: Gardena, Denar. The research was carried out in a randomized sub-block design, in three repetitions. The spacing of plants between rows was 0.75 m and within a row 0.33 m. The plot area was 7.5 m^2 and the number of plants in the plot was 30.

Organic fertilization was used as chopped straw, plowed in after harvesting winter triticale, at a dose of 5 t·ha^{-1} which was a forecrop before white mustard grown as a catch crop, plowed in autumn at a dose of 15–16 t·ha^{-1}. Mineral fertilization with phosphorus and potassium was applied 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). Mineral nitrogen fertilization in the objects with 50 and 100 kg N·ha^{-1} was applied in one dose in spring before planting tubers. In the objects with a dose of 150 kg N·ha^{-1}, the following division was applied: before planting 100 kg N·ha^{-1} and a supplementary dose of 50 kg N·ha^{-1} immediately before the emergence of potato plants, before the last dressing. Nitrogen was used in the form of ammonium nitrate (nitro-chalk – 27% N). The tubers were planted in the third decade of April and harvested after reaching full maturity (third decade of September).

Weather conditions in the years of research were determined on the basis of the sum of precipitation and average air temperatures compared to long-term averages and the Sielianinow's hydrothermal coefficient. The years of research in terms of weather conditions varied significantly. During the growing season of 2020, there was a shortage of rainfall in April and May, and the air temperature in April was close to the multi-year average, while in May it was relatively colder. In June, rainfall exceeded the multi-year total by 38.8 mm. In July, there was a shortage of rainfall in conditions of moderate air temperatures. August saw excess rainfall, while September was moderately humid and quite warm. Based on the Sielianinow's hydrothermal coefficient, 2020 was an optimal year, although rainfall exceeded the multi-year total by 31.2 mm, and the average air temperature was 1°C higher than the multi-year average. In 2021, in April there was a slight excess of rainfall, which intensified in May. The excess rainfall continued in the following months: June, July and August. Only in September there was less rainfall (by 10.5 mm) compared to the multi-year total. The air temperature in April and May remained below the multi-year average and in June and July it was over 3°C higher. In turn, in the months of August and September it was close to the multi-year average. During the entire growing season, rainfall was 134.6 mm higher than the multi-year total, and the air temperature was 0.8°C higher than the multi-year average. The growing season in 2021 was quite wet according to the Sielianinow's coefficient (Tab. 2).

Table 2. Weather conditions in the investigation years (Meteorological Station in Jadwisin)

Year	Month						
	IV	V	VI	VII	VIII	IX	Sum/Mean
sum of rainfall (mm)							
2020	5.6	65.3	113.8	40.4	120.7	51.8	397.6
2021	37.8	69.5	97.2	124.2	120.4	37.5	486.6
2000–2019	37.0	57.0	75.0	76.0	61.0	48.0	351.0
mean air temperature (°C)							
2020	8.8	11.6	18.7	19.0	20.1	15.5	14.8
2021	6.9	12.7	20.1	21.9	17.2	13.5	15.4
2000–2019	8.1	13.7	16.8	18.6	18.1	13.3	14.7
Sielianinow's hydrothermic coefficients (k)*							
2020	0.21	1.81	2.03	0.68	1.93	1.11	1.30
2021	1.83	1.76	1.61	1.82	2.26	0.92	1.70

* The value of the Sielianinov's coefficient [Skowera 2014]: extremely dry $k \le 0.4$, very dry $0.4 < k \le 0.7$, dry $0.7 < k \le 1.0$, rather dry $1.0 < k \le 1.3$, optimal $1.3 < k \le 1.6$, rather humid $1.6 < k \le 2.0$, humid $2.0 < k \le 2.5$, very humid $2.5 < k \le 3.0$, extremely humid $k > 3.0$

