agronomy

MDPI

Article

The Effect of Nitrogen Fertilization on Yield and Macronutrient Concentrations in Three Cultivars of Jerusalem Artichoke (*Helianthus tuberosus* L.)

Jadwiga Wierzbowska [1], Bożena Cwalina-Ambroziak [2] and Bożena Bogucka [3,*]

[1] Department of Agricultural and Environmental Chemistry, University of Warmia and Mazury in Olsztyn, Oczapowskiego 8, 10-744 Olsztyn, Poland; jadwiga.wierzbowska@uwm.edu.pl
[2] Department of Entomology, Phytopathology and Molecular Diagnostics, University of Warmia and Mazury in Olsztyn, Prawocheńskiego 17, 10-720 Olsztyn, Poland; bambr@uwm.edu.pl
[3] Department of Agrotechnology and Agribusiness, University of Warmia and Mazury in Olsztyn, Oczapowskiego 8, 10-719 Olsztyn, Poland
* Correspondence: bozena.bogucka@uwm.edu.pl

Abstract: In many countries, Jerusalem artichoke (JA) is a source of biomass for renewable energy production and alternative biofuel feedstock, and it is used for feed and food production. The species also has medicinal properties, and it is used in soil reclamation. The aim of this study was to evaluate the effect of N fertilization on the yield and macronutrient concentrations in JA tubers. The effect of N fertilization (control plot, unfertilized, 80 and 120 kg ha^{-1}) on aerial biomass yield, tuber yield, and the mineral composition of tubers in three JA cultivars ("cv.") (Rubik, Albik, and Gute Gelbe) was investigated in a field experiment. Tuber yield (40.99 Mg ha^{-1}) and aerial biomass yield (62.76 Mg ha^{-1}) were highest in cv. Gute Gelbe fertilized with 120 kg N ha^{-1} in the warm and moderately wet growing season of 2018. Agronomic N-use efficiency (AE) was highest in cv. Gute Gelbe. In the treatment supplied with 80 kg N ha^{-1}, the fresh matter yield (FMY) of tubers was determined at 66.4 kg kg^{-1} N, whereas in the treatment fertilized with 120 kg N ha^{-1}, the FMY of tubers reached 101.8 kg kg^{-1} N. The evaluated JA cultivars differed in their responses to an increase in the N fertilizer (marginal efficiency—ME) rate from 80 to 120 kg ha^{-1}. The strongest response was observed in cv. Gute Gelbe, where the tuber yield increased by 172.6 kg kg^{-1} N. The tubers of cv. Gute Gelbe were characterized by significantly higher concentrations of N, K, Mg, and S compared with the other cultivars. The concentrations of macronutrients in the tubers (without Mg) were higher in spring. Nitrogen fertilization did not cause differences in the concentrations of P, K, Ca, Mg, and S, but it increased the N concentration in tubers.

Keywords: tubers; aerial biomass; yield; harvest index; N-use efficiency; dry weight; macronutrients

Citation: Wierzbowska, J.; Cwalina-Ambroziak, B.; Bogucka, B. The Effect of Nitrogen Fertilization on Yield and Macronutrient Concentrations in Three Cultivars of Jerusalem Artichoke (*Helianthus tuberosus* L.). *Agronomy* **2021**, *11*, 2161. https://doi.org/10.3390/agronomy11112161

Academic Editor: Helen Suter

Received: 6 August 2021
Accepted: 25 October 2021
Published: 27 October 2021

1. Introduction

Jerusalem artichoke (JA) (*Helianthus tuberosus* L.) is a species of the family Asteraceae with a high yield potential [1]. Over 300 JA varieties and hybrids have been identified around the world [2]. Today, JA is cultivated on an area of 2.5 million ha worldwide. In Europe, this species has been grown for human consumption (although its relative importance decreased when potatoes became widespread) and as a forage crop since the second half of the 19th century. Jerusalem artichoke is cultivated over large areas in France, Scandinavia, the UK, and Austria. In Poland, in 2020, the growing area of JA was less than 2000 hectares [3].

This crop plant is highly effective in converting solar energy to biomass in both quantitative and qualitative terms [4]. In the Polish climate, the dry matter yield (DMY) of JA tubers can reach 14–30 Mg ha^{-1}, and straw yield can be as high as 20–50 Mg ha^{-1} [5].

In the EU Member States, JA is a source of biomass for renewable energy production and alternative biofuel feedstock [6]. Jerusalem artichoke has numerous applications in feed and food production. The species also has medicinal properties, and it is used in soil reclamation [7–11].

Jerusalem artichoke has low agronomic requirements; it is relatively resistant to biotic and abiotic stressors [8], and easily adapts to diverse environments [12,13]. The species thrives on moist and fertile soils, and yields are determined by the optimal combination of genetic and agronomic factors. Nutrient deficiencies, including N, K, and P, and water deficit significantly compromise JA yields [11,12,14,15]. Nitrogen exerts strong yield-forming effects because it determines the photosynthetic potential of plants and increases their water-use efficiency [16]. High N supply stimulates root growth and development, and increases the assimilation of other nutrients [17]. N, P, and K are essential for the development of aboveground plant parts, and the optimal N:P ratio determines the productivity of tubers and aerial biomass in JA [18]. EL-Anany and Anany [19] demonstrated that the application of Ca and Mg, the foliar application of B and Si, and the combined application of macronutrients and micronutrients had a beneficial influence on the tuber yield and biomass yield of JA.

Jerusalem artichoke is abundant in inulin, which increases osmotic pressure in cells and confers resistance to low temperatures. As a result, tubers can persist in frozen soil for several months [20].

The chemical composition of JA tubers is determined by the cultivar, growing conditions, and harvest date [21–23]. Jerusalem artichoke is regarded as one of the major sources of inulin in vascular plants [24]. Tubers are abundant in minerals (Fe, Mg, P, and K) and nutrients (proteins, organic acids, vitamins, phenolic compounds), and they are a valuable raw material for food processing and the pharmaceutical industry [25,26]. The N content of JA tuber proteins is similar to that of potatoes [27]. According to the literature, the crude ash content of JA tubers ranges from 40 to 75 g kg^{-1} DM [28,29] and is negatively correlated with their DM content [28]. The ash composition of JA tubers is similar to the mineral composition of potato tubers.

Different cultivars of JA respond differently to increased rates of mineral N fertilizers. The aim of this study was to evaluate the effect of N fertilization on the yield and macronutrient concentrations in JA tubers.

2. Materials and Methods

A field experiment was conducted in 2016–2018 in the Agricultural Experiment Station in Tomaszkowo, a research facility of the University of Warmia and Mazury in Olsztyn (53°41′ N, 20°24′ E).

2.1. Soil Characteristics

The experiment was established on an Eutric cambisol with the granulometric composition of medium loamy sand and loamy sand (agricultural suitability class 5, soil quality class IVb) [30]. In each plot, bulk soil samples were collected to a depth of 20 cm to determine the chemical properties of soil before the application of fertilizers. Before the experiment, the pH of the soil solution in 1 M KCl (ratio of the soil to KCl solution was 1:2.5) was in the range of 5.04 to 5.54, Polish Standard PN-ISO 10390 [31]. Soil nutrient levels were measured as follows: P—Polish Standard PN-R-04023 [32], K—Polish Standard PN-R-04022:1996+Az1:2002 [33], Mg—Polish Standard PN-R-04020:1994+Az1:2004 [34], organic carbon (C-org.)—Vario Max Cube CN elemental analyzer (Elementar Analysensysteme GmbH), and total N—Kjeldahl distillation, (KjelFlex K-360 distillation unit—BUCHI Labortechnik AG, Switzerland). The nutrient concentrations in soil were as follows: C_{org}—9.40–9.85 g kg^{-1}, total N—0.71–0.76 g kg^{-1} and available forms of P—35.6–48.8 mg kg^{-1}, K—94.2–124.0 mg kg^{-1}, and Mg—38.0–42.0 mg kg^{-1}.

2.2. Cultivars

Three JA cultivars were grown: Polish cvs. Rubik (irregular- to oval-shaped tubers, purple) and Albik (club-shaped, white), and the German cv. Gute Gelbe (oval- and round-shaped, white, preferred by German organic farmers) from an organic farm (Die Topinambur Manufaktur, Heimenkirch, Bavaria, Germany).

2.3. Experimental Design

Each year, the experiment was set up in a different field (Table 1). The forecrops were cereals (oats, winter triticale) grown in plots without organic fertilization. Jerusalem artichoke tubers were planted in heated soil in mid-April to a depth of 8 cm, 40 cm apart, with inter-row spacing of 62.5 cm, and a density of 6 plants m^{-2}.

Table 1. Production technology of Jerusalem artichoke.

Year	Date of Fertilizer Application	Planting Date	Harvest Date		
			Aerial Biomass	Tubers (Autumn)	Tubers (Spring)
2016	25.04	25.04	07.11	08.11	14.03.2017
2017	19.04	20.04	20.10	08.11	27.03.2018
2018	19.04	20.04	12.10	16.10	25.03.2019

The experiment had a randomized block design with sub-block (split-split plot) partition (blocks—N fertilization; subblocks—cultivars) and three replications. Each experimental plot had an area of 4.5 m^2. Nitrogen fertilizer (urea, 46% N) was applied at the following rates: 0 kg N ha^{-1}—control (not fertilized with N), 80 kg N ha^{-1}, and 120 kg N ha^{-1}. The rates of N fertilizers were based on German agronomic recommendations for JA cultivation. According to these guidelines, JA yields increase in response to standard N rates of 60 to 120 kg ha^{-1} [1]. All plots were fertilized with 32 kg P ha^{-1} (triple superphosphate, 20.1% P) and 96 kg K ha^{-1} (potash salt, 50% K). Mineral fertilizers were applied once before planting in spring. Identical agronomic treatments were applied in all plots. Weeds were controlled mechanically.

2.4. Harvest

Jerusalem artichoke tubers were harvested on two dates: in late autumn (by mid-November) and in early spring (by mid-March). The harvested plot area was 4.5 m^2. Stems and leaves (aerial biomass) were cut only in autumn. The harvested tubers and aerial biomass from each plot were weighed. The fresh matter yield (FMY) of the harvested tubers and aerial biomass was expressed per hectare.

The value of the harvest index (HI) was calculated from the formula:

$$HI = Yt/(Yt + Yab) \quad (1)$$

where: HI—harvest index;
Yt—tuber yield [$Mg \cdot ha^{-1}$]; and
Yab—aerial biomass yield [$Mg \cdot ha^{-1}$] [35].

2.5. Nitrogen-Use Efficiency

The following agronomic indices of N use efficiency were calculated [36]:

1. Agronomic N-use efficiency (AE, net productivity):

$$AE\ [kg\ kg^{-1}\ N] = (Y_N - Y_0)/D \quad (2)$$

where: AE—agronomic efficiency;
Y_N—crop yield in response to the applied N fertilizer rate;
Y_0—crop yield in the control treatment; and
D—N fertilizer rate [$kg \cdot ha^{-1}$].

