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ORIGINAL PAPER

THE EFFECT OF CLIMATIC CONDITIONS IN SUCCESSIVE PLANT GROWING SEASONS ON THE RESPONSE OF SELECTED VARIETIES OF APPLE TREES (*MALUS DOMESTICA* BORKH.)*

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Abstract

Changing climatic conditions in recent years, including droughts during the plant growing season, have become a serious problem in fruit production. In 2017 and 2018, the weather conditions varied considerably. The aim of study was to determine the effect of climatic conditions in consecutive plant growing seasons on the response of selected apple varieties as manifested by their growth and yielding. Significant uniformity in the tree growth was observed, expressed using trunk cross sectional area (TCSA) and leaf area. The best uniformity of yields was observed for the variety Beni Shogun (Fuji), while the varieties Gala Schniga and Ligol showed greater variation in fruiting. The tree growth and yielding were significantly dependent on the mineral content in leaves. At the same time, an apple variety was found to have a significant effect on the content of N, K, Ca, Mg, Mn and Cu in leaves, whereas no such effect was observed in the case of K, Fe, Zn and Na. Moreover, significant variation in the years of the study was recorded (for means of the cultivars) with respect to the N, P, Ca, Mg, Na, Fe, Mn, Zn and Cu content in fruit, at a lack of any such effect on the K content. An apple variety significantly modified the K content in fruit (the mean value for the two-year study), while no such effect was recorded for the content of N, P, Ca, Mg and Na, Fe, Mn, Zn and Cu.

Keywords: cultivar, leaves, fruits, growth, yielding, macroelement, microelement.

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INTRODUCTION

Intensive fruit production requires fruit growers to adopt a multi-dimensional approach, focusing on the selection of appropriate rootstocks and varieties, as well as broadly understood cultivation measures applied in order to improve the growth intensity and yielding (Jadczuk-Tobjasz, Zygmuntowska 2009, Nadernejad et al. 2013, Dorić et al. 2014). It has been repeatedly stressed that an effective, combined application of individual elements in a pomiculture technology may not only promote the intensity of cultivation, but also, and foremost, modify the chemical composition of fruits and their nutritional value (Cantuarias-Avilès et al. 2011). Maintenance of appropriate soil cultivation standards and fertilization are the measures that may significantly effect changes in the physical parameters of fruits and their chemical composition, determining their nutritional and dietary value. The only element removed from an orchard is the produced fruits, which contain relatively low levels of nutrients. In turn, leaves shed in the autumn and ground branches and twigs are left in orchards and after mineralization they may be sources of nutrients for growing trees (Wrona et al. 2001). The content of nutrient in leaves frequently depend on the used rootstock. For example, apple trees of cv. Šampion grafted on less vigorously growing rootstocks (M26, P2, M9 or even P22) are characterised by a higher N and P content in leaves (Kiczorowski et al. 2018). A study by Mészáros (2019) shows that shading in an orchard may reduce transport of N and P to leaves and fruits, while simultaneously increasing the uptake of such micronutrients as Fe, Mn and Zn.

When selecting fruit tree varieties, fruit growers need to take into consideration also consumer preferences. Nowadays, bi-coloured fruits are preferred in Poland, and therefore much of the orchard area is cropped with such varieties as Šampion, Idared, Ligol or Jonica (Ambroziak 2017).

Climate is a major factor determining the cultivation potential of specific species or varieties (Parker, Abotzoglou 2018). In recent years, droughts occurring in the plant growing period have become a significant problem in fruit production, since they exert a negative effect on yield volume and quality not only in the years when they appear, but also in the successive years, which may be due to poor flower bud formation or frequently observed shoot die-back (Lopez et al. 2014).

The aim of this study was to determine the effect of climatic conditions in various plant growing seasons on the response of selected apple varieties, as manifested in their growth, yielding and nutrient content in leaves and fruits. The research results are very important for both basic knowledge and practical production in orchards. Optimization of the plant nutrition in changing climate conditions seems to be most important way to increase yielding and to improve fruit quality.

MATERIAL AND METHODS

The study was conducted in the years 2017-2018, in an experimental orchard in the Agricultural and Horticultural Experimental Station in Przybroda (52°31′ N, 16°38′ E). The aim was to assess the effect of climatic conditions on the growth and yielding of selected varieties of apple tree (*Malus domestica* Borkh.), i.e. Ligol, Beni Shogun and Gala Schniga, grafted on M9 EMLA rootstocks. Young trees were planted in lessivé soil, formed from loamy sands, deposited on light boulder clay with <1.2% humus contents. The topsoil consisted of sandy clay containing 17 - 20% silt fraction. The chemical composition of soil in 2017 year is given in Table 1.