Weeds were destroyed mechanically by dimming twice before the emergence of potato plants and chemically using one herbicide treatment before emergence: Proman 500 SC (metobromuron) at a dose of 4 $dm^3 \cdot ha^{-1}$ and the second one after emergence of potato plants: Titus 25 WG (rimsulfuron) at a dose of 60 $g \cdot ha^{-1}$ + Trend 90 EC at a dose of 0.1 $dm^3 \cdot ha^{-1}$ (BBCH 15). In each year, fungicides against potato blight were used four times: Ridomil Gold 67.8 WG – metalaksyl + mancozeb (2.5 $kg \cdot ha^{-1}$), Carial Star 500 SC – mandipropamid + difenokonazol (0.6 $dm^3 \cdot ha^{-1}$), Acrobat MZ 69 WG – dimetomorf + + mankozeb (2 $kg \cdot ha^{-1}$), Infinito 687.5 SC – chlorowodorek propamokarbu (1.5 $dm^3 \cdot ha^{-1}$), Revus 250 SC – mandipropamid (0.6 $dm^3 \cdot ha^{-1}$) and 3 times insecticides against Colorado potato beetle: Nuprid 200 SC – imidachlopryd (0.15 $dm^3 \cdot ha^{-1}$), Calipso 480 SC – tiachlopryd (0.10 $dm^3 \cdot ha^{-1}$), Spintor 240 SC – spinosad (0.15 $dm^3 \cdot ha^{-1}$), Coragen 200 SC – chlorantraniliprol (0.60 $dm^3 \cdot ha^{-1}$).

Each year, in the flowering phase (BBCH 65) the morphological features and the physiological indicators of potato plants were assessed. The measurement included: plant height (cm), leaf area ($cm^2 \cdot plant^{-1}$), number of stems and tubers ($No. \cdot plant^{-1}$) and the weight of individual organs: roots, tubers, leaves and stems (fresh weight $plant^{-1}$). One plant from each plot was taken for measurement (3 plants from each treatment). The leaf area index (LAI) as leaf area in relation to the soil surface was measured using the LI-3000A device (LI-COR. USA). The SPAD (Soil Plant Analysis Development) index was measured using a N Tester (Minolta-502). It measures the differences between the absorption of light passing through a leaf at a wavelength of 650 nm (maximum absorption of light by chlorophylls a and b) and 940 nm (light retained by the leaf tissue). The quotient of these differences is the leaf greenness index, considered as an indicator of the relative chlorophyll content. The study was based on 10 measurements in each plot (30 measurements on each treatment). Measurements were taken on the third or fourth fully developed leaf from the top of the plant.

Immediately after harvest, the total yield of tubers from each plot was determined and 5-kilogram samples were taken to determine the structure of the yield (weight fraction of small tubers with a diameter below 35 mm, medium tubers from 36 mm to 60 mm in diameter and large tubers with a diameter above 60 mm) and share in the yield of tubers with external defects: deformed, green, infected with common scab [Roztropowicz 1999].

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

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

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:

$$X_{opt} = -b/2c$$

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

$$Y_{max} = a - b^2/4c \text{ and } Y_{max} = b \text{ x } X_{max} + a$$

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

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

Formulas for calculating parameters were taken from Vos [2009].

The results of the experiments were analyzed statistically by ANOVA Statistica 13.3. The variance analysis of the studied features (dependent variables) was carried out according to a nitrogen dose, cultivar and year (independent variables). Regression analysis was used to determine the nitrogen demand of varieties. The mean comparison analysis was performed using the Tukey test at $p = 0.05$ [TIBCO Statistica].

RESULTS AND DISCUSSION

The research showed that the experimental factors have a significant influence on morphological features and the physiological indicators of potato plants, which also had a significant impact on the tuber yield and it's quality. As the dose of mineral nitrogen fertilization was increased, taller plants were obtained. Significantly taller plants were found at dose of 100 and 150 kg N·ha^{-1}, as compared to the control (without N fertilization). In the treatment without the use of mineral nitrogen, a significantly smaller leaf area per plant was obtained compared to the treatments fertilized with this nutrient. Cv. Gardena was significantly taller than cv. Denar. The Gardena was also characterized by a significantly larger leaf area than Denar. Overall, in 2021, which was characterized by excessive rainfall, plants were significantly higher than in 2020 (Tab. 3).