2. Marginal N-use efficiency (ME):

$$\text{ME [kg kg}^{-1}\text{ N]} = \Delta Y/\Delta D \quad (3)$$

where: ME—marginal efficiency;

ΔY—increase in yield in response to increased N fertilizer rate; and

ΔD—increase in N fertilizer rate.

2.6. Chemical Analysis Methods

Five randomly selected tubers (with a total weight of approximately 0.5 kg) were collected from each plot for chemical analyses. The dry matter (DM) weight was determined by the dryer-weight method. After crushing, the tubers (50 g) were pre-dried at 65–70 °C, and then dried to constant weight at 105 °C (SUP 100 W laboratory drier, WAMED Warsaw, Poland). Before weighing, the samples were left in the desiccator until the achievement of room temperature (based on the results of three consecutive measurements).

The tubers intended for chemical composition analysis were rinsed under running water, diced into 1 cm × 1 cm × 1 cm cubes (flesh with skin), freeze dried (Alpha 1-4LD laboratory freeze-dryer, Doncerv®—Martin Christ Gefriertrocknungsanlagen GmbH, Osterode am Harz Germany), and ground in a laboratory mill (A11 basic.)

The plant material was mineralized, and the content of N, P, K, Ca, Mg, and Na was determined in accordance with the methods described by Ostrowska et al. [37]. The concentrations of macronutrients (N, P, K, Ca, Mg) and Na in JA tubers were determined in plant material mineralized in concentrated sulfuric acid (H_2SO_4) with the addition of hydrogen dioxide (H_2O_2) as the oxidant (BÜCHI Speed Digester K-439—BÜCHI Labortechnik AG, Flawil Switzerland). The nitrogen concentration in mineralized plant material was determined by the Kjeldahl method (KjelFlex K-360 distillation unit—BUCHI Labortechnik AG, Switzerland). The phosphorus concentration was determined by the colorimetric method in the presence of vanadium and molybdenum (Shimadzu UV 1201V spectrophotometer—Shimadzu Corp., Kyoto Japan). The concentrations of K, Ca, and Na were determined by atomic emission spectrometry (AES; PFP 7 flame photometer—Jenway LTD, Staffordshire UK), and the Mg concentration was determined by atomic absorption spectrometry (AAS; Shimadzu AA-6800 spectrophotometer—Shimadzu Corp., Kyoto Japan). The sulfur (S) concentration was determined with the nephelometric method [37] in plant material mineralized in a mixture of chloric and nitric acid ($HClO_4$ and HNO_3, 1:1) with the addition of magnesium nitrate (V) ($Mg(NO_3)_2$) [38].

2.7. Weather Conditions

In 2016, the average monthly temperature between tuber planting (April) and harvest (November) approximated the long-term average (1981–2010; Table 2). The average temperature in the growing season of 2017 was below the long-term average (excluding September and October), and it exceeded the long-term average in 2018. High total precipitation plays a more important role in tuber development than temperature in the initial and subsequent stages of tuber formation. The first two years of the experiment were characterized by high precipitation levels that exceeded the long-term average by 25.7% and 45.5%, respectively. Rainfall was particularly abundant in July and October, as well as in September 2017. Precipitation levels were below the long-term average in September 2016 and May 2017. In the growing season of 2018, precipitation was 7% lower than the long-term average, and May, June, and September were particularly dry months. In turn, rainfall levels were nearly twice as high as the long-term average in July.

In winter (December to March), when JA tubers remained in the ground, above-zero temperatures (maximum of 4 °C) were noted in December in all years of the experiment, in March 2016, and in February and March 2018. Winter precipitation levels were similar (December 2017) or higher than the long-term average. Below-zero temperatures ranged from −0.4 to only −4.6 °C. Precipitation (rain and snow) was below the norm in January 2016, and in February and March 2017.

Table 2. Meteorological data during the experiment.

Month	Average Monthly Temperatures (T) °C				Monthly Precipitation (P) mm			
	2016/17	2017/18	2018/19	1981–2010	2016/17	2017/18	2018/19	1981–2010
April	7.4	5.7	10.8	7.7	28.8	59.1	33.5	33.3
May	13.7	12.1	15.7	13.5	56.9	25.1	25.0	58.5
June	17.1	15.7	17.2	16.1	69.3	74.5	53.7	80.4
July	18.1	16.8	19.7	18.7	130.4	107.6	141.0	74.2
August	17.1	17.4	19.2	17.9	70.4	63.1	44.6	59.4
September	13.6	12.8	14.5	12.8	21.1	168.1	20.3	56.9
October	6.1	8.7	8.7	8.0	104.3	114.9	84.7	42.6
November	2.4	3.9	3.3	2.9	84.5	42.4	16.0	44.8
December	0.8	1.8	0.9	−0.9	41.1	35.2	58.8	38.2
January	−3.4	−0.4	−2.5	−2.4	20.2	41.5	43.5	36.4
February	−1.4	−4.6	1.8	−1.7	47.6	3.1	31.5	24.2
March	4.0	−1.3	3.9	1.8	45.3	10.4	47.2	32.9
Average/Total	8.1	7.4	9.4	7.9	721.2	745.0	599.8	581.8

2.8. Statistical Analysis

The results were processed statistically by analysis of variance (ANOVA) in the Statistica® v. 13.3 program [39]. ANOVA was performed as a 3-year series for a split-split-plot design. The significance threshold was validated in the Bonferroni test at α = 0.05.

3. Results

3.1. Effect of N Fertilization on Yield

Table 3 presents the results of a multifactorial (multivariate) ANOVA regarding the effects exerted by the experimental factors and their interactions on JA yields. Although there was a significant interaction between Y × HD × NR × C (Table 3 and Figure 1), our results and discussion are focused on only selected findings. Tuber yields were presented as the means of two harvest dates (autumn and spring) because the growing season of JA ends in autumn, and harvest shifting to the early spring of the next year was treated as tuber storage. Additionally, a significant difference in tuber yield between two harvest dates (autumn and spring) was noted only in cv. Albik (Figure 1).

The yield of JA tubers ranged from 18.31 to 40.99 Mg ha^{-1}, and it was affected by the N fertilizer rate, cultivar, and weather conditions (Tables 3 and 4). Tuber yield was lowest in 2017 in cv. Albik fertilized with 120 kg N ha^{-1}, and highest in 2018 in cv. Gute Gelbe supplied with 120 kg N ha^{-1}. The yield of aboveground plant parts was lowest in 2016 in cv. Gute Gelbe grown in the control treatment without N fertilization (32.85 Mg ha^{-1}), and highest in 2018 in cv. Gute Gelbe fertilized with 120 kg N ha^{-1} (62.76 Mg ha^{-1}). The harvest index was lowest (HI = 0.27) in 2017 in cv. Albik grown in the control treatment without N fertilization, and highest (HI = 0.44) in 2016 in cv. Gute Gelbe grown in the control treatment without N fertilization and in cv. Rubik supplied with 80 kg N ha^{-1}.

On average, in all ears of the study, the significantly highest yields of JA tubers and aerial biomass were achieved in the warm and dry year of 2018. On the other hand, the significantly lowest yield of tubers (over 13% lower than in 2018) was obtained in the cold and rain-abundant 2017. In turn, the lowest yield of aerial biomass, and at the same time the highest HI index were noted in 2016.

Tuber yield increased with a rise in the N fertilizer rate (Figure 2; Table 4). Gute Gelbe was the highest-yielding cultivar, characterized by the strongest response to N fertilization. Tuber yield increased by 48.3% after the application of 120 kg N ha^{-1} relative to the control treatment without N fertilization (25.29 Mg ha^{-1}). The tuber yield of cv. Rubik reached 23.9 Mg ha^{-1} in the treatment without N fertilization, and it increased by 17.6% in response to 120 kg N ha^{-1}. The cultivar Albik was least affected by N fertilization. In the control treatment, the tuber yield of cv. Albik was determined at 21.97 Mg ha^{-1}, and it increased by only 11% in response to 80 kg N ha^{-1}, whereas a further increase in the N fertilizer rate to 120 kg ha^{-1} had no effect on tuber yield.

Table 3. Results of a multifactorial (multivariate) analysis of variance (split-split-plot design) for the tuber yield and harvest index of Jerusalem artichoke.

Source of Variation	df	Tuber Yield		Aerial Biomass Yield		HI	
		F	*p*	F	*p*	F	*p*
Year (Y)	2	83.8	<0.0001	190	<0.0001	577	<0.0001
Error 1	6						
Harvest date (HD)	1	311	<0.0001	21.0	0.0038	362	<0.0001
Y × HD	2	605	<0.0001	0.24	0.7944	1099	<0.0001
Error 2	6						
N fertilizer rate (NR)	2	422	<0.0001	122	<0.0001	118	<0.0001
Y × NR	4	83.3	<0.0001	46.5	<0.0001	115	<0.0001
HD × NR	2	43.6	<0.0001	60.2	<0.0001	4.87	0.0168
Y × HD × NR	4	13.7	<0.0001	3.80	0.0157	20.4	<0.0001
Error 3	24						
Cultivar ©	2	793	<0.0001	120	<0.0001	370	<0.0001
Y × C	4	62.3	<0.0001	37.5	<0.0001	133	<0.0001
HD × C	2	98.3	<0.0001	20.4	<0.0001	29.1	<0.0001
NR × C	4	125	<0.0001	116	<0.0001	6.41	<0.0001
Y × HD × C	4	58.8	<0.0001	29.8	<0.0001	68.4	<0.0001
Y × NR × C	8	21.6	<0.0001	27.9	<0.0001	32.4	<0.0001
HD × NR × C	4	62.4	<0.0001	14.6	<0.0001	36.6	<0.0001
Y × HD × NR × C	8	40.9	<0.0001	18.5	<0.0001	16.6	<0.0001
Error 4	72						
Total	161						

Table 4. Yields of Jerusalem artichoke tubers and aerial biomass, and the harvest index (average ± *SE;* tuber yields are means of two harvest dates, autumn and spring).