Table 1

Chemical composition of soil in 2017 (mg kg^{-1} d.m. of soil)

Chemical composition	0-20 cm	21-40 cm	Chemical composition	0-20 cm	21-40 cm
$N-NH_4$	12.3	6.5	Fe	1085.5	598.8
$N-NO_3$	14.0	1.0	Mn	64.8	16.8
P	72.5	16.8	Zn	64.4	61.6
K	53.3	3.1	Cu	67.0	20.5
Ca	977.0	671.5	Cl	10.5	11.5
Mg	133.8	73.8	Na	20.8	26.3
$S-SO_4$	0.4	0.8	pH in H_2O	6.76	7.08
			EC (mS cm^{-1})	0.23	0.20

Agricultural plants were cultivated before the planting of trees. In autumn 2007, rye was sown as a green fertilizer for plowing. In spring 2008, a mixture of vetch and oats was sown after rye. In August, magnesium (in the form of magnesium oxide) was used in a dose of 1.2 t ha^{-1}. Before spring planting, potassium (207.5 kg K in form of 50% KCl) and phosphorous (56.7 kg P in form of triple superphosphate) were used. In the years 2016-2018, in spring time ammonium nitrate was used in a dose of 50 kg N ha^{-1}. The orchard was established in the spring of 2009 at the 3.5 x 1.2 m spacing, with trees trained as spindles. Herbicide fallow was maintained in rows of trees at a width of 1.2 m, while grass was sown in the inter-rows forming a sward of 2.3 m in width.

Drip irrigation was installed in the orchard. The total dose of water used for irrigation was respectively: in 2016 - 180 mm, 2017 - 40 mm, 2018 - 280 mm, with the dripper capacity of 2 l h^{-1}. All tending and cultivation operations were performed following recommendations for commercial orchards.

In the years 2017 - 2018, the tree growth and yielding were evaluated (4 replications with 10 trees per replication - a total of 40 trees for each variety x 3 varieties = 120 trees). The growth of apple trees was assessed based on the following parameters:

- trunk circumference – measured at a height of 10 cm above bud grafting using calipers in two directions and the mean from the measurements was calculated. The trunk cross sectional area (TCSA) was calculated in cm^2;
- leaf area – upon completion of intensive growth, tree leaves were collected from long shoots (with 2 leaves from each tree selected for detailed observations) and their area was calculated after scanning using the DigiShop computer programme. Yielding observations concerned tree flowering, fruit setting and yielding;
- number of inflorescences – on a marked shoot in each tree selected for detailed observations, the number of inflorescences and the number of flowers in each inflorescence were counted;
- the number of set fruitlets – all set fruitlets were counted on marked shoots, and on this basis the percentage (%) of set fruits was calculated;
- the number of fruits harvested from marked shoots and the percentage (%) of harvested fruits;
- the harvest index calculated for each tree based on TCSA and the volume of harvested yield the yielding index of trees was calculated.

Samples of leaves were collected in the second half of July 2018. One sample, comprising approx. 100 leaves originating from the middle part of long shoots, was collected from each plot. During harvest, 25 fruits were collected each year at random from each replication (a total of 100), from which, after core removal, the material for chemical analyses was prepared and dried. Samples of fruits and leaves were dried at 65-70°C and ground. In order to assay the total forms of N, P, K, Ca, Mg and Na, the plant material was digested in concentrated (96%, analytically pure) sulphuric acid with the addition of hydrogen peroxide (30%, analytically pure). For analyses of total Fe, Mn, Zn and Cu, the plant material was digested in a mixture of concentrated nitric (ultra pure) and perchloric acids (analytically pure) at a 3:1 ratio. After digestion of the plant material, the following determinations were performed: N-total using the distillation method according to Kjeldahl in a Parnas-Wagner apparatus; P – colorimetrically with ammonium molybdate, while K, Ca, Mg, Na, Fe, Mn, Zn and Cu were assayed using flame atomic absorption (on an AAS Carl Zeiss Jena apparatus).

