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ORIGINAL PAPER

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THE EFFECT OF NITROGEN FERTILIZATION ON YIELD AND MACRONUTRIENT CONCENTRATIONS IN ROOT CHICORY (*Cichorium intybus* L. var. *Sativus* Bisch) AND THE HEALTH STATUS OF PLANTS

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ABSTRACT

The effect of N fertilization on the health status of chicory plants, yield and the content of dry matter and macronutrients in chicory roots was determined in the study. Three root chicory cultivars, Polanowicka, Orchies and Chrysolite, were grown in a plot experiment. Three levels of topsoil N fertilization were applied before sowing: 0, 80 and 120 kg ha^{-1}. The severity of leaf diseases was estimated during the growing season. Root yield, agronomic and marginal N-use efficiency, DM content and macronutrient concentrations in roots were calculated after harvest (10–20 October). The symptoms of powdery mildew, gray mold and leaf spot on chicory leaves were significantly least severe in the unfertilized treatment. The highest yield (83 Mg ha^{-1}) was obtained in 2017, in cv. Chrysolite without N fertilization. Root yield decreased in response to the application of N fertilizer at both rates. A minor increase in yield was observed only in cv. Polanowicka in N-fertilized treatments in 2017, and in cv. Chrysolite fertilized with 80 kg N ha^{-1} in 2018. Root yield was negatively correlated with disease severity during the growing season. The DM content of chicory roots (mean values for years of the study, cultivars and N rates) was similar in all treatments. N fertilization induced changes in the content of N, K, Mg and S in chicory roots of the analyzed cultivars. The application of N fertilizer had a beneficial influence on the N content of roots in all cultivars.

Key words: *Cichorium intybus* L., nitrogen rate, root yield, N-use efficiency, macronutrient content

INTRODUCTION

Cichorium intybus L. (chicory) is a Mediterranean perennial plant species of the family Asteraceae. Chicory had been cultivated and used as a medicinal plant to treat liver, bile duct and kidney disorders already in ancient Egypt. Today chicory is widely grown in Europe, India, Central and Western Asia, Egypt, South Africa, the eastern United States, Brazil and Australia [Al-Snafi 2016]. Three *C. intybus* subspecies, *C. intybus* L. var. *foliosum* (Hegi) Bisch., *C. intybus* L. var. *silvestre* Bisch and *C. intybus* L. var. *sativus* Bishoff, have the greatest economic importance. Leaf chicory can be eaten raw as salad leaves, or cooked. The most popular and valuable leafy vegetables of the genus *Cichorium* in Europe (Belgium, the Nether-

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lands, France and Italy) are Belgian endive (*C. intybus* var. *foliosum)*, radicchio rosso (*C. intybus* var. *foliosum*) and endive (*C. endivia*) [Ivanišová et al. 2020]. In 2021, the area under chicory in Poland was nearly 1 700 ha [https://rejestrupraw.arimr.gov.pl/#]

Forage chicory is a rich source of protein, and it can be used as feedstuff for livestock [Nwafor et al. 2017]. Root chicory (*C. intybus* var. *sativum*) is cultivated mostly in Northwestern Europe (Belgium, the Netherlands), India, South Africa and Chile. In India and South Africa, root chicory is used as a coffee substitute – the roots are roasted and mixed with coffee beans. Inulin and the products of its hydrolysis – oligofructose and fructose are also derived from chicory roots [Gordon et al. 2018]. Recent years have witnessed a growing interest in the use of chicory in food production and dietary supplementation. Polyphenols, inulin (a source of soluble dietary fiber), oligofructose and sesquiterpene lactones found in chicory can be used as components of novel functional foods. Due to its prebiotic and health-improving properties, fructan (inulin) can be consumed by diabetics [Perović et al. 2021].

Cichorium intybus is a rich source of bioactive compounds for food fortification. According to Jangra and Madan [2018], the nutrient content of chicory roots (g kg^{-1} DM) is as follows: fat 65.40, protein 50.60, crude fiber 285.00, total carbohydrates 461.50, crude ash 38.70. According to other sources, chicory roots contain (g kg^{-1} DM): 704.3–907.7 carbohydrates (mostly fiber and sugars), 4.20–669.3 soluble fiber and 51.20–273.20 crude fiber [Zarroug et al. 2016, Nwafor et al. 2017, El Zeny et al. 2019]. All parts of chicory plants contain bioactive compounds such as inulin, sesquiterpene lactones, coumarins, vitamins, polyphenols (caffeic acid derivatives), natural flavonoids, alkaloids, terpenoids, oils, volatile compounds, sterols and tannins [Zarroug et al. 2016]. The bioactive compounds found in chicory roots exert antimicrobial, anti-inflammatory, antioxidant, hepatoprotective, tranquilizing, immunological, cardioprotective, hypolipidemic, antidiabetic, anticancer and gastroprotective effects [Al-Snafi 2016].

Chicory roots have a high content of Ca, K, Mg and Na [Biesiada and Kołota 2010, Aly et al. 2017, Nwafor et al. 2017, Ivanišová et al. 2020], which are essential for the human body due to their involvement in metabolism and other vital functions such as maintaining pH and osmotic pressure, regulating muscle contraction, and energy production. They also play a key role in growth, bone development, synthesis of vitamins, enzymes and hormones, normal functioning of the nervous system, blood circulation and maintaining cell integrity [Oliveira et al. 2012].