Year	Cultivar	N Fertilizer Rate [kg ha^{-1}]	Tuber Yield	Aerial Biomass Yield	HI *
			Mg ha^{-1}		
2016	Rubik	Control	26.45 ± *0.50* a−d	34.41 ± *0.79* ab	0.43 ± *0.01* fg
		80	27.70 ± *0.59* a−d	35.00 ± *0.83* a−c	0.44 ± *0.02* g
		120	26.53 ± *0.35* a−d	39.81 ± *0.81* a−f	0.40 ± *0.01* d−g
	Albik	Control	24.07 ± *1.56* a−c	43.19 ± *3.60* b−g	0.36 ± *0.02* a−g
		80	25.70 ± *1.43* a−d	38.93 ± 0.90 a−e	0.40 ± *0.03* d−g
		120	22.59 ± *0.63* a−c	35.19 ± *1.29* a−c	0.39 ± 0.01 c−g
	Gute Gelbe	Control	25.99 ± *1.89* a−d	32.85 ± *0.90* a	0.44 ± *0,04* g
		80	29.36 ± *0.76* a−e	39.74 ± *0.47* a−f	0.42 ± *0.02* fg
		120	33.32 ± *0.22* c−e	51.63 ± *2.02* g−j	0.39 ± *0.02* c−g
2017	Rubik	Control	19.21 ± *0.51* a	43.41 ± *0.89* c−g	0.31 ± *0.02* a−d
		80	23.48 ± *2.61* a−c	48.78 ± *1.04* g−j	0.32 ± *0.05* a−e
		120	26.91 ± *2.64* a−d	46.04 ± 0.80 d−I	0.37 ± *0.05* b−g
	Albik	Control	19.80 ± *1.51* ab	52.85 ± *2.93* h−j	0.27 ± *0.01* a
		80	21.77 ± *0.57* a−c	53.48 ± *1.66* h−j	0.29 ± *0.02* a−c
		120	18.31 ± *0.46* a	47.22 ± *1.24* e−j	0.28 ± *0.02* ab
	Gute Gelbe	Control	24.28 ± *2.14* a−c	38.15 ± 0.55 a−d	0.39 ± *0.06* c−g
		80	31.92 ± *1.36* b−e	53.85 ± *1.35* h−j	0.37 ± *0.03* b−g
		120	38.23 ± 1.75 de	54.63 ± *0.61* i−k	0.41 ± *0.03* e−g

Table 4. *Cont.*

Year	Cultivar	N Fertilizer Rate [kg ha^{-1}]	Tuber Yield	Aerial Biomass Yield	HI *
			Mg ha^{-1}		
2018	Rubik	Control	26.04 ± *3.02* a−d	45.87 ± *0.87* d−I	0.36 ± *0.07* a−g
		80	24.92 ± *1.87* a−c	45.32 ± *0.69* d−h	0.35 ± *0.05* a−f
		120	30.85 ± *1.64* a−e	51.45 ± *0.53* g−j	0.37 ± *0.03* b−g
	Albik	Control	22.03 ± *2.67* a−c	45.50 ± *0.73* d−h	0.33 ± *0.07* a−e
		80	25.46 ± *3.03* a−c	48.30 ± *0.83* f−j	0.35 ± *0.06* a−f
		120	32.28 ± *4.84* b−e	49.18 ± *0.49* g−j	0.40 ± *0.10* d−g
	Gute Gelbe	Control	25.61 ± *3.85* a−c	55.28 ± *4.69* jk	0.32 ± *0,03* a−e
		80	30.54 ± *5.54* a−e	48.66 ± *1.43* g−j	0.39 ± *0.10* c−g
		120	40.99 ± *1.05* e	62.76 ± *0.96* k	0.40 ± *0.02* d−g
Average for year		2016	26.86 ± *0.51* ab	38.97 ± *0.89* a	0.41 ± *0.00* b
		2017	24.88 ± *1.00* a	48.71 ± *0.84* b	0.33 ± *0.01* a
		2018	28.75 ± *1.29* b	50.26 ± *0.91* b	0.36 ± *0.01* a

HI—harvest index; * values followed by the same letters do not differ significantly at $p < 0.05$.

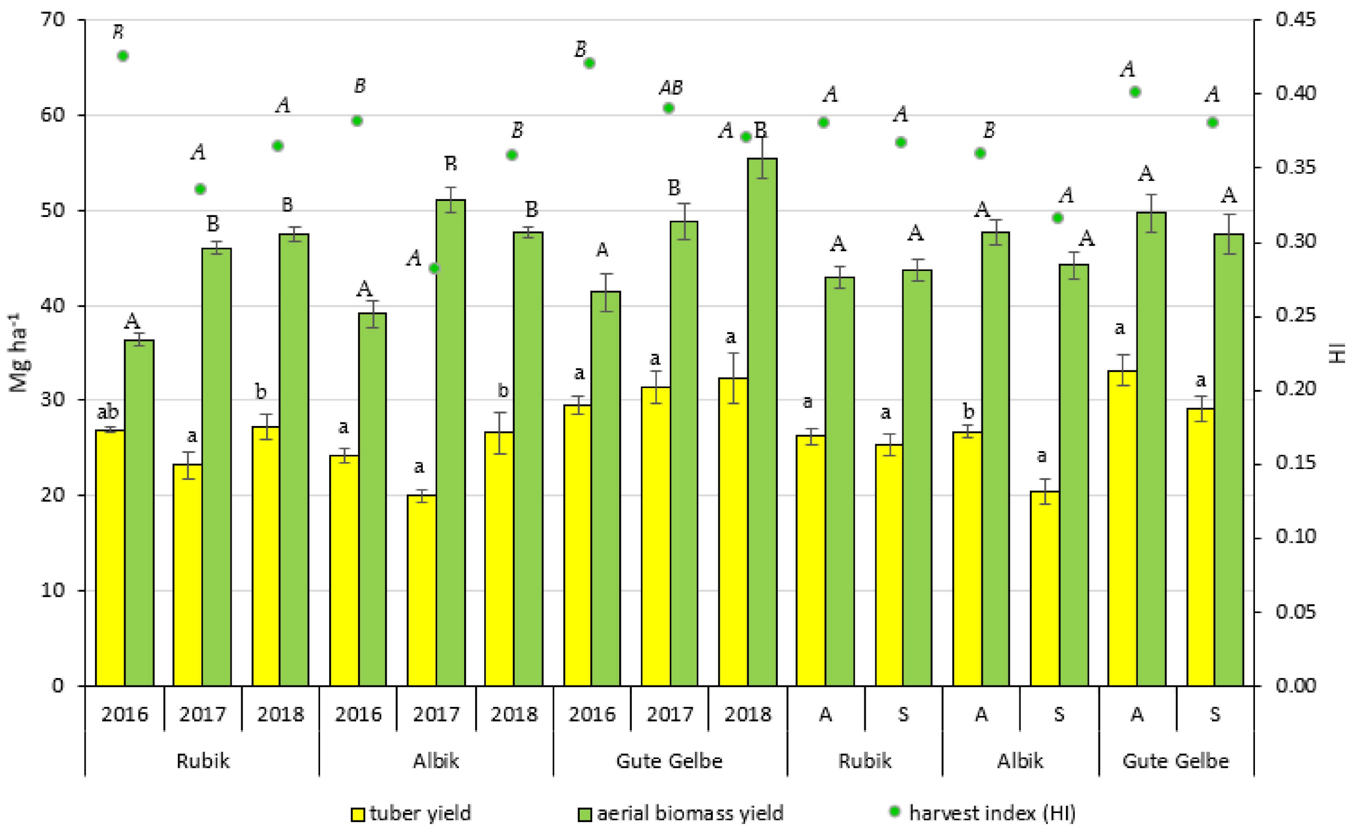

Figure 1. Jerusalem artichoke yields and harvest index (HI) (average ± SE) in the experimental years and on different harvest dates (3-year average ± SE) (Explanations: A—autumn; S—spring, SE—standard error; lower case letters for tuber yield, upper case letters for aerial biomass yield, and italicized upper-case letters for HI; bars followed by the same letters do not differ significantly at $p < 0.05$).

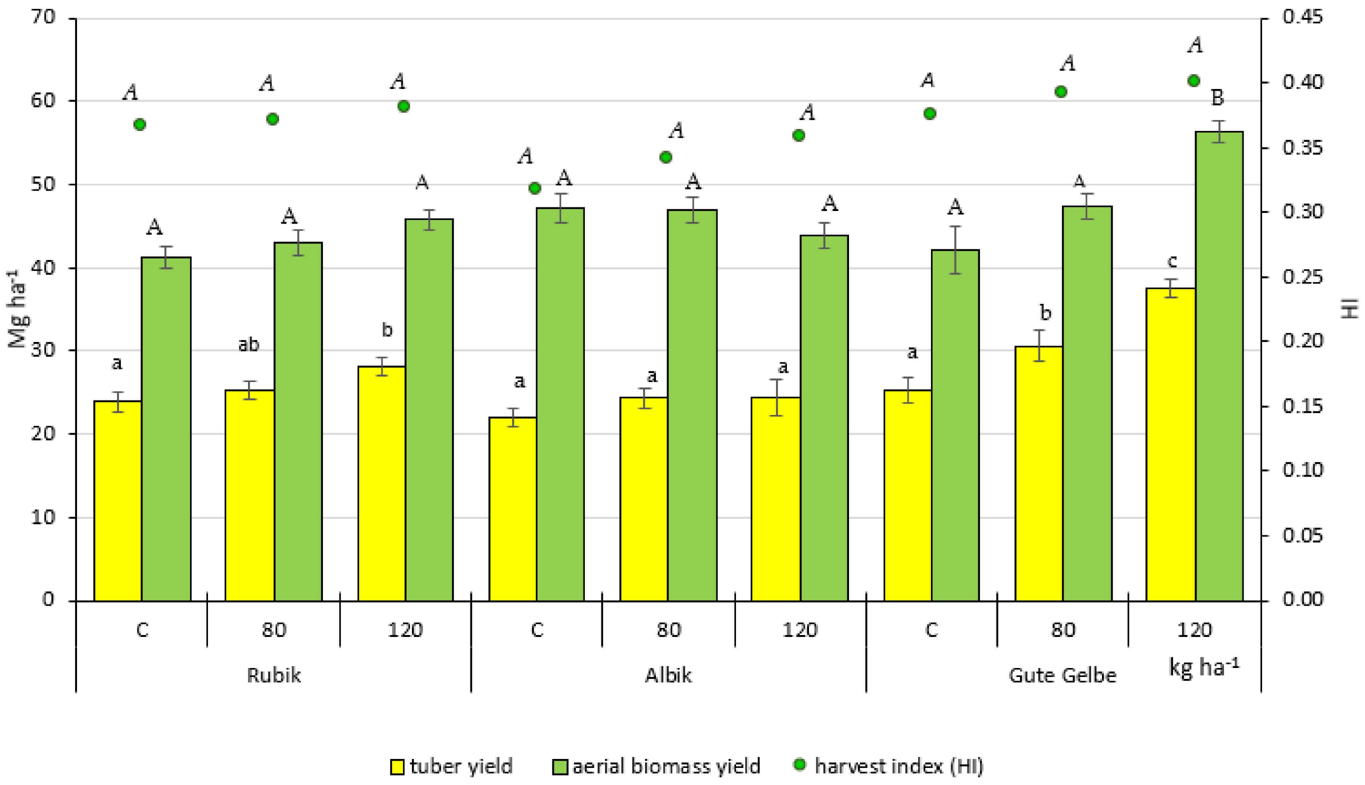

Figure 2. The effect of the nitrogen fertilizer rate and cultivar on Jerusalem artichoke yields and harvest index (HI) (3-year average ± SE) (explanations: SE—standard error; C—control, lower case letters for tuber yield, upper case letters for aerial biomass yield and italicized upper-case letters for HI; bars followed by the same letters do not differ significantly at $p < 0.05$.

The aerial biomass yield of cv. Gute Gelbe increased by 33.9% in response to 120 kg N ha^{-1} relative to the control treatment (42.09 Mg ha^{-1}) (Figure 2; Table 4). In cv. Rubik, the application of 120 kg N ha^{-1} increased the aerial biomass yield by around 11% relative to the unfertilized treatment (41.23 Mg ha^{-1}). The above N rate decreased the yield of aboveground biomass in cv. Albik by 7% (43.86 Mg ha^{-1}) relative to the control treatment.