The results were subjected to one- or two-way statistical analyses, with a variety and year of study as the experimental factors. Computations were performed using the Statistica 13.3 programme. Statistical analyses were conducted using the analysis of variance, while differences between the means were assessed applying the Duncan test at the significance level $\alpha = 0.05$. Additionally, the correlation coefficients were calculated for the significance level $p < 0.05$.

RESULTS AND DISCUSSION

Climatic conditions

The course of weather conditions is a major factor influencing the growth and yielding of fruit trees in orchards. Wielkopolska is a region in Poland with a relatively high variability of air masses reaching this area, which cause relative instability of weather conditions and the transitional type of the climate observed over a longer time perspective (Farat 2004). The considerable variability is verified by the comparison of two plant growing periods in which analyses were conducted. In 2017, the precipitation total was by 124.5 mm greater compared to the multiannual average, while air temperature was by 0.3°C lower (Table 2). In turn, in 2018 a lower precipitation total was recorded (by 219.2 mm) and a higher air temperature (by 1.4°C) compared to the multiannual mean. These changes may contribute to changes in the length of the plant growing period, which in Poland has been extending in recent years (Nieróbca et al. 2013).

Table 2

Course of temperatures and rainfall in the growing season 2017-2018 in the area of Przybroda

Month	The sum of rainfall (mm)					Average temperature (°C)				
	average from 1982--2012	2017	change in relation to the long-term average	2018	change in relation to the long-term average	average from 1982--2012	2017	change in relation to the long-term average	2018	change in relation to the long-term average
January	31.1	17.6	-13.5	36.8	+5.7	-0.8	-2.7	-1.9	1.9	+2.7
February	26.3	28.0	+1.7	7.4	-18.9	-0.1	0.0	+0.1	-2.5	-2.4
March	34.3	35.0	+0.7	25.0	-9.3	3.6	5.9	+2.3	0.8	-2.8
April	28.0	36.4	+8.4	50.4	22.4	9.3	7.0	- 2.3	13.0	+3.7
May	48.0	31.2	-16.8	22.4	-25.6	14.6	13.3	-1.3	17.3	+2.7
June	63.5	85.6	+22.1	31.6	-31.9	17.2	17.5	+0.3	18.8	+1.6
July	78.8	182.4	+103.6	85.8	+7.0	19.5	17.8	-1.7	20.5	+1.0
August	61.9	80.0	+18.1	13.8	-48.1	18.9	18.2	- 0.7	21.2	+2.3
September	41.0	47.2	+6.2	60.0	+19.0	14.1	12.9	- 1.2	15.9	+1.8
October	32.0	56.8	+24.8	31.2	-0.8	9.0	10.2	+1.2	10.7	+1.7
November	37.2	35.0	-2.2	12.2	-25.0	3.7	2.7	- 1.0	4.9	+1.2
December	39.0	40.6	+1.6	48.8	+9.8	0.2	2.2	+2.0	3.1	+2.9
Total/ Average	520.1	644.6	+124.5	425.4	-219.2	9.1	8.8	-0.3	10.5	1.4

Plant growth

In the 8th year of orchard tree culture, significant variation between the varieties was observed in the tree growth, as evidenced by the calculated TCSA. The strongest tree growth was observed in cv. Beni Shogun (Fuji), while the lowest TCSA was recorded for the apple cv. Gala Schniga (Table 3). Significant variation in the growth of apple trees based on the calculated TCSA depending on a variety was also shown in their study by Reig et al. (2019).

Table 3

Growth and yielding of trees

Year	Cultivar	TCSA (cm^2)	Cumulative yield efficiency ($kg\ cm^{-2}$)	Yield ($t\ ha^{-1}$)	Leaf area (cm^2)
2017	Beni Shogun (Fuji)	64.96 *c**	0.13 *a*	18.9 *b*	33.3 *a*
	Gala Schniga	40.29 *a*	0.37 *b*	33.7 *c*	35.7 *a*
	Ligol	44.74 *ab*	0.14 *a*	13.9 *a*	42.7 *b*
2018	Beni Shogun (Fuji)	69.41 *c*	0.33 *b*	51.4 *d*	35.2 *a*
	Gala Schniga	44.80 *ab*	0.32 *b*	31.5 *c*	54.8 *c*
	Ligol	47.98 *b*	0.48 *c*	52.3 *d*	50.7 *c*
Mean	Beni Shogun (Fuji)	67.18 *b***	0.23 *a*	35.1 *a*	34.3 *a*
	Gala Schniga	42.55 *a*	0.34 *b*	32.5 *a*	45.3 *b*
	Ligol	46.36 *a*	0.31 *b*	33.0 *a*	46.7 *b*
	2017	50.00 *a****	0.21 *a*	22.0 *a*	37.2 *a*
	2018	54.06 *b*	0.37 *b*	45.2 *b*	46.9 *b*