Plants need minerals for growth and development. The rational use of fertilizers, including N fertilizers, is an important consideration in sustainable agriculture. The health status of plants is affected by N fertilization. The following dangerous pathogens attack the aerial parts of chicory plants and decrease root yield: *Golovinomyces cichcoracearum* (powdery mildew), *Botrytis cinerea* (gray mold), *Puccinia cichorii* (chicory rust), *Alternaria cichorii, A. alternata, A. sonchi* and *Cercospora cichorii* (leaf spot) [Paz Lima et al. 2003, Trdan et al. 2004, Patkowska and Konopiński 2013]. The mineral content of plants is affected by environmental stresses (salinity, drought, extreme temperatures, excessive/insufficient light). Nitrogen deficiency can decrease crop yields and quality, whereas excess N can lead to nitrate leaching and, consequently, environmental pollution. Nitrogen supply must meet plant requirements to optimize N-use efficiency [Di and Cameron 2002, Wang et al. 2021].

Therefore, the aim of this study was to determine the effect of N fertilization on the health status of chicory plants, yield, agronomic N-use efficiency (AE) and macronutrient content of chicory roots.

MATERIALS AND METHODS

Location of the experiment and methodological assumptions

Three root chicory cultivars, Polanowicka (Poland), Orchies and Chrysolite (France), were grown in a plot experiment, conducted in 2016–2018 at the Agricultural Experiment Station in Tomaszkowo near Olsztyn (owned by the University of Warmia and Mazury in Olsztyn, (53°41'N, 20°24"E). The experiment was established on Eutric cambisol with the granulometric composition of medium loamy sand and loamy sand (agricultural suitability class 5, soil quality class IVb) [WRB 2015]). Before the experiment, the pH of the soil solution in 1 mol KCl dm^{-3} was determined at 5.04–5.54 in the topsoil layer of 0–20 cm (PN-ISO 10390:1997). Nutrient concentrations in soil were as follows: C_{org} – 9.40–9.85 g kg^{-1} (Elementar® Vario Max Cube CN elemental analyzer), total N – 0.71–0.76 g kg^{-1} (Kjeldahl distillation, KjelFlex K-360 distillation unit – BUCHI® Labortechnik AG, Switzerland) and available forms of P – 35.6–48.8 mg kg^{-1} (PN-R-04023:1996), K – 94.2–124.0 mg kg^{-1} (PN-R-04022: 1996/Az1:2002), Mg – 38.0–42.0 mg kg^{-1} (PN-R-04020:1994/Az1:2004), Ca – 350.0–517.0 mg kg^{-1} and S-SO_4^{2-} – 10.8–12.6 mg kg^{-1} (using the nephelometric method on the Shimadzu® UV 1201V, Japan) apparatus and Ca removable – 350.0–517.0 mg kg^{-1}.

Seeds were sown in the last ten days of April, in plots with an area of 3.6 m^2 (3 × 1.2 m) each, in three rows, 15 cm apart in each row, at row spacing of 40 cm. The prior crop was oats. The experiment had a randomized subblock design (split plot; blocks – levels of fertilization; subblocks – cultivars) with three replications. Three levels of topsoil N fertilization (granular urea – 46% N, single application) were applied one day before sowing: 0, 80 and 120 kg ha^{-1}. The fertilizer also included 32 kg P (granular triple superphosphate – 20.1% P) and 96 kg K (potash salt – 50% K) per ha^{-1}. Agronomic treatments were identical in all plots. Weeds were controlled mechanically (hoeing). Roots were harvested between 10 and 20 October, and were weighed with an electronic scale (Wagi Tarczyn WT 125).

Severity of chicory leaf diseases

The severity of powdery mildew (*Golovinomyces cichoracearum*), gray mold (*Botrytis cinerea*) and leaf spot (*Alternaria cichorii*, *Alternaria* spp., *Cercospora cichorii*) was evaluated twice during the experiment on 25 chicory plants in each of three plots per treatment, on a 5-point scale, where 0° – no symptoms, 5° – more than 50% of leaf area has been infected. The results were expressed as a percentage by calculating the infestation index Ii [Łacicowa 1970].

Nitrogen-use efficiency

The following indices of N-use efficiency were calculated:

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

$$AE\ (\text{kg kg}^{-1}\ \text{N}) = (YN - Y0)/D$$

where: AE – agronomic efficiency;
YN – crop yield in response to the applied N fertilizer rate;
Y0 – crop yield in the control treatment;
D – N fertilizer rate (kg ha^{-1}).

2. Marginal N-use efficiency (ME)

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

where: ME – marginal efficiency;
ΔY – increase in yield in response to increased N fertilizer rate;
ΔD – increase in N fertilizer rate.

Chemical analysis

Five randomly selected chicory roots (with a total weight of approximately 0.5 kg) were collected from each plot for chemical analyses. Root dry weight was determined by the gravimetric method. After crushing, the roots (50 g) were pre-dried at 65–70°C, and then dried to constant weight at 105°C (SUP 100 W laboratory drier, WAMED, Poland). Before weighing, the samples were left in the desiccator until the achievement of room temperature 20°C (based on the results of three consecutive measurements).

The roots intended for chemical composition analysis were rinsed under running water, diced into 1 cm × 1 cm × 1 cm cubes, freeze dried (Alpha 1-4LD laboratory freeze-drier, Doncerv®-Martin Christ Gefriertrocknungsanlagen GmbH), and ground in a laboratory mill (A11 basic). The macronutrient content of *C. intybus* roots (N, P, K, Ca, Mg and Na) was determined in plant material mineralized in concentrated sulfuric acid (H_2SO_4) with the addition of hydrogen peroxide (H_2O_2) as the oxidant (BÜCHI Speed Digester K-439). The N content of mineralized plant material was determined by the Kjeldahl method (KjelFlex K-360 distillation unit); P content was determined by the colorimetric method in the presence of vanadium and molybdenum (Shimadzu UV 1201V spectrophotometer); the content of K, Ca, Na was determined by atomic emission spectrometry (AES; Jenway LTD PFP 7 flame photometer) and Mg content was determined by atomic absorption spectrometry (AAS; Shimadzu AA-6800 spectrophotometer) [Ostrowska et al. 1991]. Sulfur (S) content was determined with the nephelometric method [Ostrowska et al. 1991] in plant material mineralized in a mixture of chloric and nitric acids ($HClO_4$ and HNO_3, 1 : 1) with the addition of magnesium nitrate (V) ($Mg(NO_3)_2$).