Cultivars exerted a minor but significant effect on HI values. Depending on the N fertilizer rate, the HI was determined at 0.37–0.38 in cv. Rubik and 0.38–0.40 in cv. Gute Gelbe. The above parameter was somewhat lower in cv. Albik (0.32–0.36). In all studied cultivars, N fertilization induced a minor increase in the HI.

Weather conditions significantly differentiated JA tuber yields across years (Figure 1; Table 4). In cvs. Rubik and Albik, tuber yield was lowest in the second year of the study (23.20 and 19.96 Mg ha^{-1}, respectively) and highest in 2018 (27.27 and 26.59 Mg ha^{-1}, respectively). Cultivar Gute Gelbe was less sensitive to weather, and its tuber yield ranged from 29.55 Mg ha^{-1} in 2016 to 32.38 Mg ha^{-1} in 2018.

Despite its lowest tuber yield, cv. Albik was characterized by the highest aerial biomass yield (51.2 Mg ha^{-1}) in the second year of the experiment (Figure 1; Table 4). The aerial biomass yield of the remaining cultivars was highest in 2018 (Rubik—47.5 Mg ha^{-1}; Gute Gelbe—55.6 Mg ha^{-1}).

In all cultivars, the HI was highest in the first year of the study (Rubik and Gute Gelbe—HI = 0.42; Albik—HI = 0.38) (Figure 2; Table 4). In cvs. Rubik and Albik, the greatest differences in tuber and aerial biomass yields were noted in 2017 (HI = 0.33 and 0.28, respectively), and in Gute Gelbe in 2018 (HI = 0.37). The tuber to stem yield ratio was more favorable in autumn.

3.2. Effect of N Fertilization on Agronomic N-Indices

In the present study, agronomic N-use efficiency (AE) was highest in cv. Gute Gelbe (Figure 3a). In the treatment supplied with 80 kg N ha^{-1}, the FMY of tubers was determined at 66.4 kg per kg of N, whereas in the treatment fertilized with 120 kg N ha^{-1}, the FMY of tubers reached 101.8 kg per kg of N. In cv. Rubik, N-use efficiency reached 18.3 kg kg^{-1} N in response to 80 and 34.9 kg kg^{-1} N in response to 120 kg N ha^{-1}. Cultivar Albik responded somewhat differently to N fertilization. A lower N rate increased tuber yield by 29.3 kg kg^{-1} N, but tuber yield reached only 20.5 kg kg^{-1} N in response to 120 kg N ha^{-1}.

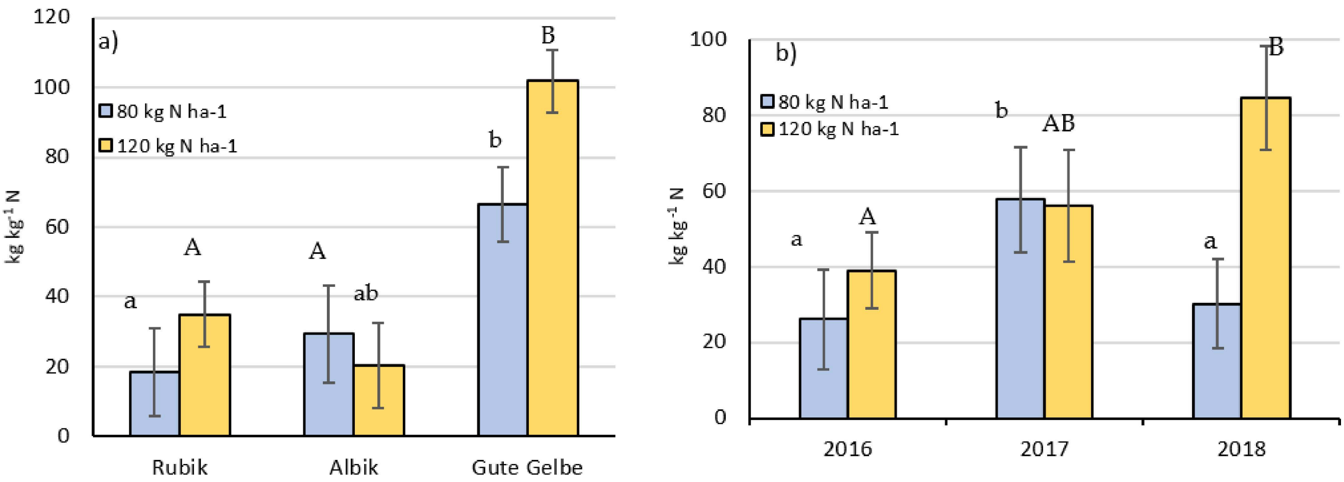

Figure 3. Agronomic N-use efficiency (AE) for cultivars (**a**) and years of the study (**b**)—(average ± SE, lower case letters for N rate of 80 kg N ha^{-1}; upper case letters for N rate of 120 kg N ha^{-1}; bars followed by the same letters do not differ significantly at $p < 0.05$).

The weakest JA response to N fertilization was observed in the first year of the study (Figure 3b). After fertilization with 80 kg N ha^{-1}, the increase in FMY was only 26.1 kg kg^{-1} N. Fertilization with 120 kg N ha^{-1} increased tuber yield by 38.9 kg kg^{-1} N. In the relatively humid and cold 2017, N fertilization increased FMY by 57.8 and 56.0 kg kg^{-1} N (at 80 and 120 kg N ha^{-1}, respectively). Under warm and moderately humid conditions, in the growing season of 2018, FMY increased by 84.5 kg kg^{-1} N in response to 120 kg N ha^{-1}.

Marginal N-use (ME) efficiency is the increase in crop yield per kg of N applied at a given rate. The evaluated JA cultivars differed in their responses to an increase in the N fertilizer rate from 80 to 120 kg ha^{-1} (Figure 4a). The strongest response was observed in cv. Gute Gelbe, where tuber yield increased by 172.6 kg kg^{-1} N. In cv. Rubik, tuber yield increased by 68.3 kg kg^{-1} N. Nitrogen was least effective in cv. Albik, where an increase in the N rate from 80 to 120 kg ha^{-1} increased tuber yield by only 2.1 kg kg^{-1} N.

In 2016, increasing the N rate from 80 to 120 kg ha^{-1} resulted in a decrease in tuber yield by 2.6 kg kg^{-1} N (Figure 4b). In the next year, the higher N rate increased tuber yield by 52.4 kg kg^{-1} N. However, in the warm and relatively dry 2018, which was favorable for JA cultivation, increasing the N rate from 80 to 120 kg ha^{-1} resulted in an increase in FMY by over 190 kg kg^{-1} N.

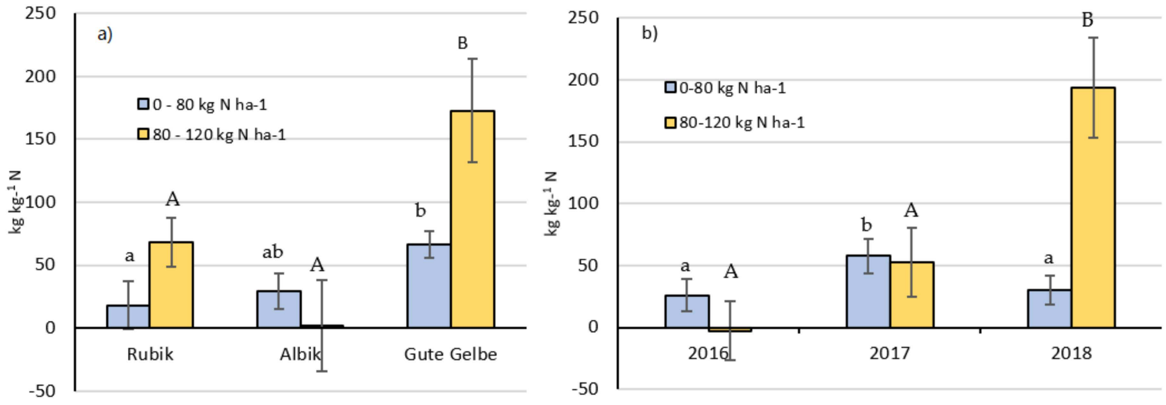

Figure 4. Marginal N-use efficiency (ME) for cultivars (**a**) and years of the study (**b**)–(average ± SE, lower case letters for rate 0–80 kg N ha^{-1}; upper case letters for rate 80–120 kg N ha^{-1}; bars followed by the same letters do not differ significantly at $p < 0.05$).

3.3. Effect of N Fertilization on the Dry Matter Weight and Macronutrients and Na Concentration

The dry matter (DM) content of JA tubers was similar in the control treatment and in the treatment supplied with 80 kg N ha^{-1} (27.35%), but it was significantly lower (24.76%) in the treatment fertilized with 120 kg N ha^{-1} (Table 5). During the entire experiment, average DM content in JA tubers in all studied cultivars was similar in the range of 26.14 to 26.67%. The analyzed parameter was higher in tubers that were harvested in autumn (27.95% on average) than in spring (25.03% on average).

Nitrogen concentration in JA tubers was influenced by the N fertilizer rate. This parameter was higher (12.76 g N kg^{-1} DM) in tubers supplied with 120 kg N ha^{-1}, and it was 7.3% higher relative to the unfertilized treatment. In turn, the concentrations of the remaining macronutrients were not affected by the N fertilizer rate.

The concentrations of N, K, Mg, and S were highest in cv. Gute Gelbe (12.69, 16.98, 0.60, and 1.26 g kg^{-1} DM, respectively). Only the concentration of Na (0.51 g kg^{-1} DM) was significantly highest in the tubers of cv. Rubik (with purple skinned). The analyzed cultivars did not differ significantly ($p < 0.05$) in P 3.94–4.15 g kg^{-1} DM) or Ca (0.56–0.61 g kg^{-1} DM) concentrations. Tubers harvested in the first year of the experiment contained more P and Ca but less K and Na. The concentrations of the remaining macronutrients did not differ significantly across years. Tubers harvested in spring had significantly higher concentrations of macronutrients, excluding Mg.

The uptake of N, P, K, Mg, Na, and S by JA tubers was affected by the N fertilizer rate and reached 77.66–95.87, 24.80–39.15, 101.33–126.70, 3.77–4.55, 3.00–3.62, and 7.02–8.49 kg ha^{-1} on average, respectively (Table 6). The N rate had no significant effect on Ca uptake by JA tubers (3.89–4.34 kg ha^{-1}). Cultivar influenced nutrient uptake by tubers. Gute Gelbe was characterized by the highest uptake of N, P, K, Mg, and S. The uptake of P and K was highest in the third year, and Ca uptake was highest in the first year of the experiment. Harvest date also determined nutrient uptake, and the uptake of N, K, Ca, Mg, and Na was significantly higher in tubers harvested in autumn.

Table 5. Dry matter weight and macronutrients and Na concentration in Jerusalem artichoke tubers (average ± *SE*).