Table 3. The value of parameters characterizing the size of potato plant organs in relation to dose of nitrogen and cultivar

Cultivar	N dose (kg·ha^{-1})	Tubers (No.·plant^{-1})	Stems (No.·plant^{-1})	Plant height (cm)	Leave area (cm^2·plant^{-1})
Gardena	0	14.10 ^{a}	9.50 ^{a}	58.66 ^{b}	4786 ^{ab}
	50	13.10 ^{a}	6.83 ^{a}	70.33 ^{ab}	6518 ^{ab}
	100	12.10 ^{a}	8.66 ^{a}	84.83 ^{a}	7699 ^{a}
	150	14.10 ^{a}	9.50 ^{a}	82.00 ^{ab}	7874 ^{a}
Denar	0	18.50 ^{a}	7.50 ^{a}	44.00 ^{c}	2827 ^{b}
	50	22.80 ^{a}	7.00 ^{a}	59.50 ^{abc}	4766 ^{ab}
	100	19.80 ^{a}	8.00 ^{a}	69.16 ^{abc}	5476 ^{ab}
	150	19.18 ^{a}	8.33 ^{a}	77.50 ^{ab}	4691 ^{ab}
Mean for N doses	0	16.33 ^{A}	8.50 ^{A}	51.33 ^{B}	3807 ^{B}
	50	18.00 ^{A}	6.91 ^{A}	64.91 ^{AB}	5728 ^{A}
	100	16.00 ^{A}	8.33 ^{A}	77.00 ^{A}	5763 ^{A}
	150	16.91 ^{A}	8.91 ^{A}	79.75 ^{A}	5594 ^{A}
Mean for cultivars	Gardena	13.40 ^{B}	8.62 ^{A}	73.95 ^{A}	6006 ^{A}
	Denar	20.20 ^{A}	7.70 ^{A}	62.54 ^{B}	4440 ^{B}
Mean for years	2020	15.83 ^{A}	8.50 ^{A}	54.66 ^{B}	5770 ^{A}
	2021	17.79 ^{A}	7.83 ^{A}	81.83 ^{A}	5389 ^{A}

a, b – for interaction cultivar × dose of nitrogen; A, B, C – for average values.
Mean values indicated by the same letters are not statistically significant at the 0.05 level, according to Tukey's test.

Increasing nitrogen doses varied the weight of potato plant organs more than their size. The highest root mass was obtained after using of 150 kg N·ha^{-1}, and the smallest one in the treatment without N fertilization. Similarly the significantly highest mass of roots, stems and leaves per plant was obtained in the treatment with a dose of 150 kg N·ha^{-1}, and the lowest mass of these organs was recorded in control treatment. The Gardena was characterized by a significantly higher weight of roots, stems and leaves, while Denar has significantly higher weight of tubers per plant (Tab. 4). A large variability of morphological features related to the mass of the above-ground part (leaves, stems) and the mass of the root system of potato plants shaped under the influence of the genetic properties of varieties was demonstrated by Demirel et al. [2017].

Table 4. The value of parameters characterizing the fresh mass of potato plant organs in relation to dose of nitrogen and cultivar