Weather conditions

Weather conditions during the experiment are presented in Table 1. During the growing season, from sowing (April) to harvest (October), mean monthly air temperatures were comparable with the long-term average (1981–2010) in 2016, they were lower than the long-term average in 2017 (except in September and October), and higher than the long-term average in 2018. The first two growing seasons were wet (total precipitation levels exceeded the long-term average by 18.7% and 51.1%, respectively). Precipitation was within the norm (long term average) in the growing season of 2018. Throughout the experiment, abundant rainfall was noted in July as well as in September and October 2017. Low precipitation levels (more than two-fold lower than the long-term average) were recorded in May 2017 and 2018, and in September 2016 and 2018.

Statistical analysis

The results were processed statistically by analysis of variance (ANOVA), using the STATISTICA 13.3® software package. Differences between mean values were determined by Tukey's test at a significance level of $P < 0.05$. The relationships between root yield and infection index *Ii* (%) for chicory leaves were determined by linear regression analysis. The coefficients of linear correlation (Pearson's *r*) were calculated.

RESULTS AND DISCUSSION

Severity of chicory leaf diseases

The growing season of 2018, with relatively high temperatures and precipitation total close to the long-term average, was conducive to leaf colonization by *Golovinomyces cichoracearum*. The highest value of the Ii (54.3%) was noted in cv. Polanowicka (Tab. 2). The first two growing seasons, characterized by moderate temperatures and above-average rainfall amounts, provided better conditions for the development of the remaining pathogens, i.e. *Botrytis cinerea*, *Alternaria cichorii*, *Alternaria* spp. and *Cercospora cichorii.* The leaves of cvs. Polanowicka and Orchies were infected in more than 50% by *B. cinerea* in 2017. An analysis of the mean rates of infections caused by *Golovinomyces cichoracearum* and *Botrytis cinerea* revealed that Chrysolite was the healthiest cultivar. However, the differences between cultivars were not significant. In all chicory cultivars, the severity of the analyzed diseases was exacerbated by N fertilization, but the noted differences were not significant. Patkowska and Konopiński [2013] found that *A. alternata* and *B. cinerea* as well as *Rhizoctonia solani*, *Sclerotinia sclerotiorum* and selected *Fusarium* species exerted pathogenic effects on root chicory seedlings. In the cited study, cover crops (oats, phacelia and spring vetch)

Table 1. Weather conditions monitored by the Weather Station in Tomaszkowo

Year	Month							
	April	May	June	July	August	September	October	
	X Temperature °C							Mean
2016	7.4	13.7	17.1	18.1	17.1	13.6	6.1	13.3
2017	5.7	12.1	15.7	16.8	17.4	12.8	8.7	12.7
2018	10.8	15.7	17.2	19.7	19.2	14.5	8.7	15.1
1981–2010	7.7	13.5	16.1	18.7	17.9	12.8	8.0	13.5
	∑ Rainfall mm							Total
2016	28.8	56.9	69.3	130.4	70.4	21.1	104.3	481.2
2017	59.1	25.1	74.5	107.6	63.1	168.1	114.9	612.4
2018	33.5	25.0	53.7	141.0	44.6	20.3	84.7	402.8
1981–2010	33.3	58.5	80.4	74.2	59.4	56.9	42.6	405.3

Table 2. Effects of nitrogen rate and growing conditions on the severity of foliar diseases in root chicory (infestation index Ii)

Foliar disease	Cultivar	Nitrogen rate (kg ha^{-1})			Year of study			
		0	80	120	2016	2017	2018	Mean
Powdery mildew *Golovinomyces cichoracearum*	Polanowicka	22.8a*	42.2a	38.1 a	30.5ab**	18.3b	54.3a	34.4a
	Chrysolite	17.7a	24.1a	20.2 a	23.9b	12.5b	25.6b	20.7a
	Orchies	21.2a	31.4a	25.8 a	31.1ab	16.2b	31.0ab	26.1a
Mean		20.6a	32.6a	28.0a	28.5a	15.7b	37.0a	–
Gray mold *Botrytis cinerea*	Polanowicka	41.5ab	41.7ab	50.4ab	37.1b	59.8a	36.7b	44.5a
	Chrysolite	25.7b	47.0ab	43.9ab	35.9b	47.4ab	33.2b	38.9a
	Orchies	34.7a	54.9a	45.4ab	41.6ab	59.4a	34.0b	45.0a
Mean		34.0b	47.9a	46.6ab	38.2b	55.5a	33.6b	–
Leaf spot *Alternaria cichorii, Alternaria* spp., *Cercospora cichorii*	Polanowicka	17.2b	21.7ab	27.4ab	22.1a	20.9a	23.3a	22.1a
	Chrysolite	15.9b	31.1a	28.0ab	28.5a	25.2a	21.3a	25.0a
	Orchies	18.9b	31.3a	33.2a	33.9a	26.9a	22.7a	27.8a
Mean		17.4b	28.0a	29.5a	28.2a	24.3a	22.4a	–

* Values for N rate denoted by the same letters do not differ significantly at 5% error (Tukey's test)
** Values for year denoted by the same letters do not differ significantly at 5% error (Tukey's test)

reduced the severity of infections caused by the above pathogens. Rogers and Stevenson [2010] stated differences in the severity of Alternaria leaf blight between carrot cultivars, which were reflected in the total root yield. According to Töfoli et al. [2019], the planting of resistant varieties and balanced fertilization can be effective in protecting carrots against *Alternaria* spp.