Factor		Dry Matter (DM)	N	P	K	Ca	Mg	S	Na
		%	$g\ kg^{-1}$ DM						
N fertilizer rate [kg ha^{-1}] (*n* = 54)	Control	27.38 ± *0.47* b*	11.81 ± *0.19* a	4.05 ± *0.08* a	15.56 ± *0.43* a	0.59 ± *0.02* a	0.55 ± *0.01* a	1.05 ± *0.03* a	0.46 ± *0.01* a
	80	27.33 ± *0.45* b	12.35 ± *0.14* ab	3.96 ± *0.10* a	15.37 ± *0.35* a	0.58 ± *0.03* a	0.56 ± *0.01* a	1.12 ± *0.03* a	0.46 ± *0.01* a
	120	24.76 ± *0.62* a	12.67 ± *0.16* b	4.08 ± *0.08* a	15.60 ± *0.42* a	0.57 ± *0.03* a	0.57 ± *0.01* a	1.12 ± *0.03* a	0.50 ± *0.01* a
Cultivar (*n* = 54)	Rubik	27.38 ± *0.68* a	12.29 ± *0.19* ab	3.99 ± *0.08* a	14.57 ± *0.31* a	0.56 ± *0.02* a	0.55 ± *0.01* b	1.05 ± *0.02* a	0.51 ± *0.01* b
	Albik	26.14 ± *0.49* a	11.85 ± *0.18* a	3.94 ± *0.10* a	14.99 ± *0.35* a	0.61 ± *0.02* a	0.52 ± *0.01* a	0.98 ± *0.01* a	0.44 ± *0.02* a
	Gute Gelbe	24.76 ± *0.62* a	12.69 ± *0.14* b	4.15 ± *0.07* a	16.98 ± *0.45* b	0.58 ± *0,02* a	0.60 ± *0.01* c	1.26 ± *0.03* b	0.46 ± *0.02* a
Year (*n* = 54)	2016	26.91 ± *0.71* a	12.40 ± *0.20* a	4.43 ± *0.08* b	13.81 ± *0.12* a	0.71 ± *0.01* b	0.57 ± *0.01* a	1.11 ± *0.02* a	0.37 ± *0.01* a
	2017	25.70 ± *0.36* a	12.24 ± *0.15* a	3.81 ± *0.07* a	16.36 ± *0.44* b	0.51 ± *0.02* a	0.55 ± *0.01* a	1.10 ± *0.03* a	0.52 ± *0.01* b
	2018	26.87 ± *0.64* a	12.19 ± *0.16* a	3.85 ± *0.08* a	16.37 ± *0.44* b	0.51 ± *0.02* a	0.55 ± *0.01* a	1.08 ± *0.03* a	0.52 ± *0.01* b
Harvest date (*n* = 81)	Autumn	27.95 ± *0.40* b	11.79 ± *0.16* a	3.88 ± *0.07* a	14.32 ± *0.20* a	0.46 ± *0.02* a	0.55 ± *0.01* a	1.00 ± *0.02* a	0.47 ± *0.01* a
	Spring	25.03 ± *0.40* a	12.76 ± 0.09 b	4.17 ± *0.06* b	16.70 ± *0.37* b	0.70 ± *0.01* b	0.56 ± *0.01* a	1.19 ± *0.02* b	0.47 ± *0.01* a

* values followed by the same letters for each main factor do not differ significantly at $p < 0.05$.

Table 6. Macronutrient and Na uptake by Jerusalem artichoke tubers (average ± *SE*).

Factor		N	P	K	Ca	Mg	Na	S
		kg ha^{-1}						
N fertilizer rate [kg ha^{-1}] (n = 54)	Control	77.66 ± *2.47* a*	24.80 ± *1.75* a	101.33 ± *4.69* a	3.86 ± *0.19* a	3.37 ± *0.12* a	3.00 ± *0.13* a	7.02 ± *0.26* a
	80	86.49 ± *3.14* ab	30.49 ± *2.14* a	102.49 ± *4.08* a	3.94 ± *0.18* a	3.97 ± *0.15* b	3.34 ± *0.15* b	7.73 ± *0.36* ab
	120	95.87 ± *3.91* b	39.15 ± *3.04* b	126.70 ± *6.06* b	4.34 ± *0.26* a	4.55 ± *0.20* c	3.62 ± *0.19* c	8.49 ± *0.39* c
Cultivar (n = 54)	Rubik	86.43 ± *2.69* ab	27.59 ± *1.46* a	103.08 ± *3.91* a	3.95 ± *0.21* a	3.93 ± *0.13* b	3.57 ± *0.14* b	7.41 ± *0.27* b
	Albik	76.40 ± *3.19* a	24.13 ± *2.23* a	97.36 ± *4.91* a	3.95 ± *0.24* a	3.31 ± *0.13* a	2.86 ± *0.16* a	6.29 ± *0.26* a
	Gute Gelbe	97.19 ± *3.56* b	42.71 ± *2.84* b	130.08 ± *5.67* b	4.24 ± *0.19* a	4.64 ± *0.19* c	3.52 ± *0.15* b	9.52 ± *0.33* c
Year (n = 54)	2016	87.29 ± *1.83* a	32.10 ± *1.16* ab	97.39 ± *1.75* a	5.03 ± *0.11* b	4.02 ± *0.08* a	2.64 ± *0.11* a	7.85 ± *0.21* a
	2017	81.26 ± *3.33* a	26.30 ± *2.37* a	108.50 ± *4.99* ab	3.31 ± *0.18* a	3.71 ± *0.19* a	3.42 ± *0.13* a	7.33 ± *0.38* a
	2018	91.47 ± *4.34* a	36.03 ± *3.32* b	124.63 ± *6.93* b	3.80 ± *0.26* a	4.15 ± *0.21* a	3.89 ± *0.18* a	8.06 ± *0.40* a
Harvest date (n = 81)	Autumn	94.51 ± *2.76* b	31.10 ± *1.78* a	114.79 ± *3.87* b	3.69 ± *0.16* a	4.41 ± *0.15* b	3.73 ± *0.12* b	8.02 ± *0.27* a
	Spring	79.65 ± *2.58* a	26.03 ± *2.15* a	104.25 ± *4.21* a	4.37 ± *0.17* b	3.50 ± *0.12* a	2.93 ± *0.14* a	7.43 ± *0.27* a

* values followed by the same letters for each main factor do not differ significantly at $p < 0.05$.

4. Discussion

4.1. Effect of N Fertilization on Yield

The present findings confirm the hypothesis that the analyzed JA cultivars respond differently to increasing rates of N fertilizer. The tuber yield of cv. Gute Gelbe increased with increasing rates of N fertilizer, whereas N fertilization had no significant effect on the tuber yield of cv. Albik (Figure 1).

According to Prośba-Białczyk [40], the tuber yield of JA grown in south-western Poland without fertilization or chemical protection can reach 40 Mg ha^{-1}. In turn, in a study by Skiba and Sawicka [41], N applied together with PK fertilizers had a positive effect on the yield of JA tubers. The cited authors obtained the highest tuber yield when N was applied at the rate of 50 kg ha^{-1}. Different JA cultivars responded differently to the applied fertilization. In a study by Rodrigues et al. [42], the yield of JA tubers reached 65.6 Mg ha^{-1}. The above authors achieved the highest tuber yield after applying 100 kg N ha^{-1} and planting 2 m^{-2} plants. Similar results were reported by Bogucka et al. [15], where the FMY of tubers of cv. Topstar reached 60.53 Mg ha^{-1}, DMY reached 14.18 Mg ha^{-1}, and these parameters were 40% and 60% higher, respectively, than in cv. Violette de Rennes. Aerial biomass yield was also determined by genotype, and it was highest in cv. Topstar (65.74 FMY Mg ha^{-1}, and 24.42 DMY Mg ha^{-1}) and around 20% lower in cv. Waldspindel. In the work of Baldini et al. [43], the FMY of JA tubers ranged from 55.5 to 80 Mg ha^{-1} and the FMY of aerial biomass ranged from 29.5 to 58.7 Mg ha^{-1}. In an experiment by Izsáki and Kádi [14], the ratio of tuber yield to aerial biomass yield ranged from 1:1 (cv. Tápiói Korai, an early cultivar with a short growing season) to 1:4.5 (cv. Tápiói Sima, a late cultivar with a long growing season). In cv. Tápiói Korai, aerial biomass yield peaked (38.34 Mg ha^{-1}) in response to 100 kg N ha^{-1} and P fertilization, and in cv. Tápiói Sima (78–80 Mg ha^{-1})—in response to 200 kg N ha^{-1}. The above fertilization treatment induced the greatest increase in tuber yield.

In a study by Losavio et al. [44], N fertilizer applied at 50 and 100 kg ha^{-1} had no significant effect on JA tuber yield. In contrast, Schittenhelm [45] analyzed different N rates (0, 60, and 120 kg ha^{-1}) and found that JA tuber yield (DM basis) peaked in response to the rate of 60 kg N ha^{-1}. In a later study, Sun et al. [46] analyzed JA tuber yield (DM basis) and reported that fertilization levels of 180 kg N ha^{-1} and 135 kg P_2O_5 ha^{-1} were most effective. Tuber yield and nutrient concentrations increased significantly up to the N fertilizer rate of 120 kg ha^{-1} [47].

In an experiment performed by Stolarski et al. [48], organic and mineral N fertilizers (85 and 170 kg ha^{-1}) had a positive effect on the dry aerial biomass yield of JA, which was higher in the first year than in the subsequent two years. According to Gao et al. [49], the yields of *H. tuberosus* tubers and aerial biomass were highest in irrigated treatments fertilized with 20 to 50 kg N ha^{-1}.

Cultivars also respond differently to water stress. Tuber yield was higher in cv. Albik in a year with a wet growing season, and in cv. Rubik in a year characterized by a water deficit between July and September [50]. Potassium speeds up the translocation of carbohydrates from leaves to tubers and improves water management in plants. Early cultivars are generally more sensitive to drought than late cultivars [51]. Pimsaen et al. [52] studied 15 JA cultivars in north-eastern Thailand and found that environmental conditions exerted a greater influence on the FMY, number, and size of tubers (plant growth was accelerated in dry regions with irrigation than in wet regions) than genotype. In the work of Izsáki and Kádi [14], the average tuber yield ranged from 15 to 28 t ha^{-1}, subject to water availability and soil type. According to Matias et al. [53], JA tubers tend to rot in winter, in particular in heavy and wet soils, and winter yield could be significantly smaller than autumn yield. Aerial biomass yield was also much lower in winter than in autumn, and it was less influenced by mineral NPK fertilization than harvest date. Gao et al. [49] found that both FMY and DMY were higher during tuber harvest in October (sub-zero temperatures) than in September (above-zero temperatures). In the present study, the tuber yield of cv. Albik was also significantly lower (approximately 24%) in spring than in autumn (Figure 2). This was caused by greater overwintering losses in cv. Albik, compared with the remaining cultivars.

4.2. Effect of N Fertilization on Agronomic N-Indices

Agronomic N-use efficiency (AE) measures the increase in crop yield per kg of N fertilizer. This parameter is usually higher in crops with a higher productive potential and when precision fertilizer and irrigation techniques are applied [54]. The knowledge of agronomic fertilization efficiency indicators, in particular marginal efficiency, can be used to refine the N rates used in the fertilization of new higher-yielding JA cultivars.