TCSA – trunk cross sectional area, * values in columns for years 2017 and 2018 followed by different letters are significantly varied, ** mean values for cultivars followed by different letters are significantly varied, *** values for years followed by different letters are significantly varied

The calculated correlation coefficients showed that TCSA was significantly negatively correlated with the content of N, P, Ca, Mg, Na, Mn, Zn and Cu, while being positively correlated with the content of K and Fe in leaves of apple trees (Table 4). Another parameter characterizing the tree growth was the area of leaf blades, which was found to be significantly dependent on a year of the study and an apple variety. Regardless of the cultivar, the leaf area was significantly smaller in the 2017 plant growing season (Table 3). Leaves of cv. Ligol (in 2017 and 2018) and Gala Schniga (only in 2018) were characterized by a significantly greater area compared to those of Beni Shogun (Fuji). No correlation was shown between the leaf area and the nutrient content in leaves (Table 4).

Table 4

Correlation coefficients for content of nutrients and sodium in leaves, TCSA, harvest index and leaf area

Nutrient	TCSA	Harvest index	Leaf area
N	-0.6015*	0.0545	0.0937
P	-0.6103*	0.2771*	0.0912
K	0.4197*	0.2191*	-0.0698
Ca	-0.6087*	0.0779	0.0944
Mg	-0.2281*	-0.3642*	0.0421
Na	-0.3740*	-0.2606*	0.0633
Fe	0.6152*	-0.2596*	-0.0923
Mn	-0.1887*	-0.3862*	0.0363
Zn	-0.5902*	0.0240	0.0924
Cu	-0.4845*	-0.1489	0.0788

n=120, * significant at $p \leq 0.05$

An important indicator in pomiculture is tree yielding, which in our study varied greatly between the years of the study. The most uniform yielding was recorded in trees of Gala Schniga (Table 3), which was 33.7 in 2017 and 31.5 t ha^{-1} in 2018. The greatest variation was observed for cv. Ligol, which yielded 13.9 t ha^{-1} in 2017, while in the 2018 season it produced a yield of 52.3 t ha^{-1}. Similar variability in yielding was determined for the variety Beni Shogun (Fuji). Such variation may result from low temperatures during the period of tree flowering, which limited flights of pollinating insects, and from the genetic trend to alternate yielding in these varieties. Productivity of trees, i.e. the yield harvested from a tree in relation to its TCSA, also varied greatly and was dependent on a year of the study (Table 3). In 2017, regardless of a variety, the harvest index was 0.21 kg cm^{-2}, while in 2018 it was by 76% greater. Among the varieties, the lowest harvest index in both plant growing seasons was recorded for Beni Shogun (Fuji). Significant variability in values of the harvest index between varieties has also been demonstrated by Sus et al. (2018).

Assessment of inflorescences on marked shoots, conducted in the 2018 plant growing season, showed considerable variability in their numbers depending on a variety (Table 5). The greatest number of inflorescences was recorded on shoots of cv. Ligol. This may have been caused by the very poor yielding of trees in the 2017 season.

The apple varieties differed also in terms of the mean number of flowers in the inflorescence, which was greater in cv. Gala Schniga and Ligol compared to Beni Shogun (Fuji) – Table 5. The greatest number of inflorescences in the apple variety Ligol affected the number of fruitlets, the percentage of set fruits and the number of fruits (Table 5). However, this was not reflected in the percentage of harvested fruits, which in the case of cv. Ligol

Table 5

The effect of a variety on the intensity of flowering and fruit setting in 2018

Cultivar	Number of inflo-rescence on the shoot	Number of flowers in the inflo-rescence	Number of flowers on the shoot	Number of fruitlets on the shoot	Percent of fruitlets	Number of fruits	Percent of fruits
Beni Shogun (Fuji)	8.78 *a*	4.9 *a*	42.6 *a*	15.5 *a*	25.9 *a*	8.8 *a*	22.76 *b*
Gala Schniga	9.60 *a*	5.9 *b*	56.4 *a*	17.0 *a*	36.8 *b*	9.1 *a*	21.72 *b*
Ligol	19.0 *b*	5.8 *b*	110.8 *b*	26.5 *b*	41.1 *b*	13.0 *b*	13.00 *a*

Values in columns followed by different letters are significantly varied.

was the lowest and amounted to as little as 13% flowers, being by nearly 70% higher in Gala Schniga and Beni Shogun (Fuji).