Effect of nitrogen fertilization on chicory root yield. Assessment of chicory root yield by linear regression analysis

Chicory root yields ranged from 22.14 to 83.00 Mg ha^{-1}, depending on N fertilizer rate, cultivar and weather conditions in years of the study (Tab. 3). In all cultivars, the highest root yields were achieved in the control treatment (without N fertilization). The application of 80 and 120 kg N ka^{-1} decreased chicory root yields by 9.2% and 25.8%, respectively (mean values for years of the study and cultivars), compared with plants grown without N fertilization. In the growing season of 2016, characterized by moderate precipitation and temperature, the yield of cv. Polanowicka was nearly 1.5-fold lower than in the subsequent years. In all cultivars, the highest yields were noted in the moderately wet and warm year 2018. Chrysolite was the highest-yielding cultivar (62.45 Mg ha^{-1}), which was characterized by the most stable yields regardless of weather conditions. Polanowicka was the lowest-yielding cultivar (39.35 Mg ha^{-1}). In the present study, root yield was negatively correlated with disease severity during the growing season. Based on the calculated coefficients of correlation (Pearson's r), the strongest correlations were observed in 2017 due to infections caused by *Botrytis cinerea* ($r = -0.748$), *Alternaria cichorii*, *Alternaria* spp. and *Cercospora cichorii* ($r = -0.465$), and in 2018 due to the infection caused by *Golovinomyces cichoracearum* ($r = -0.495$) (Fig. 2a, b, c).

The selection of cultivars, which should be adapted to specific environmental conditions, and agronomic treatments, including N fertilization, are important factors influencing chicory root yields. In a study by Wilson et al. [2004], the root yield of cv. Orchies varied across years, from 43.1 to 47.4 Mg ha^{-1}. According to many authors, the fresh and dry matter yields of chicory roots vary across cultivars [Aly et al. 2017], which was also noted in the present experiment. Patel et al. [2000] demonstrated that the fresh and dry root yields increased with increasing N fertilizer rates up to 100 kg ha^{-1} (although the noted differences were

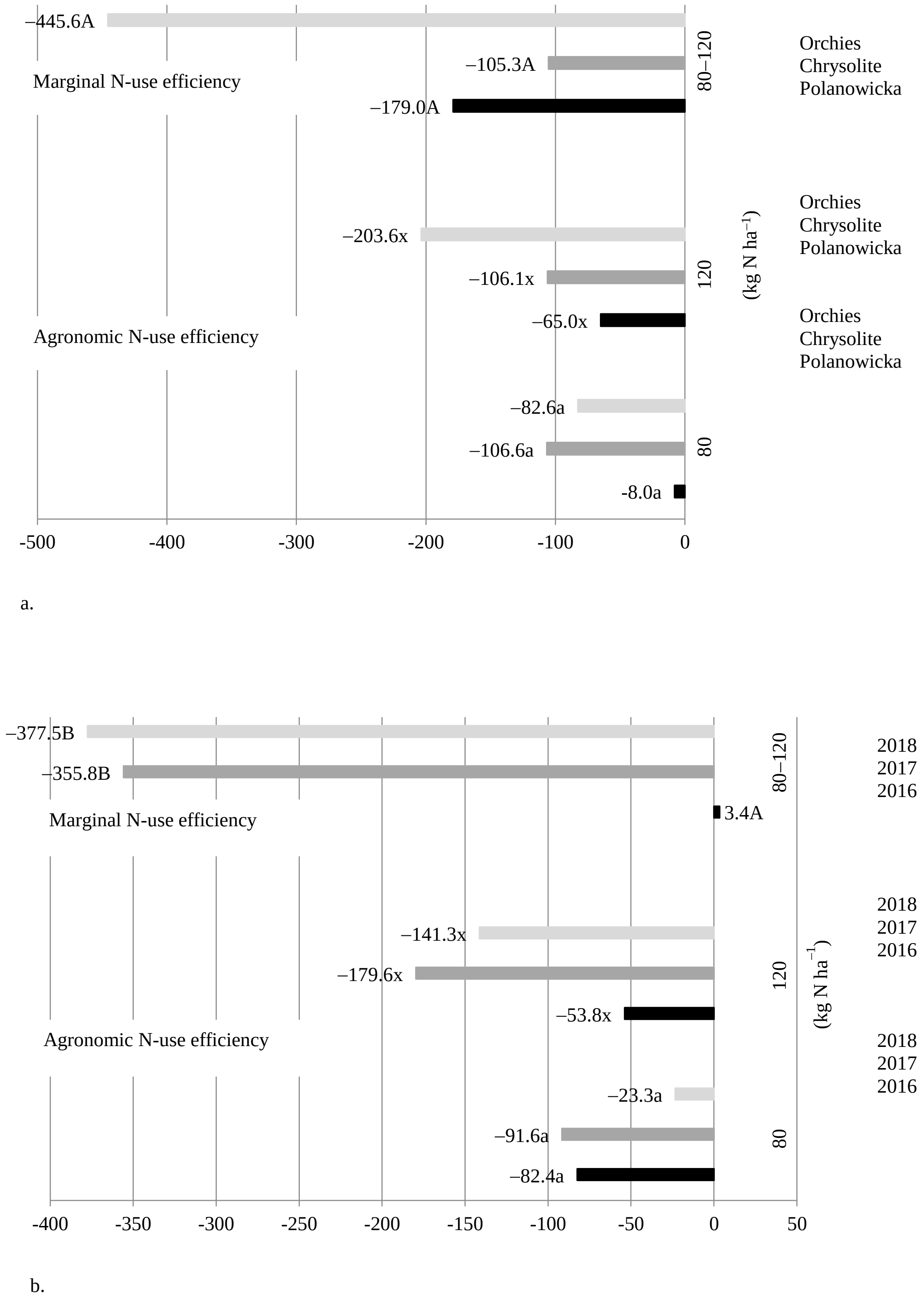


Fig. 1. Agronomic N-use efficiency (AE) and marginal N-use efficiency (ME): a. for cultivars, b. for years of the study (kg kg^{-1} N)