In the present study, the agronomic efficiency of N fertilization was affected not only by JA genotype, but also by weather conditions during the growing season (Figure 3a,b). The agronomic efficiency of N fertilization was highest in cv. Gute Gelbe and lowest in cv. Albik. After the application of 80 kg N ha^{-1}, the highest agronomic efficiency of N fertilization (57.8 kg of tubers per kg of N) was noted in the relatively cold and wet year of 2017. After the application of 120 kg N ha^{-1}, the highest agronomic efficiency of N fertilization (84.5 kg of tubers per kg of N) was observed in the relatively warm and moderately wet year of 2018. Unfortunately, the available literature does not provide much information on the economic efficiency of fertilization in JA. Therefore, the present results were compared with those reported for potatoes, due to similar agronomic practices in both crop species (wide-row sowing) and yield specificity (main yield with high sugar content, below the soil surface). In a study by Stolarski et al. [48], JA cultivated as a perennial plant for energy purposes produced from 10 to 19 kg of the DMY (aerial biomass) per kg of applied N. Grzebisz et al. [55] reported that an increase in potato tuber yield ranged from 40 to 97 kg per kg of applied N depending on soil and climatic conditions (Poland, the Czech Republic, Albania), N rates, and cultivar. The agronomic efficiency of N fertilization was lowest in the growing season characterized by considerable precipitation deficiency. Grzebisz et al. [55] and Awgchew et al. [56] found that the agronomic efficiency of N fertilization decreases with increasing N rates applied to potatoes. In turn, N-use efficiency expressed by the DMY of celery roots at different rates of N fertilizer ranged from 10.23 to 27.41 kg kg^{-1} N [57].

4.3. Effect of N Fertilization on the Dry Matter Weight and Macronutrients and Na Concentration

Dry matter weight is an important indicator of nutritional value, which determines the flavor and consistency of tubers. In plants, DM weight is conditioned genetically, but it can be modified by agronomic factors (NPK fertilization) as well as soil and weather conditions [28,51,58]. According to the literature, the DM content of JA tubers ranges from 20.00 to 31.90% [24,59,60], and the major DM components are simple sugars, disaccharides, and polysaccharides, mostly inulin.

In a study by Florkiewicz et al. [21], the average DM content of JA tubers was determined at 23.60%, and it was significantly higher in cv. Rubik (25.60%) than in cv. Albik (21.5%). The authors of this study found no significant differences in DM content between tubers that were harvested in autumn (November) and spring (March) after overwintering in soil. In the work of Bach et al. [61], harvest date had no effect on the DM content of JA tubers.

In turn, Praznik et al. [62] reported a decrease in the DM content of tubers that were left in the soil for winter and harvested in spring. Additionally, in the present study, JA tubers harvested in autumn had a significantly higher DM content compared with those harvested in spring (Table 5). The DM content of tubers could be higher in autumn than in spring due to rapid biochemical changes, including oxidation (mainly of sugars), occurring in the respiration process.

In contrast, Danilčenko et al. [60] observed that the DM content of organically grown JA tubers (cvs. Albik, Rubik, and Sauliai) was significantly higher in spring after overwintering in frozen soil.

Total N concentration and, consequently, protein concentration in JA tubers are similar to or even higher than in potatoes or root vegetables [63]. However, the protein in JA tubers is characterized by very high biological value, and it contains all essential amino acids in highly desirable proportions. In comparison with potato protein, JA protein is also a richer source of methionine [64]. In a study of more than 110 open-pollinated genotypes of JA, total N concentration in tubers ranged from 6.95 to 21.79 g kg^{-1} DM [65]. Total N concentration and protein concentration increased up to the N fertilizer rate of 60 kg ha^{-1} and remained unchanged in response to higher N rates (90 or 120 kg ha^{-1}) [66]. In a study by Žaldarienė et al. [28], total protein concentration in JA tubers ranged from 51.2 to 77.9 g kg^{-1} DM. In another experiment, the protein content in tubers in wild-growing JA populations varied between 62.3 and 107.1 g kg^{-1} DM [67].

In the current experiment, similarly to the study by Sawicka and Kalembasa [68], the protein content of JA tubers was conditioned by genotype. The N content of tubers in cv. Albik was similar to that in cv. Rubik but significantly lower than in cv. Gute Gelbe (Table 5). In contrast, Sawicka and Kalembasa [68] reported that protein concentration was considerably higher in cv. Rubik than in cv. Albik. The application of P and K fertilizers increased the total protein content of tubers relative to the control treatment.

Jerusalem artichoke tubers contain crude ash with a high concentration of alkaline minerals [69,70], mostly K (480–760 g kg^{-1}) [27,70,71]. They also contain Mg (14.0 g kg^{-1}), Ca (11.0 g kg^{-1}), and Na (1.3 g kg^{-1}) [70]. Ekholm et al. [72] found that JA tubers contained K (32.10 g kg^{-1} DM), Ca (0.89 g kg^{-1} DM), Mg (1.12 g kg^{-1} DM), and P (2.80 g kg^{-1} DM). According to Afoakwah et al. [73], freeze-dried and oven-dried pulverized JA tubers contained (in g kg^{-1}, respectively) Ca (1.85 and 1.93), K (10.83 and 10.56), P (3.85 and 4.17), and Na (0.14 and 0.15).

In a study by Skiba and Sawicka [26], the average macronutrient concentrations in JA tubers were arranged in the following descending order: K (26.29 g kg^{-1} DM) > P (2.92 g kg^{-1} DM) > Ca (1.45 g kg^{-1} DM) > Mg (0.81 g kg^{-1} DM). Genetic factors significantly influenced the concentrations of K and Ca in JA tubers [26]. Cultivar Rubik had significantly higher concentrations of P, K, Mg, and N, whereas cv. Violet de Rennes accumulated most Ca. The above authors [74,75] reported higher concentrations of Ca and Mg in cv. Rubik, whereas cv. Albik contained more K and Na. Catania et al. [76] demonstrated that red-skinned tubers were generally a richer source of minerals than white-skinned tubers. On the other hand, in the present study, the tubers of cv. Rubik (red-skinned) had the highest Na content, whereas the content of other components was higher in light-skinned tubers, in particular cv. Gute Gelbe (Table 5). Jerusalem artichoke tubers had a high concentration of K (19.05–21.00 g kg^{-1} DM) and contained significant amounts of P (3.00–3.45 g kg^{-1} DM), Mg (0.85–0.90 g kg^{-1} DM), and Ca (0.50–0.57 g kg^{-1} DM) [76]. In wild-growing JA populations in Turkey [67], tubers contained 3–4 times more Ca (1.57–2.07 g kg^{-1} DM) and around 30% more K (21.62–26.25g kg^{-1} DM) than the tubers analyzed in the present study (Table 5). In turn, the concentrations of Mg (1.71 and 1.96 g kg^{-1} DM) and P (2.59 and 4.79 g kg^{-1} DM) were similar to those noted in this study.

Biel et al. [58] reported that total protein concentration and crude ash concentration in JA tubers increased with a rise in the rate of biomass ash fertilizer. In turn, the crude protein concentration decreased significantly in tubers fertilized with sewage sludge. Sewage sludge increased crude ash content but decreased the protein concentration in JA tubers relative to the control treatment. According to Gao et al. [12], the tuber yield of JA grown in a semi-arid area, and the concentrations of N and C in tubers can be effectively increased by removing inflorescences.

Macronutrient concentrations in JA tubers and aboveground plant parts are determined by the fertilizer rate. Nitrogen fertilizer increased the concentrations of N, Mg, S, and N in aerial biomass [77]. Potassium and Ca concentrations in aerial biomass were highest in treatments fertilized only with P and K. In turn, aerial biomass in the unfertilized control treatment was highest in P. Macronutrient concentrations in aboveground plant parts were higher in cv. Albik than in cv. Rubik. In cv. Rubik, the mineral composition of aerial biomass was more stable. In a study of 26 JA clones grown in China (pre-planting fertilization, kg ha^{-1}: N—150; P_2O_5—75; K_2O—120), N concentration (6.85–5.72 g kg^{-1}) and K concentration (2.45–4.59 g kg^{-1}) were lower in tubers at harvest than in aerial biomass (9.33–22.66 g N kg^{-1} and 14.53–20.38 g K kg^{-1}), whereas P concentration was higher (2.53–3.65 g kg^{-1}) in tubers [78].

Izsáki and Kádi [14] observed great differences in the specific macronutrient uptake by two JA varieties, as there was a substantial deviation in the ratio of the tubers and leafy stalks in the maximum dry matter mass (1:1 for cv. Tápiói Korai and 1:4.5 for cv. Tápiói Sima). The specific nutrient uptake required for 10 t tuber yield plus the corresponding leafy stalks was 48 kg N, 10 kg P, 83 kg K, 30 kg Ca, and 10 kg Mg for Tápiói Korai, and 162 kg N, 30 kg P, 300 kg K, 84 kg Ca, and 45 kg Mg for Tápiói Sima. Depending on the cultivar, the share of tubers in the accumulation of components was N—86 and 65%; P—91 and 64%; K—86 and 45%; Ca—20 and 4%; and Mg—55 and 8% (cvs. Tápiói Korai and Tápiói Sima, respectively).

5. Conclusions

The warm and moderately wet growing season of 2018 created the most favorable conditions for the development of JA plants and the achievement of high yields (excluding aerial biomass yield in cv. Albik). Tuber yield was highest in cv. Gute Gelbe. In this cultivar, tuber and aerial biomass yields increased with a rise in the N fertilizer rate to 120 kg N ha^{-1}, as demonstrated by high agronomic N-use efficiency. The evaluated JA cultivars differed in their responses to an increase in the N fertilizer rate from 80 to 120 kg ha^{-1}. The strongest response was observed in cv. Gute Gelbe, where tuber yield increased by 172.6 kg kg^{-1} N. Nitrogen was least effective in cv. Albik, where an increase in the N rate from 80 to 120 kg ha^{-1} increased tuber yield by only 2.1 kg kg^{-1} N. Jerusalem artichoke tubers from the control treatment (without N fertilization) and from the treatment with 80 kg N ha^{-1} were characterized by higher DM than after the application of 120 kg N ha^{-1}. Tubers harvested in autumn were characterized by a higher content of DM than those harvested in spring. The concentrations of N, K, Mg, and S were highest in the tubers of cv. Gute Gelbe, and the highest concentration of Na was determined in the tubers of cv. Rubik. Tubers harvested in spring were characterized by higher concentrations of the analyzed macronutrients (excluding Mg) than those harvested in autumn. Macronutrient (excluding Ca) uptake by tubers was highest in JA plants fertilized with 120 kg N ha^{-1}. Cultivar Gute Gelbe was characterized by the highest tuber yield, the highest macronutrient concentration, and the highest macronutrient uptake. Nitrogen fertilization did not cause differences in the concentrations of P, K, Ca, Mg, and S, but it increased the N concentration in tubers. Cultivar Gute Gelbe can be recommended for cultivation in high-input farms that use high rates of N fertilizers, which allow to achieve high tuber yields. The tuber yields of cvs. Albik and Rubik, grown without N fertilization or fertilized with low N rates, are lower, but their cultivation is more environmentally friendly and less expensive.