Chemical composition of leaves

The assayed content of macronutrients in leaves was markedly greater (from 1.6-fold in the case of K up to 48.6-fold for Ca), while for micronutrients it ranged from 3.1-fold (in the case of Zn) up to 44.2-fold greater (for Mn) than in fruit. In most cases (except for P, Na, Fe and Zn) a variety significantly differentiated the chemical composition of leaves (Tables 6, 7).

Table 6

Mean content of macroelement and sodium (g kg^{-1} d.m.) and ratios between them (in relations to N as 1.00) in apple leaves

Cultivar	N	P	K	Ca	Mg	Na
Content						
Beni Shogun (Fuji)	12.15 *b*	1.33 *a*	7.95 *a*	21.53 *b*	6.425 *b*	0.193 *a*
Gala Schniga	9.35 *a*	1.24 *a*	11.50 *b*	16.53 *a*	5.450 *a*	0.163 *a*
Ligol	11.08 *b*	1.34 *a*	11.13 *b*	19.83 *ab*	5.075 *a*	0.163 *a*
Mean	10.86	1.30	10.19	19.30	5.650	0.173
CV (%)	11.9	5.3	17.8	13.6	11.9	13.0
Ratios						
Fuji Benishogun	1.00	0.11	0.65	1.77	0.53	0.02
Gala Schniga	1.00	0.13	1.23	1.77	0.58	0.02
Ligol	1.00	0.12	1.00	1.79	0.46	0.01
Mean	1.00	0.12	0.96	1.78	0.52	0.02

Values in columns followed by different letters are significantly varied.

Table 7

Mean content of metallic microelements (mg kg^{-1} d.m.) and their mutual ratios (in relation to Fe as 1.00) in apple leaves in 2018

Cultivar	Fe	Mn	Zn	Cu
Content				
Beni Shogun (Fuji)	97.90 *a*	27.03 *b*	17.63 *a*	8.175 *b*
Gala Schniga	106.75 *a*	19.83 *a*	15.45 *a*	6.400 *a*
Ligol	97.38 *a*	16.20 *a*	16.68 *a*	6.850 *a*
Mean	100.68	21.02	16.59	7.142
CV (%)	9.0	24.9	7.5	12.7
Ratios				
Beni Shogun (Fuji)	1.00	0.28	0.18	0.08
Gala Schniga	1.00	0.19	0.14	0.06
Ligol	1.00	0.17	0.17	0.07
Mean	1.00	0.21	0.16	0.07

Values in columns followed by different letters are significantly varied.

Simultaneously the determined proportions between the nutrients differed from those recorded for fruits.

Optimal ranges of nutrients in leaves are as follows (g kg^{-1}): N 20-26, P 1.6-3.0, K 13-15, Ca 11-16, Mg 3-5, while for microelements (mg kg^{-1}) B 25-50, Cu 10-20, Fe 150-250, Mn 50-80, Zn 20-40 (Hanson 2014). In this study, comparable content was recorded for Mg, Zn and Cu, the levels of N, P, K, Fe and Mn were lower, while the Ca content was greater than presented by the aforementioned author. At the same time, the content of N assayed in this study was lower than the one presented by Gjamovski et al. (2017) – N 23.3-26.5 g kg^{-1}, at a comparable range of content in the case of P (1.0-1.2 g kg^{-1}) and K (6.9-8.1 g kg^{-1}). The content of Ca assayed by the mentioned authors was almost 2-fold lower than in this study. In turn, the levels of micronutrients given by Gjamovski et al. (2017) were similar in the case of Fe (83.2-108.2 mg kg^{-1} d.m.), lower for Cu (3.7-4.8 mg kg^{-1} d.m.) and markedly greater for Mn (70.4-92.0 mg kg^{-1} d.m.) and Zn (46.5-56.7 mg kg^{-1} d.m.). In turn, compared to this study, Kowalczyk et al. (2017) reported greater ranges of the N content in leaves (19.1-23.70 g kg^{-1} d.m.) depending on the adopted N nutrition level. The authors cited above determined a relatively greater P content, depending on the experimental treatment, amounting to 1.70-3.00 g kg^{-1} d.m., K (10.63-15.60 g kg^{-1} d.m.) and Mg (19.33-30.66 g kg^{-1} d.m.). At the same time, the assayed Ca content was consistent with the range reported by those authors, and amounted to 21.23-21.84 g kg^{-1} d.m..