Table 3. Chicory root yields (Mg ha^{-1})

Factor interactions			Nitrogen rate (kg ha^{-1}) 0	80	120	Mean
Cultivar × year	Polanowicka	2016	35.14g-j*	29.56ij	22.14j	28.95D
		2017	41.39f-i	46.03e-i	47.86e-h	45.09C
		2018	49.89e-h	48.92e-h	33.03hij	43,94C
	Chrysolite	2016	57.56b-f	53.03c-f	58.06b-f	56.22B
		2017	83.00a	60.50b-e	45.58e-i	63.03AB
		2018	67.44a-d	68.89abc	67.98a-d	68.10A
	Orchies	2016	50.97d-g	41.31f-i	44.11e-i	45.47C
		2017	56.58b-f	52.47c-g	22.86j	43.97C
		2018	73.14ab	67.08a-d	40.42f-i	60.22AB
Mean			57.24X	51.98Y	42.47Z	–
Means for cultivars	Polanowicka		42.14c	41.50c	34.34c	39.35C
	Chrysolite		69,33a	60.81b	57.20b	62.45A
	Orchies		60.23b	53.62b	35.80c	49.89B
Means for years of the study	2016		47.89cd	41.31d	41.44d	43.55Z
	2017		60.33ab	53.00bc	38.78d	50.70Y
	2018		63.50a	61.64ab	47.23cd	57.46X

* Values denoted by the same letters do not differ significantly at 5% error (Tukey's test)

not significant). Biesiada and Kołota [2010] found that a single application of 150 kg N ha^{-1} before the growing season contributed to the highest marketable yield of radicchio chicory grown in fall. In the work of Aminian et al. [2020], the fresh root weight of common chicory peaked (18.5 Mg ha^{-1}) in response to the application of 100 kg N ha^{-1} with the simultaneous inoculation of seeds with *Azotobacter*. In a study by Baldini et al. [2006], who investigated the productivity of chicory fertilized with N applied pre-sowing and post-emergence, fresh root yield ranged from 38.7 to 65.6 Mg ha^{-1}.

Wilson et al. [2004] found that the yield of chicory roots was determined by planting and harvest dates – it increased with earlier planting and delayed harvest. Gajc-Wolska et al. [2012] reported that mineral-organic fertilizers had no effect on the yield or the content of DM and minerals in *C. endivia*; the values of these parameters were determined by planting and harvest dates.

Nitrogen fertilizer rates should be determined based on environmental conditions such as temperature and soil moisture content. Greyling [2010] found that N had no significant influence on the yields of root chicory grown in the dry regions of South Africa, and the application of 50 kg N ha^{-1} was required to achieve the acceptable yield of 22 Mg ha^{-1}. In an experiment conducted by Khaghani et al. [2012] in the hot and dry climate of Iran, the yield of root chicory grown on loamy soil, fertilized with N and irrigated, peaked in response to 150 kg of urea ha^{-1}, corresponding to 69 kg N ha^{-1}. In contrast to the warm climate of Iran and South Africa, in the colder climate of Europe and North America, the rates of N fertilizer should be reduced due to N leaching and the presence of residual N in soil. In an experiment established on irrigated sandy loam (containing residual N) in Switzerland, chicory root yield of satisfactory quality was achieved when 90 kg N h^{-1} was applied in split doses [Neuweiler et al. 2007]. In northern France, Loaëc et al. [2014] obtained the maximum and minimum root yields when chicory was fertilized with 30 and 120 kg N ha^{-1}, respectively. According to Eurostat [2012], the average yield of chicory in Belgium and the Netherlands, the two leading European producers, reached 46.8 t ha^{-1} and 42.7 t ha^{-1} in response to the application of 70 kg N ha^{-1}.

Effect of nitrogen fertilization on agronomic and marginal N-use efficiency

The analyzed chicory cultivars responded by a decrease in root yields to N fertilization at 80 and 120 kg ha^{-1}. The response was weakest in cv. Polanowicka (–7.9 and –65.0 kg kg^{-1} N, respectively) and strongest in cv. Orchies (–82.6 and –203.6 kg kg^{-1} N, respectively). The greatest yield decline per kg N (regardless of N fertilizer rate) was observed in 2017 (Fig. 1a, b).

An analysis of marginal N-use efficiency (ME revealed that an increase in N fertilizer rate from 80 to 120 kg ha^{-1} had an adverse effect on chicory root yields. The weakest negative response (105.3 kg kg^{-1} N) was noted in the highest-yielding cv. Chrysolite. In cv. Orchies, the increase in N fertilizer rate from 80 to 120 kg ha^{-1} decreased root yield by 445.6 kg kg^{-1} N. Only in 2016, root yield increased by 3.4 kg kg^{-1} N when N rate was increased from 80 to 120 kg ha^{-1} (Fig. 1a, b).

Agronomic N-use efficiency (AE) can provide a basis for establishing optimal N fertilizer rates in new crop varieties, including chicory. Research has shown that N-use efficiency is determined by N fertilization as well as genetic factors, weather conditions and agronomic treatments. In a study by Schittenhelm [1999], N-use efficiency was highest when root chicory was fertilized with 60 kg N ha^{-1}. Many authors have demonstrated that N-use efficiency decreases in response to increasing N fertilizer rates. Seghatoleslami et al. [2014] investigated chicory responses to N fertilization (0, 100 and 200 kg ha^{-1} N as urea) and found that root yield increased after the application of 200 kg N ha^{-1}, but N-use efficiency declined in the highest N treatment. Grzebisz et al. [2017] studied N-use efficiency in potatoes and found that AE values were lower at the N rate of 160 kg ha^{-1} than 120 kg ha^{-1} (i.e. 75% of the recommended rate). Awgchew et al. [2017] also demonstrated that N-use efficiency decreased with increasing N fertilizer rates in potatoes; the maximum AE (163 kg tubers kg^{-1} N) was noted after the application of 46 kg N ha^{-1}, and AE values were lower after the application of 184 and 230 kg N ha^{-1} (102 and 135 kg tuber kg^{-1} N, respectively). In a study by Wierzbowska et al. [2021], N-use efficiency in Jerusalem artichoke was affected not only by N rate but also by cultivar and weather conditions during the growing season.