Cultivar	N dose (kg·ha^{-1})	Roots (g·plant^{-1})	Tubers (g·plant^{-1})	Steams (g·plant^{-1})	Leaves (g·plant^{-1})
Gardena	0	83.00 ^{b}	434.3 ^{ab}	216.0 ^{c}	330.0 ^{cd}
	50	86.00 ^{b}	438.3 ^{ab}	273.6 ^{bc}	496.3 ^{bc}
	100	114.0 ^{ab}	412.0 ^{b}	454.0 ^{ab}	643.6 ^{ab}
	150	138.0 ^{a}	507.6 ^{ab}	540.0 ^{a}	753.0 ^{a}
Denar	0	71.00 ^{b}	606.6 ^{ab}	80.33 ^{c}	187.0 ^{d}
	50	76.66 ^{b}	741.3 ^{a}	127.3 ^{c}	237.3 ^{d}
	100	99.00 ^{ab}	711.0 ^{ab}	267.6 ^{bc}	370.3 ^{cd}
	150	82.33 ^{b}	680.6 ^{ab}	257.6 ^{bc}	391.0 ^{cd}
Mean for N doses	0	77.00 ^{C}	520.5 ^{A}	148.1 ^{B}	258.5 ^{B}
	50	81.33 ^{BC}	589.8 ^{A}	200.5 ^{B}	341.8 ^{B}
	100	106.5 ^{AB}	581.5 ^{A}	360.8 ^{A}	473.6 ^{A}
	150	110.1 ^{A}	594.1 ^{A}	399.0 ^{A}	547.0 ^{A}
Mean for cultivars	Gardena	105.2 ^{A}	448.0 ^{B}	371.0 ^{A}	514.0 ^{A}
	Denar	82.25 ^{B}	684.9 ^{A}	183.2 ^{B}	296.4 ^{B}
Mean for years	2020	83.91 ^{B}	328.91 ^{B}	282.1 ^{A}	451.4 ^{A}
	2021	103.58 ^{A}	804.08 ^{A}	272.0 ^{A}	400.7 ^{A}

Explanation as in Tab. 3

The weight of plant organs was also influenced by years of research. In 2021, a significantly higher mass of roots and tubers was obtained than in 2020 (Tab. 4). The dependence of the increase in the yield of tubers on the development of morphological organs and physiological indicators of potato plants depending on weather conditions has been demonstrated in studies by Rozentsvet et al. [2021] and Tehulie and Misgan [2019]. Based on the analysis of 24 varieties differing in earliness groups, an increase in the yield of tubers was shown by an increase in plant height, number of stems and leaf area, and a decrease in yield with an increase in air temperature and a decrease in soil moisture, which in early varieties amounted to 13%, and for medium-early and medium-late ones accounted to 32%–43% [Rozentsvet et al. 2021]. Significant changes in morphological, biochemical characteristics and physiological indicators assessed during the growing season, correlated with potato tuber productivity, have been confirmed in other studies [Hancock et al. 2014, Mahgoub et al. 2015, Demirel et al. 2017, Escuredo et al. 2020]. From the research of Escuredo et al. [2020] and Rozentsveta et al. [2021] showed that weather conditions are responsible for up to 80% of the variability of morphological features. Among the physiological features, the experimental factors significantly differentiated both LAI and SPAD. The LAI ranged from 1.52 for the treatment without N fertilization to an average of 2.23 in the range of 50 – 150 kg N·ha^{-1} and these were statistically proven differences. Due to the increase in the dose of N fertilization, a gradual, significant increase in the value of SPAD was recorded. LAI was significantly higher, but SPAD was lower in Gardena than in Denar. The analysis in relation to study years showed significant differences only in SPAD. A significantly higher SPAD value was obtained in 2020 (with less rainfall) than in 2021 (Tab. 5).

Table 5. The value of parameters characterizing the physiological indicators of potato plants in relation to dose of nitrogen and cultivar

Cultivar	N dose ($kg \cdot ha^{-1}$)	LAI	SPAD
Gardena	0	1.91 ab	29.57 c
	50	2.60 ab	33.72 b
	100	3.07 a	36.67 a
	150	3.14 a	37.94 a
Denar	0	1.13 b	30.96 c
	50	1.90 ab	34.34 b
	100	2.19 ab	37.23 a
	150	1.87 ab	38.15 a
Mean for N doses	0	1.52 B	30.26 D
	50	2.29 A	34.03 C
	100	2.30 A	36.95 B
	150	2.23 A	38.04 A
Mean for cultivars	Gardena	2.40 A	34.47 B
	Denar	1.77 B	35.17 A
Mean for years	2020	2.30 A	37.70 A
	2021	2.15 A	31.94 B