Nagy, Holb (2006) claimed that younger leaves contained more N and P than older ones. These authors reported an upward trend for the Ca content (within the range from 6.6 to 22.0 g kg^{-1}) in leaves with the progression of the plant growing season, and noted a significant effect of the plant growing period on the Mg content, which was within the range of 3.0-5.0 g kg^{-1}. Moreover, they reported a general downward trend for the K content, ranging from 11.1 to 17.5 g kg^{-1} d.m. Macronutrient values were dependent on a cultivar. Kviklys et al. (2017) stated that the root system (i.e. the rootstock) is a factor significantly differentiating nutrient uptake and transport, which may significantly affect differences in the chemical composition of leaves. This diversification in nutrient uptake may be used in the production of young trees adapted to unfavourable soil conditions. A comparison of the results obtained in this study with those reported by the aforementioned authors indicates comparable ranges of the P and K content, at a simultaneous almost 2-fold greater N content (19.2-21.0 g kg^{-1}) and a lower Ca content (11.6-14.6 g kg^{-1}).

Magnesium levels presented by Kviklys et al. (2017) were markedly lower (2.1-2.9 g kg^{-1} d.m.) compared to this study. At the same time, the cited authors determined, depending on the used rootstocks, a lower Fe content (57.5-70.1 mg kg^{-1} d.m.) at a markedly higher Mn content (71.6-83.8 mg kg^{-1} d.m.), comparable content of Zn (19.2-21.1 mg kg^{-1} d.m.) and Cu (6.03-7.18 mg kg^{-1} d.m.). In turn, Jivan, Sala (2014) in their study determined a greater content of N and K in leaves and a lower Fe content at a relatively similar content of P, Cu and Zn.

Other factors which may potentially modify the chemical composition of leaves include the applied plant nutrition and microbiological factors (Gąstoł, Domagała-Świątkiewicz 2015). Those authors in their studies under the influence of mycorrhizal inoculants and biofertilisers assayed greater contents of N (mean 25.9-27.0 g kg^{-1}) and K (14.5-21.2 g kg^{-1}) at simultaneous slightly greater P contents (1.54-1.92 g kg^{-1}) in leaves. At the same time, contents of Ca (8.7-15.7 g kg^{-1}) and Mg (2.2-2.4 g kg^{-1}) in leaves were lower than in this study. Those authors confirmed a significant variability of nutrient contents in leaves (except for Mn and B) observed between the years of the study. In the opinion of Gjamovski et al. (2017), contents of Mg, B, Zn, Cu, Al, Mn and Fe in leaves are negatively correlated with the level of Ca in fruits. In contrast, N, P and K contents are positively related with the Ca concentration, which is very important for fruit firmness.

Nachtigall, Dechen (2006) stated that in general leaf concentrations of N, P, K, Cu, and B decreased seasonally, the level of Ca increased, while the content of Mg, Fe, Mn and Zn varied significantly. In fruits, the initial nutrient concentrations decreased quickly, then undergoing slow and continuous reduction, subsequently to remain almost constant until the end of fruit maturation, indicating nutrient dilution once the total nutrient accumulation increased gradually with fruit growth.

Average proportions between macronutrients and sodium (N : P : K : Ca : : Mg : Na) in leaves in this study amounted to 1.00 : 0.12 : 0.96 : 1.78 : 0.52 : : 0.02, while in the case of micronutrients (Fe : Mn : Zn : Cu) the ratio was 1.00 : 0.21 : 0.16 : 0.07, respectively. Relationships between nutrients recorded by NAGY, HOLB (2006) were different, namely N : K 2.01 and K : Mg 2.80. In turn, the mean N : Ca ratio of 1.56, K : Ca of 0.53 and Ca : Mg of 3.62 were relatively consistent with the results obtained in this study. In contrast, different relationships between macronutrients in leaves were reported by GĄSTOŁ, DOMAGAŁA-ŚWIĄTKIEWICZ (2015), e.g. N : Ca at 1.00:0.46 on average, at the same time indicating differences in relationships of micronutrients (e.g. Fe : Mn as 1.00 : 2.25). In contrast to this study, KVIKLYS et al. (2017) in their information on the Fe : Mn ratio indicated greater content of Mn in leaves. In turn, JIVAN, SALA (2014) stated that the relationship between N and Fe in apple leaves is positive, which means that an increase in the leaf N content is associated with an increase of the leaf Fe content. GĄSTOŁ, DOMAGAŁA-ŚWIĄTKIEWICZ (2015) assayed relatively similar content of Fe (88-161 mg kg^{-1} d.m.) and Cu (5.32-6.79 mg kg^{-1} d.m.) in leaves, at markedly greater content of Mn (on average 261-299 mg kg^{-1} d.m.) and Zn (mean 37.1-58.5 mg kg^{-1} d.m.).