Author Contributions: Conceptualization, methodology, B.C.-A., B.B., methodology and formal analysis, J.W., writing—original draft preparation, J.W., B.C.-A., B.B. All authors have read and agreed to the published version of the manuscript.

Funding: Project financially supported by Minister of Education and Science in the range of the program entitled "Regional Initiative of Excellence" for the years 2019–2022, Project No. 010/RID/2018/19, amount of funding 12 000 000 PLN.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The results presented in this paper were obtained as part of a comprehensive study financed by the University of Warmia and Mazury in Olsztyn, Faculty of Agriculture and Forestry, Department of Agricultural and Environmental Chemistry (grant No. 30.610.003-110) and Department of Agrotechnology and Agribusiness (grant No. 30.610.013-110).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kays, S.J.; Nottingham, S.F. *Biology and Chemistry of Jerusalem Artichoke: Helianthus tuberosus L.*; CRC Press/Taylor & Francis Group: London, UK, 2008; ISBN 9781420044959.
2. Breton, C.; Kiru, S.D.; Berville, A.; Anushkevich, N.Y. Breeding of Jerusalem Artichoke with the desired traits for different directions of use: Retrospective, approaches and prospects. *Agric. Biol.* **2017**, *52*, 940–951. [CrossRef]
3. Rejestrupraw.arimr.gov.pl. Available online: https://rejestrupraw.arimr.gov.pl/# (accessed on 14 July 2021). (In Polish)
4. Bolibok, Ł. Energy value of the straw of selected Jerusalem artichoke cultivars. *Episterme* **2011**, *12*, 15–20. (In Polish)
5. Sawicka, B. Energy value Jerusalem artichoke (*Helianthus tuberosus* L.) as a source of biomass. *Zesz. Nauk. UP Wrocław. Rol.* **2010**, *97*, 245–256. (In Polish)
6. Liava, V.; Karkanis, A.; Danalatos, N.; Tsiropoulos, N. Cultivation Practices, Adaptability and Phytochemical Composition of Jerusalem Artichoke (*Helianthus tuberosus* L.): A Weed with Economic Value. *Agronomy* **2021**, *11*, 914. [CrossRef]
7. Zelenkov, N.; Romanova, N.G. Jerusalem Artichoke: An Agrobiological Portrait and Prospects for Innovative Using. Available online: https://www.topinambour.ru/information/170914195656.html (accessed on 14 October 2019).
8. Yang, L.; He, Q.S.; Corscadden, K.; Udenigwe, C.C. The prospects of Jerusalem artichoke in functional food ingredients and bioenergy production. *Biotechnol. Rep.* **2015**, *5*, 77–88. [CrossRef]
9. Antonkiewicz, J.; Kołodziej, B.; Bielińska, E.J.; Witkowicz, R.; Tabor, S. Using Jerusalem Artichoke to Extract Heavy Metals from Municipal Sewage Sludge Amended Soil. *Pol. J. Environ. Stud.* **2018**, *27*, 513–527. [CrossRef]
10. Zhang, F.; Tai, F.N.; Brestic, M. Jerusalem artichoke (*Helianthus tuberosus*), a medicinal salt-resistant plant has high adaptability and multiple-use values. *J. Med. Plants Res.* **2011**, *5*, 1272–1279.
11. Rossini, F.; Provenzano, M.E.; Kuzmanovíc, L.; Ruggeri, R. Jerusalem Artichoke (*Helianthus tuberosus* L.): A Versatile and Sustainable Crop for Renewable Energy Production in Europe. *Agronomy* **2019**, *9*, 528. [CrossRef]
12. Gao, K.; Zhang, Z.; Zhu, T.; Coulter, J.A. The influence of flower removal on tuber yield and biomass characteristics of *Helianthus tuberosus* L. in a semi-arid area. *Ind. Crops Prod.* **2020**, *150*, 112374. [CrossRef]
13. Fang, Y.R.; Liu, J.A.; Steiberger, Y.; Xie, G.H. Energy use efficiency and economic feasybility of Jerusalem artichoke production on arid and coastal saline lands. *Ind. Crops Prod.* **2018**, *117*, 131–139. [CrossRef]
14. Izsáki, Z.; Kádi, G.N. Biomass acumulation and nutrient uptake of Jerusalem artichoke (*Helianthus tuberosus* L.). *Am. J. Plant Sci.* **2013**, *4*, 1629–1640. [CrossRef]
15. Bogucka, B.; Pszczółkowska, A.; Okorski, A.; Jankowski, K. The Effects of Potassium Fertilization and Irrigation on the Yield and Health Status of Jerusalem Artichoke (*Helianthus tuberosus* L.). *Agronomy* **2021**, *11*, 234. [CrossRef]
16. Soja, G.; Haunold, E. Leaf gas exchange and tuber yield in Jerusalem artichoke (*Helianthus tuberosus* L.) Cultivars. *Field Crops Res.* **1991**, *26*, 241–252. [CrossRef]
17. Amtmann, A.; Armengaud, P. Effects of N, P, K and S on metabolism: New knowledge gained from multi-level analysis. *Curr. Opin. Plant Biol.* **2009**, *12*, 275–283. [CrossRef] [PubMed]
18. He, C.H.; Wang, H.X.; Liu, W.B.; Deng, G.X. The study on neonatal pig anaemia treatment with *Helianthus tuberosus*. *China Anim. Husb. Vet. Med.* **2010**, *37*, 194–195.
19. EL-Anany, A.M.A.; Anany, T.G. Effect of some mineral nutrients on productivity, tuber seed quality and storability of Jerusalem artichoke. *Middle East J. Agric. Res.* **2020**, *9*, 779–790. [CrossRef]
20. Swanton, C.J.; Clements, D.R.; Moore, M.J.; Cavers, P.B. The biology of Canadian weeds. 101. *Helianthus tuberosus* L. *Can. J. Plant Sci.* **1992**, *72*, 1367–1382. [CrossRef]
21. Florkiewicz, A.; Cieślik, E.; Filipiak-Florkiewicz, A. The cultivar and harvesting time influence on the chemical composition in tubers of Jeruzalem artichoke (*Helianthus tuberosus* L.). *Żywność. Nauka. Technol. Jakość.* **2007**, *3*, 71–81. (In Polish)
22. Černiauskienė, J.; Kulaitienė, J.; Jarienė, E.; Danilčenko, H.; Žaldarienė, S.; Jeznach, M. Relationship between harvesting time and carbohydrate content of Jerusalem artichoke (*Helianthus tuberosus* L.) tubers. *Acta Sci. Pol. Hortorum Cultus* **2018**, *17*, 41–48. [CrossRef]
23. Bogucka, B.; Jankowski, K. Jerusalem Artichoke: Quality Response to Potassium Fertilization and Irrigation in Poland. *Agronomy* **2020**, *10*, 1518. [CrossRef]
24. Saengthongpinit, W.; Sajjaanantakul, T. Influence of harvest time and storage temperature on characteristics of inulin from Jerusalem artichoke (*Helianthus tuberosus* L.) tubers. *Postharvest Biol. Technol.* **2005**, *37*, 93–100. [CrossRef]
25. Danilčenko, H.; Jariené, E.; Gajewski, M.; Sawicka, B.; Kulaitiene, J.; Cerniauskiene, J. Changes in amino acids content in tubers of jerusalem artichoke (*Helianthus tuberosus* L.) cultivars during storage. *Acta Sci. Pol. Hortorum Cultus* **2013**, *12*, 97–105.
26. Skiba, D.; Sawicka, B. The influence of the genetic properties and the content of selected minerals in tubers of *Helianthus tuberosus* L. *Herbalism* **2016**, *1*, 128–137. (In Polish) [CrossRef]