Explanation as in Tab. 3

In the study by Bărăscu et al. [2016], the average values of SPAD were much higher than those obtained in our own research and were on average 44.7. A smaller SPAD was obtained in a wet year, which confirmed the current research. The lower value of SPAD index in a wet year than in a year with moderate rainfall could be related to the washing out of some of the mineral nitrogen, especially the nitrate form, which is more labile in the soil. Our research, similarly to Bărăscu et al. [2016] showed differences in the SPAD index in relation to varieties. Although differences between cultivars were smaller than in the study by Bărăscu et al. [2016], however, this has been statistically proven. The morphological characteristics of plants, especially the aboveground mass and SPAD index correlated with the years of study and in relation to varieties were demonstrated in studies by Dahal et al. [2019]. Plant height and leaf area, higher in optimal wet conditions, and lower due to high temperature and drought, were confirmed in the study by Boguszewska-Mańkowska et al. [2022] and Escuredo et al. [2020]. A significant impact of the dose of mineral nitrogen fertilization, up to 200 $kg \cdot ha^{-1}$, on the morphological characteristics of potato plants and LAI and SPAD, and consequently an increase in the yield of tubers, was confirmed by Rykaczewska [2005a, 2005b]. In other studies on various potato varieties, using the SPAD-502 meter, critical values of plant nitrogen nutrition were found, ranging from 40 to 45 SPAD units [Gianquinto et al. 2004], which is similar to those obtained in research by Trawczyński [2019]. However, in the current study, SPAD values were much lower and amounted to an average of 35 units. This could be due to the fact that in both years of the current research, rainfall was recorded significantly above the long-term average. Research by Rykaczewska [2005a] in the range of nitrogen fertilization from 0 to 200 $kg\ N \cdot ha^{-1}$ showed SPAD values ranging from 30 to 50 units.

Under the influence of the N fertilization dose, in relation to the varieties and in the years of study, significant differences in tuber yield after harvest were obtained (Tab. 6). On average for the varieties, a significant increase in tuber yield was observed up to 100 $kg\ N \cdot ha^{-1}$, which amounted to 43.46 $t \cdot ha^{-1}$. Under the influence of a dose of 150 $kg\ N \cdot ha^{-1}$, a decreasing tendency was noted in the tuber yield level compared to the dose of 100 $kg\ N \cdot ha^{-1}$.

Table 6. The value of parameters characterizing the tubers yield and structure in relation to dose of nitrogen and cultivar

Cultivar	N dose ($kg \cdot ha^{-1}$)	Tubers yield ($t \cdot ha^{-1}$)	Share of small tubers (%)	Share of middle tubers (%)	Share of large tubers (%)
Gardena	0	29.06^{e}	0.98^{c}	77.31^{ab}	21.71^{ab}
	50	31.25^{de}	3.66^{ab}	73.10^{ab}	23.24^{ab}
	100	37.97^{c}	1.74^{bc}	63.70^{b}	34.56^{a}
	150	37.27^{cd}	1.08^{bc}	64.73^{b}	34.19^{a}
Denar	0	33.06^{de}	5.49^{a}	80.95^{a}	13.56^{b}
	50	40.28^{b}	3.16^{b}	77.00^{ab}	19.84^{b}
	100	48.95^{a}	1.64^{bc}	71.96^{ab}	26.40^{ab}
	150	44.00^{ab}	2.57^{bc}	74.16^{ab}	23.27^{ab}
Mean for N doses	0	31.06^{C}	3.23^{B}	79.13^{A}	17.63^{C}
	50	35.77^{B}	3.41^{A}	75.05^{B}	21.53^{B}
	100	43.46^{A}	1.69^{C}	67.83^{C}	28.71^{A}
	150	40.63^{A}	1.83^{C}	69.45^{C}	30.47^{A}
Mean for cultivars	Gardena	33.89^{B}	1.86^{B}	69.71_{B}	28.41^{A}
	Denar	41.57^{A}	3.22^{A}	76.02^{A}	20.75^{B}
Mean for years	2020	40.40^{A}	0.29^{B}	66.25^{B}	33.44^{A}
	2021	35.42^{B}	4.79^{A}	79.47^{A}	15.71^{B}