Effect of nitrogen fertilization on the dry matter content and macronutrient concentrations in chicory roots

The highest DM content (approx. 32%) was noted in the roots of cv. Polanowicka in 2017 and cv. Chrysolite in 2018 (Tab. 4). The DM content of roots was affected by weather conditions only in cv. Polanowicka, and it was significantly lowest (25.8%) in 2018. The rates of N fertilizer had no influence on the DM content of chicory roots. An analysis of mean values for years of the study, cultivars and N rates revealed that the DM content of roots remained at a similar

Table 4. Dry matter content of chicory roots (%)

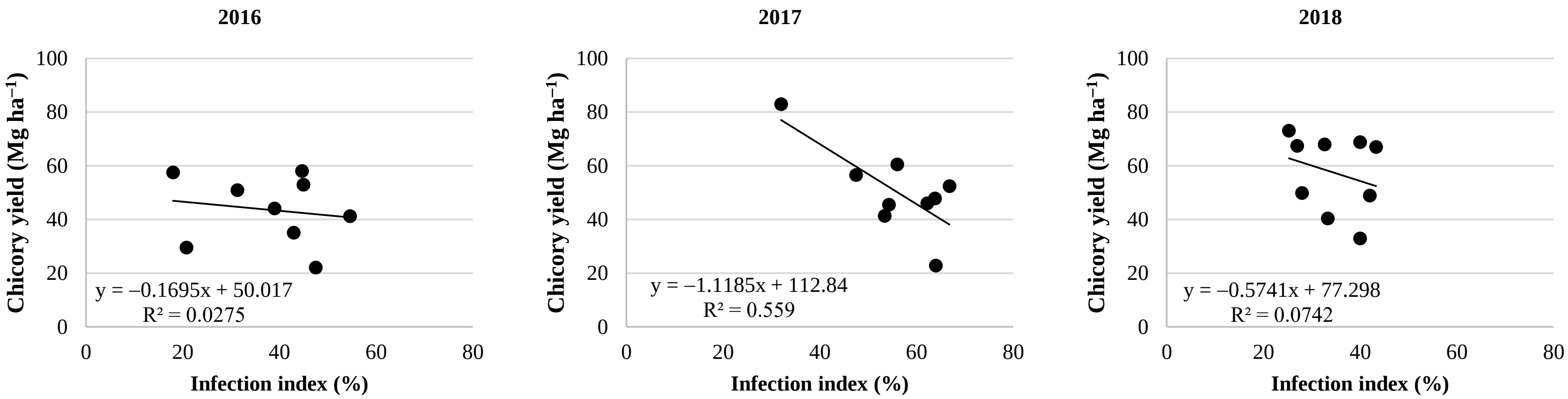
Factor	Cultivar			
	Polanowicka	Chrysolite	Orchies	Mean
2016	29.60ab	28.51a-c	28.65a-c	28.92A
2017	31.58a	29.50ab	26.87bc	29.32A
2018	25.83c	31.96a	29.75ab	29.18A
Nitrogen rate (kg ha^{-1})				
0 kg	30.46a	30.39a	27.95a	29.60A
80 kg	28.38a	29.03a	28.06a	28.49A
120 kg	28.17a	30.55a	29.26a	29.33A
Mean	29.00A	29.99A	28.43A	

Explanation as in Table 2

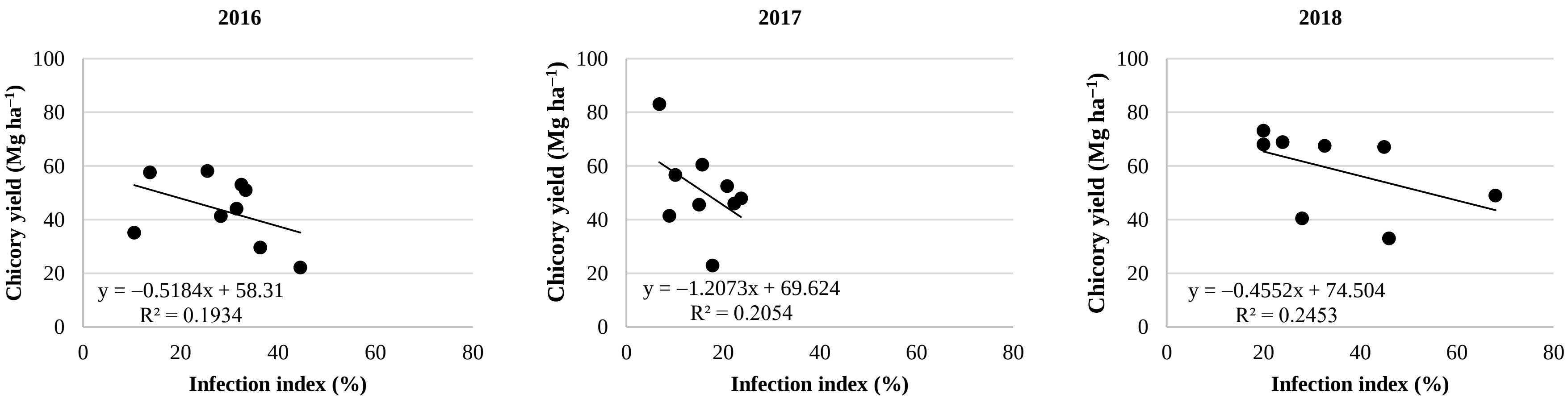
Table 5. Concentrations of macronutrients in chicory roots (g kg^{-1} DM)