27. Góral, S. Jerusalem artichoke—*Helianthus tuberosus*. In *New Crops for Food, Industrial and as Sources Renewable Energy*; Warsaw University of Life Sciences Press: Warsaw, Poland, 1996; pp. 76–86. (In Polish)
28. Žaldarienė, S.; Kulaitienė, J.; Černiauskienė, J. The quality comparison of different Jerusalem artichoke (*Helianthus tuberosus* L.) cultivars tubers. *Žemės Ūkio Mokslai* **2012**, *19*, 268–272. [CrossRef]
29. Harmankaya, M.; Al Juhaimi, F.; Özcan, M.M. Mineral Contents of Jerusalem Artichoke (*Helianthus tuberosus* L.) Growing Wild in Turkey. *Anal. Lett.* **2012**, *45*, 2269–2275. [CrossRef]
30. IUSS Working Group WRB. World Reference Base for Soil Resources. In *International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*; World Soil Resources Reports 106; FAO: Roma, Italy, 2015; p. 188.
31. Polish Standard PN-ISO 10390. *Soil Quality—Determination of Soil pH*; Polish Committee for Standardization: Warsaw, Poland, 1997; p. 15. (In Polish)
32. Polish Standard PN-R-04023. Chemical analysis of agricultural soils. In *Determination of Available Phosphorus Content in Mineral Soils*; Polish Committee for Standardization: Warsaw, Poland, 1996; p. 12. (In Polish)
33. Polish Standard PN-R-04022(1996)+Az1:2002. Chemical analysis of agricultural soils. In *Determination of Available Potassium Content in Mineral Soils*; Polish Committee for Standardization: Warsaw, Poland, 1996; p. 4. (In Polish)
34. Polish Standard PN-R-04020:1994+Az1:2004. Chemical analysis of agricultural soils. In *Determination of Available Magnesium Content in Mineral Soils*; Polish Committee for Standardization: Warsaw, Poland, 1994; p. 4. (In Polish)
35. Navarre, R.; Pavek, M. *The Potato: Botany, Production and Uses*; CABI: Boston, MA, USA, 2014; p. 370.
36. Dobermann, A. Nitrogen Use Efficiency: Measurement and Management. In *Fertilizer Best Management Practices*; Krauss, A., Isherwood, K., Heffer, P., Eds.; IFA: Paris, France, 2007; pp. 1–28.
37. Ostrowska, A.; Gawliński, S.; Szczubiałka, Z. *Methods of Analysis and Assessment of Soil and Plant Properties*; Institute of Environmental Protection: Warsaw, Poland, 1991; pp. 334–340. (In Polish)
38. Khan, A.H. Improvement of Total Sulphur Measurement Techniques for Management of Reactive Mine Tailings. Master's Thesis, The University of Western Ontario, London, ON, Canada, 2012; p. 855.
39. Statsoft Inc. *Statistica (Data Analysis Software System)*, 10th ed.; Statsoft Inc.: Tulsa, OK, USA, 2011. Available online: http://www.statsoft.com (accessed on 1 April 2020).
40. Skiba, D.; Sawicka, B. Effect of mineral fertilization on the yield and shape of tubers of *Helianthus tuberosus*. *Agron. Sci.* **2017**, *72*, 155–166. (In Polish) [CrossRef]
41. Rodrigues, M.A.; Sousa, L.; Cabanas, J.E.; Arrobas, M. Tuber yield and leaf mineral composition of Jerusalem artichoke (*Helianthus tuberosus* L.) Grown under different cropping practices. *Span. J. Agric. Res.* **2007**, *5*, 545–553. [CrossRef]
42. Baldini, M.; Danuso, F.; Monti, A.; Amaducci, M.T.; Stevanato, P.; Mastro, G. Chichory and Jerusalem artichoke productivity in different areas of Italy, in relation to water availability and time of harvest. *Ital. J. Agron. Riv. Agron.* **2006**, *2*, 291–307. [CrossRef]
43. Losavio, N.; Lamascese, N.; Vonella, A.V. Water requirements and nitrogen fertilization in Jerusalem artichoke (*Helianthus tuberosus* l.) grown under mediterranean conditions. *Acta Hort.* **1997**, *449*, 205–209. [CrossRef]
44. Schittenhelm, S. Agronomic performance of root chicory, Jerusalem artichoke and sugarbeet in stress and non-stress environment. *Crop Sci.* **1999**, *39*, 1815–1823. [CrossRef]
45. Sun, X.E.; Meng, X.F.; Liu, Z.P.; Long, X.H. Effects of nitrogen and phosphorus interaction on the tuber yield and its quality of Jerusalem artichoke. *Chin. J. Ecol.* **2013**, *32*, 363–367.
46. El-Araby, S.M. Effect of biofertilization under nitrogen fertilization rates on growth, yield and chemical constituents of jerusalem artichoke tubers. *Adv. Agric. Res.* **2004**, *9*, 55–68.
47. Stolarski, M.; Krzyzaniak, M.; Warmiński, K.; Tworkowski, J.; Szczukowski, S. Perennial herbaceous crops as a feedstock for energy and industrial purposes: Organic and mineral fertilizers versus biomass yield and efficient nitrogen utilization. *Ind. Crops Prod.* **2017**, *107*, 244–259. [CrossRef]
48. Gao, K.; Zhu, T.; Wang, Q. Nitrogen fertilization, irrigation, and harvest times affect biomass and energy value of *Helianthus tuberosus* L. *J. Plant Nutr.* **2016**, *39*, 1906–1914. [CrossRef]
49. Prośba-Białczyk, U. Productivity of jerusalem artichoke (*Helianthus tuberosus* L.) cultivated without fertilization). *Fragm. Agron.* **2007**, *24*, 106–112. (In Polish)
50. Szpunar-Krok, E.; Bobrecka-Jamro, D.; Grochowska, S.; Buczek, J. Yield of the aboveground parts and tubers of Jerusalem artichoke (*Helianthus tuberosus* L.) depending on plant density. *Acta Sci. Pol. Agric.* **2016**, *15*, 69–78.
51. Long, X.H.; Mehta, S.K.; Liu, Z.P. Effect of NO_3^- -N enrichment on seawater stress tolerance of Jerusalem artichoke (*Helianthus tuberosus*). *Pedosphere* **2008**, *18*, 113–123. [CrossRef]
52. Pimsaen, W.; Jogloy, S.; Suriharn, B.; Kesmala, T.; Pensuk, V.; Patanothai, A. Genotype by Environment (GxE) Interactions for Yield Components of Jerusalem Artichoke (*Helianthus tuberosus* L.). *Asian J. Plant Sci.* **2010**, *9*, 11–19. [CrossRef]
53. Matias, J.; Gonzales, J.; Cabanillas, J.; Royano, L. Influence of NPK fertilisation and harvest date on agronomic performance of Jerusalem artichoke crop in the Guadiana Basin (Southwestern Spain). *Ind. Crops Prod.* **2013**, *48*, 191–197. [CrossRef]
54. Cui, Z.L.; Zhang, F.S.; Chen, X.P.; Miao, Y.X.; Li, J.L.; Shi, L.W.; Xu, J.F.; Ye, Y.L.; Liu, C.S.; Yang, Z.P.; et al. On-farm estimation of indigenous nutrient supply for site-specific nitrogen management in the North China plain. *Nutr. Cycl. Agroecosys.* **2008**, *81*, 37–47. [CrossRef]
55. Grzebisz, W.; Čermák, P.; Rroco, E.; Szczepaniak, W.; Potarzycki, J.; Füleky, G. Potassium impact on nitrogen use efficiency in potato—A case study from the Central-East Europe. *Plant Soil Environ.* **2017**, *63*, 422–427. [CrossRef]

56. Awgchew, H.; Gebremedhin, H.; Taddesse, G.; Alemu, D. Influence of Nitrogen Rate on Nitrogen use Efficiency and Quality of Potato (*Solanum tuberosum* L.) Varieties at Debre Berhan, Central Highlands of Ethiopia. *Int. J. Soil Sci.* **2017**, *12*, 10–17. [CrossRef]
57. Niemiec, M.; Szeląg-Sikora, A.; Cupiał, M. Evaluation of the Efficiency of Celeriac Fertilization with the Use of Slow-acting Fertilizers. *Agric. Agric. Sci. Procedia* **2015**, *7*, 177–183. [CrossRef]
58. Biel, W.; Jaroszewska, A.; Zapałowska, A.; Łysoń, E.; Hury, G. Influence of fertilisation with ash from conifers biomass and sewage sludge on selected nutrients in tubers of Jerusalem artichoke (*Helianthus tuberosus* L.). *Acta Agroph.* **2017**, *24*, 17–28. (In Polish)
59. Barta, J.; Patkai, G. Chemical composition and storability of Jerusalem artichoke tubers. *Acta Aliment. Hung.* **2007**, *36*, 257–267. [CrossRef]
60. Danilčenko, H.; Jariene, E.; Slepetiene, A.; Sawicka, B.; Zaldariene, S. The distribution of bioactive compounds in the tubers of organically grown Jerusalem artichoke (*Helianthus tuberosus* L.) during the growing period. *Acta Sci. Pol. Hortorum Cultus* **2017**, *16*, 97–107. [CrossRef]
61. Bach, V.; Kidmose, U.; Bjørn, G.K.; Edelenbos, M. Effects of harvest time and variety on sensory quality and chemical composition of Jerusalem artichoke (*Helianthus tuberosus*) tubers. *Food Chem.* **2012**, *133*, 82–89. [CrossRef]
62. Praznik, W.; Cieślik, E.; Filipiak, A. The influence of harvest time on the content of nutritional components in tubers of Jerusalem artichoke (*Helianthus tuberosus* L.). In Proceedings of the Seventh Seminar on Inulin, Louvain, Belgium, 22–23 January 1998; pp. 154–157.
63. Catană, L.; Catană, M.; Iorga, E.; Lazăr, A.G.; Lazăr, M.A.; Teodorescu, R.I.; Asănică, A.C.; Belc, N.; Iancu, A. Valorification of Jerusalem Artichoke Tubers (Helianthus tuberosus) for Achieving of Functional Ingredient with High Nutritional Value. *"Agric. Life Life Agric." Conf. Proc.* **2018**, *1*, 276–283. [CrossRef]
64. Terzić, S.; Atlagić, J. Nitrogen and sugar content variability in tubers of Jerusalem artichoke (*Helianthus tuberosus*). *Genetika* **2009**, *41*, 289–295. [CrossRef]
65. Feleafel, M.N. Effect of ntirogen and potassium fertilization and their interactions on growth, yield and quality of Jerusalem artichoke. *J. Agric. Environ. Sci. Alex. Univ. Egypt* **2004**, *3*, 59–74.
66. Seiler, G.J. Protein and mineral concentrations in tubers of selected genotypes of wild and cultivated Jerusalem artichoke (*Helianthus tuberosus*, Asteraceae). *Econ. Bot.* **1990**, *44*, 322–335. [CrossRef]
67. Cieślik, E.; Gębusia, A.; Florkiewicz, A.; Mickowska, B. The content of protein and of amino acids in Jerusalem artichoke tubers (*Helianthus tuberosus* L.) of red variety Rote Zonenkugel. *Acta Sci. Pol. Technol. Aliment.* **2011**, *10*, 433–441. [PubMed]
68. Sawicka, B.; Kalembasa, S. Fluctuation of Protein Nitrogen Level in Tubers of *Helianthus tuberosus* L. Caused by Varying Levels of Nitrogen Fertilisation. *Ecol. Chem. Eng. A* **2013**, *20*, 213–223. [CrossRef]
69. De Santis, D.; Frangipane, M.T. Evaluation of chemical composition and sensory profile in Jerusalem artichoke (*Helianthus tuberosus* L.) tubers: The effect of clones and cooking conditions. *Int. J. Gastro. Food Sci.* **2018**, *11*, 25–30. [CrossRef]
70. Cieślik, E. The content of minerals in tubers of new varieties of Jerusalem artichoke (*Helianthus tuberosus L.*). *Zesz. Nauk. AR Krak.* **1998**, *10*, 23–30. (In Polish)
71. Barta, J.; Fodor, P.; Torok, S.Z.; Vukov, K. Mineral components and micro-elements in Jerusalem artichoke tubers grow in Hungary. *Acta Aliment. Hung.* **1990**, *19*, 41–46.
72. Ekholm, P.H.; Reinivuo, P.; Mattila, H.; Pakkala, J.; Koponen, A.; Happonen, J.; Hellström Ovaskainen, M.L. Changes in the mineral and trace element contents of cereals, fruits and vegetables in Finland. *J. Food Comp. Anal.* **2007**, *20*, 487–495. [CrossRef]
73. Afoakwah, N.A.; Dong, Y.; Zhao, Y.; Xiong, Z.; Owusu, J.; Wang, Y.; Zhang, J. Characterization of Jerusalem artichoke (*Helianthus tuberosus* L.) powder and its application in emulsion-type sausage. *LWT—Food Sci. Technol.* **2015**, *64*, 74–81. [CrossRef]
74. Danilčenko, H.; Jariené, E.; Gajewski, M.; Cerniauskiene, J.; Kulaitiene, J.; Sawicka, B.; Aleknaviciene, P. Accumulation of elements in some organically grown alternative horticultural crops in Lithuania. *Acta Sci. Pol. Hortorum Cultus* **2011**, *10*, 23–31.
75. Sawicka, B.; Danilčenko, H.; Jariene, E.; Skiba, D.; Rachoń, L.; Barbaś, P.; Pszczółkowski, P. Nutritional Value of Jerusalem Artichoke Tubers (*Helianthus tuberosus* L.) Grown in Organic System under Lithuanian and Polish Conditions. *Agriculture* **2021**, *11*, 440. [CrossRef]
76. Jarienė, E.; Jeznach, M.; Danilčenko, H.; Žaldarienė, S.; Tarasevičienė, Ž.; Wawrzyniak, A.; Tul-Krzyszczuk, A. Distribution of macronutrients in organically grown Jerusalem artichoke (*Helianthus tuberosus* L.) tubers throughout the growing period. *J. Element.* **2016**, *21*, 1315–1325. [CrossRef]
77. Sawicka, B.; Kalembasa, D.; Skiba, D. Variability in macroelement content in the aboveground part of *Helianthus tuberosus* L. at different nitrogen fertilization levels. *Plant Soil Environ.* **2015**, *61*, 158–163. [CrossRef]
78. Fu, T.; Liu, Z.; Yang, Y.; Xie, G.H. Accumulation and concentration of nitrogen, phosphorus and potassium in Jerusalem artichoke in a semi-arid region. *Ital. J. Agron.* **2018**, *13*, 185–193. [CrossRef]