Explanation as in Tab. 3

Determining the relationship between tuber yield and the increasing dose of mineral N fertilization made it possible to precisely determine the dose of mineral nitrogen for varieties, which was confirmed by other researchers [Vos 2009, Venkatasalam et al. 2019]. The research showed that the varieties differed in the response of tuber yield to increasing dose of N fertilization. In cv. Denar, a 2° polynomial relationship was found, and the optimal dose of mineral nitrogen (X_{opt}) was 111 $kg \cdot ha^{-1}$, the tuber yield at this dose (Ymax) was 47.0 $t \cdot ha^{-1}$ and the agronomic efficiency of nitrogen (AE) was 133 kg of tubers per 1 kg of N (Fig. 1).

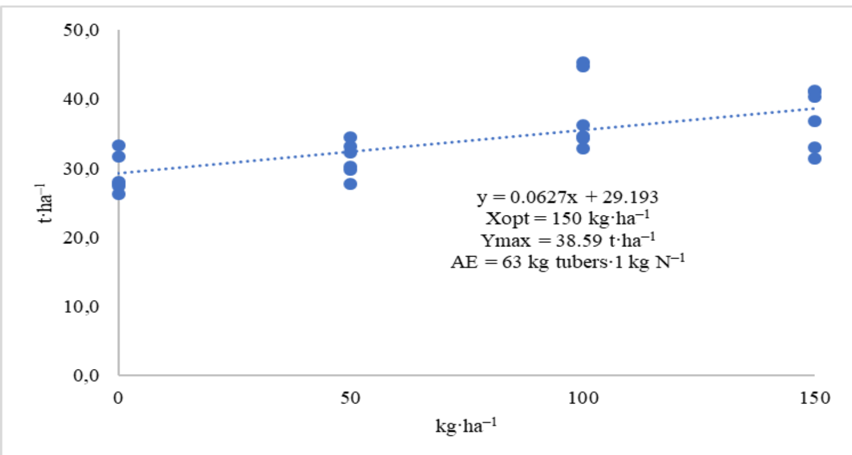

Fig. 1. Dependence of the tuber yield of cv. Gardena on the dose of N fertilization

In turn, cv. Gardena was characterized by a linear increase in tuber yield in relation to the applied level of mineral nitrogen, hence the dose (X_{opt}) was 150 kg N·ha^{-1}, and the yield (Y_{max}) at this dose was 38.59 t·ha^{-1}, while the agronomic efficiency (AE) was 63 kg of tubers per 1 kg of N (Fig. 2). Previous research showed an increase in tuber yield up to a specific dose level and then a gradual decrease in yield, but also in some varieties an increase in tuber yield up to the highest applied nitrogen dose of 150 kg·ha^{-1} was noted [Trawczyński 2021]. The varied response of tuber yield in relation to mineral nitrogen fertilization of varieties was confirmed by many studies conducted so far [Fontes et al. 2010, Giletto and Echeverría 2015, Rens et al. 2016, Cohan et al. 2018, Lombardo et al. 2020]. Inresearch conducted by Trawczyński [2020] the optimal doses of N for varieties with different earliness ranged from 100 to 140 kg·ha^{-1}. A similar range of doses was found in the studies by Rens et al. [2018]. However, greater variation in relation to the optimal N dose for varieties, from 94 to 170 kg N·ha^{-1}, was demonstrated by Maltas et al. [2018] and Cohan et al. [2018]. In our research, higher values of morphological characteristics of individual plant organs (roots, leaves, stems) did not translate into a higher weight of the final tuber yield compared to the tested varieties. In cv. Denar, which was characterized by lower weight of individual organs, a significantly higher tuber yield was obtained than in cv. Gardena. Moreover, in the optimal year in relation to the Sielianinow's coefficient 2020, a significantly higher tuber yield was obtained than in 2021.