Factor interactions			Macronutrients						
			N	P	K	Ca	Mg	Na	S
Cultivar × year	2016	Polanowicka	9.10abc	4.87a	24.24bc	2.11a	0.94ab	0.39d	0.91a
		Chrysolite	8.26bc	5.02a	24.31bc	2.35a	0.82bc	0.43cd	0.88a
		Orchies	8.63bc	5.25a	21.55c	1.69b	0.82bc	0.45bcd	0.77a
	2017	Polanowicka	11.52a	4.36b	26.35b	1.39bc	0.85abc	0.53abc	0.90a
		Chrysolite	9.10abc	3.70c	24.27bc	1.20c	0.80c	0.55ab	0.89a
		Orchies	9.97abc	3.44c	22.16c	1.19c	0.84bc	0.55ab	0.81a
	2018	Polanowicka	10.45ab	3.30c	31.01a	1.45bc	0.96a	0.50a-d	0.99a
		Chrysolite	7.72bc	3.50c	24.26bc	1.17c	0.80c	0.54ab	0.75a
		Orchies	7.36c	3.53c	24.35bc	1.15c	0.85abc	0.60a	0.84a
N rate × year	2016	0 kg	6.21c	5.28a	22.95a	1.92a	0.82a	0.44bc	0.85a
		80 kg	9.46ab	4.97a	22.82a	2.13a	0.89a	0.40c	0.84a
		120 kg	10.31ab	4.91a	24.34a	2.11a	0.87a	0.43bc	0.87a
	2017	0 kg	9.14ab	3.75bc	23.11a	1.22b	0.80a	0.53ab	0.87a
		80 kg	10.34ab	4.14b	25.73a	1.42b	0.89a	0.54ab	0.91a
		120 kg	11.12a	3.61bc	23.95a	1.14b	0.80a	0.56a	0.83a
	2018	0 kg	8.13bc	3.43c	25.61a	1.14b	0.85a	0.56a	0.86a
		80 kg	8.38bc	3.51bc	27.64a	1.42b	0.92a	0.52abc	0.89a
		120 kg	9.02ab	3.40c	26.38a	1.21b	0.84a	0.56a	0.83a
N rate × cultivar	Polanowicka	0 kg	8.89ab	4.30a	26.11ab	1.54a	0.88ab	0.48a	1.04a
		80 kg	10.81a	4.29a	26.72ab	1.74a	0.97a	0.45a	0.90ab
		120 kg	11.37a	3.95a	28.78a	1.68a	0,89ab	0.48a	0.86ab
	Chrysolite	0 kg	7.50b	4.05a	23.09b	1.53a	0.77b	0.49a	0.71b
		80 kg	8.19b	4.36a	26.19ab	1.64a	0.84ab	0.55a	0.94ab
		120 kg	9.38ab	3.82a	23.56b	1.56a	0.82ab	0.48a	0.87ab
	Orchies	0 kg	7.08b	4.10a	22.47b	1.21a	0.83ab	0.56a	0.83ab
		80 kg	9.16ab	3.97a	23.28b	1.59a	0.88ab	0.46a	0.79b
		120 kg	9.71ab	4.15a	22.32b	1.22a	0.80ab	0.58a	0.80b
Year	2016		8.66b	5.05a	23.37b	2.05a	0.86a	0.42b	0.85a
	2017		10.19a	3.83b	24.26b	1.26b	0.83a	0.54a	0.87a
	2018		8.51b	3.45c	26.54a	1.26b	0.87a	0.55a	0.86a
Cultivar	Polanowicka		10.36a	4.18a	27.20a	1.65a	0.92a	0.47b	0.93a
	Chrysolite		8.36b	4.08a	24.28b	1.58a	0.81b	0.51ab	0.84a
	Orchies		8.64b	4.07a	22.69c	1.34b	0.84b	0.53a	0.81a
N rate	0 kg		7.83b	4.15a	23.89a	1.43a	0.83a	0.51a	0.86a
	80 kg		9.39 a	4.21a	25.40a	1.66a	0.90a	0.49a	0.88a
	120 kg		10.15a	3.97a	24.89a	1.49a	0.84a	0.52a	0.84a