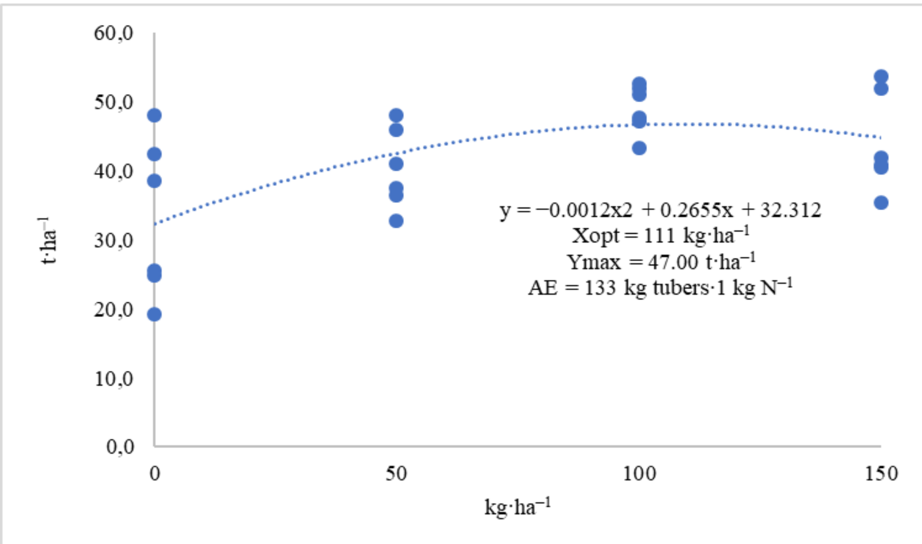

Fig. 2. Dependence of the tuber yield of cv. Denar on the dose of N fertilization

The quality of potato tubers in the study included the yield structure and the share of tubers with external defects in the yield. With the increase in a dose of mineral N fertilization, a significant decrease in the share of small tubers in the yield was found and medium-sized tubers. An opposite tendency was observed in relation to the share of large tubers. The significantly lowest share of large tubers in yield was obtained in the treatment without the N fertilization, and with the increase in the N dose, a significant increase in tubers of this fraction was obtained (Tab. 6). An increase in the share of tubers with a diameter above 60 mm in the yield structure in the dose range 0–180 kg N·ha^{-1} from 58 to 74% was achieved by Kołodziejczyk [2014]. In cv. Denar a significantly higher share of small and medium-sized tubers in the yield was found compared to cv. Gardena. In turn, the share of large tubers in the yield of Gardena was higher than that of the Denar. Moreover, in a moderately wet year, a significantly higher share of large tubers in the yield was obtained, and in a year with a significant excess of rainfall, more small and medium-sized tubers were noted (Tab. 6).

Previous studies, in addition to mineral fertilization, also showed significant differences in the yield structure in relation to the genotype and weather conditions over the years. The smaller share in the structure of large tubers in favor of medium-sized tubers resulted, among others, from their specific purpose and direction of production, and the greater share in the yield of large tubers was related to favorable weather conditions, mainly sufficient rainfall during the plant vegetation period [Trawczyński 2020]. Similar relationships regarding the influence of weather conditions on the structure of tuber yield were confirmed by Badr et al. [2012] and Kołodziejczyk [2014]. The experimental factors had a smaller impact on the share of tubers with external defects in the yield than on the yield structure. Significant differences only related to the higher share of deformed and green tubers in the yield of cv. Gardena than in cv. Denar (Tab. 7).

Table 7. The value of parameters characterizing the external defects of tubers in relation to dose of nitrogen and cultivar (percentage of weight)

Cultivar	N dose (kg·ha^{-1})	Deformations	Greenings	Common scab	Sum of defects
Gardena	0	5.29 ^{ab}	4.80 ^{a}	0.00 ^{a}	10.09 ^{ab}
	50	4.88 ^{ab}	4.25 ^{a}	0.00 ^{a}	9.13 ^{ab}
	100	6.30 ^{a}	5.07 ^{a}	0.00 ^{a}	11.37 ^{a}
	150	5.13 ^{ab}	5.34 ^{a}	0.00 ^{a}	10.47 ^{ab}
Denar	0	2.35 ^{b}	3.19 ^{a}	0.00 ^{a}	5.54 ^{ab}
	50	3.30 ^{ab}	2.93 ^{a}	0.00 ^{a}	6.23 ^{ab}
	100	2.42 ^{b}	1.83 ^{a}	0.46 ^{a}	4.71 ^{b}
	150	2.85 ^{ab}	2.96 ^{a}	0.67 ^{a}	6.48 ^{ab}
Mean for N doses	0	3.22 ^{A}	4.00 ^{A}	0.00 ^{A}	7.22 ^{A}
	50	4.09 ^{A}	3.59 ^{A}	0.00 ^{A}	7.68 ^{A}
	100	4.36 ^{A}	3.45 ^{A}	0.23 ^{A}	8.04 ^{A}
	150	3.99 ^{A}	4.15 ^{A}	0.33 ^{A}	8.47 ^{A}
Mean for cultivars	Gardena	5.40 ^{A}	4.87 ^{A}	0.00 ^{A}	10.27 ^{A}
	Denar	2.73 ^{B}	2.73 ^{B}	0.28 ^{A}	5.74 ^{B}
Mean for years	2020	3.99 ^{A}	3.78 ^{A}	0.00 ^{A}	7.77 ^{A}
	2021	4.14 ^{A}	3.81 ^{A}	0.28 ^{A}	8.23 ^{A}

Explanation as in Tab. 3

In other research, the share of tubers with defects in the yield was also determined by genotypic properties, and among the defects assessed, the largest share was deformed tubers, a smaller share was green tubers, and the smallest share was tubers infected with common scab [Trawczyński 2021]. In the current research, a similar level of deformed and green tubers was obtained, which could have been caused by excess rainfall and, to some extent, the blurred ridges contributed to the increase in the greenness of the tubers. However, similarly to previous studies [Trawczyński 2021], the lowest share of tubers with common scab was obtained among the analyzed external defects, and there was no differentiation of tuber defects in relation to mineral nitrogen fertilization. Lutomirska and Jankowska [2012] confirmed that the most deformed tubers in the crop were found in the year with the greatest rainfall deficiency, those that were green in the year with the greatest rainfall, and those infected with common scab in the dry year.

CONCLUSIONS

1. Mineral nitrogen fertilization up to a dose of 150 kg $N \cdot ha^{-1}$ stimulated plant growth (the mass of roots, stems, leaves), increased the SPAD index and the share of large tubers in the yield compared to the treatment without mineral nitrogen fertilization.
2. Comparison of cultivars indicates that Gardena is characterized by a larger above-ground mass of plants and root system and a smaller share of small and medium-sized tubers in the yield, and Denar is characterized by a significantly higher number of tubers and yield.
3. The cv. Gardena was characterized by greater requirements for mineral nitrogen fertilization, but the effectiveness of its use was very low compared to cv. Denar.
4. Excess rainfall during the growing period stimulated plant growth (the mass of the root system, stems and leaves) and limited nitrogen uptake in the tuber yield, while under conditions of optimal rainfall, the tuber yield and the share of large tubers increased.

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The source of funding: This work was supported by the European Agricultural Fund for Rural Development: Europe investing in rural areas. The publication is co-financed from the European Union funds under the COOPERATION of the Rural Development Programme for 2014–2020. The Managing Authority of the Rural Development Programme for 2014–2020 – the Minister of Agriculture and Rural Development.

Received: 2.12.2023
Accepted: 16.07.2024
Published: 02.12.2024