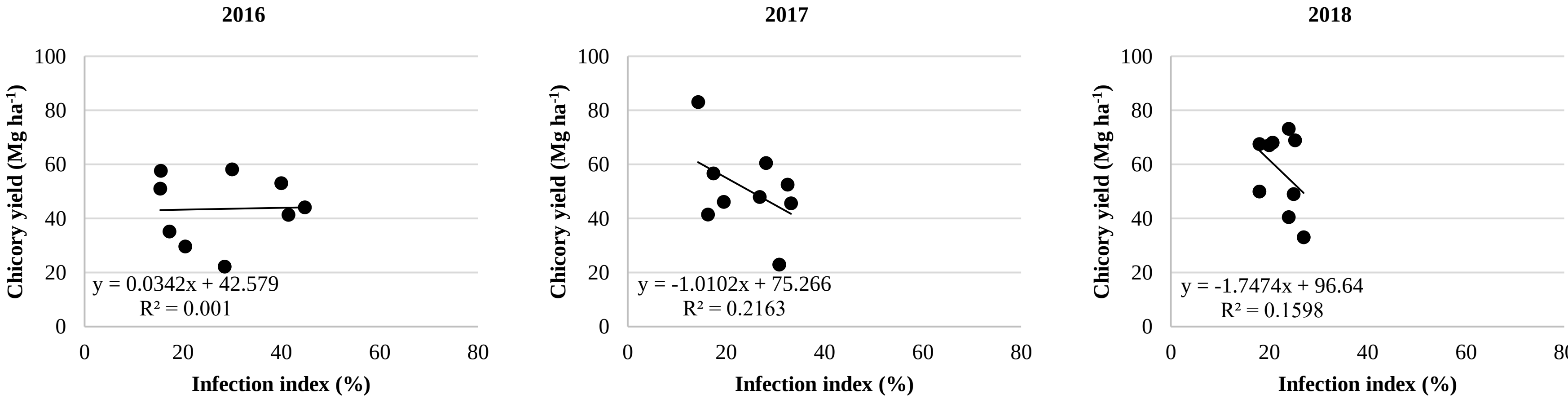
Explanation as in Table 2



a. *Botrytis cinerea*



b. *Golovinomyces cichoracearum*



c. *Alternaria cichorii, Alternaria* spp., *Cercospora cichorii*

Fig. 2. Relationships between root chicory yield and severity of disease

level, and the noted differences were not significant. According to Monti et al. [2005], DM accumulation in chicory roots increases over a prolonged growing season and under high temperatures, especially in the fully ripe stage. In the work of Tilova et al. [2021], *C. intybus* accumulated more DM in the 50 kg N ha^{-1} treatment, compared with 0 and 25 kg N ha^{-1} treatments. In another study, an increase in N rate from 90 to 180 kg N ha^{-1} had no significant effect on the DM content of sugar beet tubers [Pytlarz-Kozicka 2005]. Wang et al. [2021] reported that the application of 120 kg N ha^{-1} increased DM accumulation in sugar beet tubers, compared with the unfertilized treatment, irrespective of irrigation method. Fernandes et al. [2021] stressed a beneficial influence of N fertilization on the DM content of storage roots in sweet potatoes grown after legumes.

Significant differences in the content of N, P, K, Ca and Na in chicory roots were observed in successive growing seasons (Tab. 5). Chicory roots accumulated the highest amounts of N (10.19 g kg^{-1} DM) and Na (0.54 g kg^{-1} DM) in the relatively cold and wet year 2017. Chicory roots had the significantly highest content of P and Ca (5.05 and 2.05 g kg^{-1} DM, respectively) in the first year, and the highest K content (26.54 g kg^{-1} DM) in the third year of the study. Weather conditions had no significant effect on the concentrations of Mg and S in chicory roots throughout the experiment.

Among the analyzed cultivars, the roots of cv. Polanowicka had the highest content of N, K, Ca and Mg (10.36, 27.20, 1.65 and 0.92 g kg^{-1} DM, respectively), whereas the roots of cv. Orchies had the lowest concentrations of K and Ca (22.69 and 1.34 g kg^{-1} DM, respectively) and the highest Na content (0.53 g kg^{-1} DM). No significant differences were found in the content of P and S in roots between the tested chicory cultivars.

Nitrogen fertilization increased the N content of chicory roots. The concentration of N in roots increased by 29.6% after the application of 120 kg N ha^{-1}, compared with control plants. Nitrogen fertilization had no influence on the content of the remaining macronutrients in chicory roots.

According to the literature, the crude ash content of chicory roots ranges from 38.7 [Jangra and Madan 2018] to 56.0 g kg^{-1} [El Zeny et al. 2019]. In the experiment conducted by Zarroug et al. [2016], chicory roots contained (g kg^{-1}) 3.80 K, 5.40 Ca and 1.40 Na. In study by Stanciu et al. [2019], chicory roots contained (g kg^{-1} DW) 0.028 Mg, 0.008 Na and 5.00 Ca. Samples of homogenized chicory roots had the following content of macronutrients (g kg^{-1}): Ca 2.52, K – 12.34, Mg – 1.82, Na – 7.08, P – 2.82, S – 1.19 [Ivanišová et al. 2020]. In the work of Perović et al. [2021], the content of macronutrients (g kg^{-1} FW) in raw chicory (*C. intybus* L.) was as follows: Ca – 0.19, Mg – 0.10, P – 0.26, K – 2.11, Na – 0.020. Aly et al. [2017] found differences in the content of Ca and K between two root chicory varieties. Intensive N fertilization of radicchio chicory (150 and 200 kg N ha^{-1}) contributed to an increase in the concentrations of K, Ca and Mg, whereas P content was insignificantly affected by N rate [Biesiada and Kołota 2010]. An increase in the rate of N fertilizer from 90 to 180 kg N ha^{-1} led to a significant increase in the content of K and N-αNH_2 in sugar beet tubers [Pytlarz-Kozicka 2005]. In a rain-fed treatment (without irrigation) fertilized with 120 kg N ha^{-1}, the N content of sugar beet tubers increased by 37.6% and 42.2% relative to the unfertilized treatment [Wang et al. 2021]. The application of N fertilizer increased the content of protein, Ca and Mg, and decreased the content of P in the storage roots of selected sweet potato varieties [Ukom et al. 2009].

CONCLUSIONS

Chicory plants that were not fertilized with N were healthiest. Chicory root yield decreased with a rise in the severity of powdery mildew, gray mold and leaf spot. Weather conditions and genetic factors exerted the greatest influence on the qualitative yield of chicory roots. The highest yield was obtained in 2017, in cv. Chrysolite without N fertilization. The analyzed chicory cultivars responded to N fertilization by a decrease in root yield, which was reflected in the negative values of agronomic and marginal N-use efficiency. The adverse effect of N fertilization was least pronounced in cv. Polanowicka. Dry matter content was highest (means for cultivars and fertilizer rates) in the roots of cv. Chrysolite (yield was highest in the treatment without N fertilization), and in the treatment without N fertilization. The roots of cv. Polanowicka had the highest content of N, K, Ca and Mg. The tested chicory cultivars grown without N fertilization were characterized by satisfactory root yields. The application of N fertilizer had no influence on the concentrations of macronutrients, except for N whose content was significantly higher in chicory roots fertilized with N. The evaluated chicory cultivars can be recommended for low-input farming systems with minimized environmental impacts.

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