Chemical composition of fruits

In the two consecuitve years of the study, a differentiating and significant effect of a variety on the content of N, K and Ca in fruits was observed (Table 8). The assayed levels in 2017 were the greatest for N and K in the case of Beni Shogun (Fuji), and for Ca in Gala Schniga, while in 2018 the highest levels were of N and K (in Ligol and Gala Schniga) and Ca in Gala Schniga. Importanly, in the successive years of the study significantly the lowest Ca content was recorded in cv. Ligol. No significant differences between the varieties were observed in terms of the P and Mg content. In turn, the sodium content varied between the years of the study, with significant differences between the varieties observed only in 2018. Considering the mean from the 2 years of the study, a variety had no significant effect on the content of macronutrients (except for P) and sodium. At the same time, significant variation was found in the content of N, P, Ca, Mg and Na in the years of the study (in terms of means for the apple varieties).

In the case of micronutrients, significant variation in their content was recorded only for Mn in 2017 (reduced contents in Beni Shogun (Fuji) compared to the other varieties) in the absence of significant variability in the content of Fe, Zn and Cu (Table 9). In 2018, significant changes were found in the content of Mn and Zn, with the highest levels of these nutrients assayed in cv. Gala Schniga. At the same time, for the means from the 2 years of the study, no significant differences were observed in the content of micronutrients between the investigated varieties. Significant differences in the content of Fe, Mn, Zn and Cu (means for all the varieties) were shown for the successive years of the study.

Table 8

Mean content of macroelement and sodium (g kg^{-1} d.m.) and their mutual ratios (in relation to N as 1.00) in apple fruits

Year	Cultivar	N	P	K	Ca	Mg	Na
	content						
2017	Beni Shogun (Fuji)	3.53 *b**	0.61 *a*	6.71 *b*	0.24 *b*	0.36 *a*	0.09 *a*
	Gala Schniga	2.63 *a*	0.59 *a*	6.33 *ab*	0.30 *c*	0.36 *a*	0.08 *a*
	Ligol	2.35 *a*	0.61 *a*	5.80 *a*	0.13 *a*	0.34 *a*	0.09 *a*
	mean	2.84	0.60	6.28	0.22	0.35	0.09
	CV (%)	19.1	6.1	7.6	32.7	9.8	13.0
2018	Beni Shogun (Fuji)	4.23 *a*	0.38 *a*	5.78 *a*	0.50 *b*	0.50 *a*	0.07 *b*
	Gala Schniga	4.20 *a*	0.44 *a*	7.60 *b*	0.34 *a*	0.56 *a*	0.05 *a*
	Ligol	5.18 *b*	0.35 *a*	5.43 *a*	0.35 *a*	0.50 *a*	0.06 *ab*
	mean	4.54	0.39	6.27	0.40	0.52	0.06
	CV (%)	13.7	10.6	16.1	21.7	8.2	21.2
Mean	Beni Shogun (Fuji)	3.78 *a***	0.50 *a*	6.24 *b*	0.37 *a*	0.43 *a*	0.09 *a*
	Gala Schniga	3.41 *a*	0.51 *a*	6.97 *b*	0.32 *a*	0.46 *a*	0.07 *a*
	Ligol	3.76 *a*	0.48 *a*	5.61 *a*	0.23 *a*	0.42 *a*	0.08 *a*
	2017	2.83 *a****	0.60 *b*	6.28 *a*	0.23 *a*	0.35 *a*	0.09 *b*
	2018	4.53 *b*	0.39 *a*	6.27 *a*	0.40 *b*	0.52 *b*	0.06 *a*
	2017+2018	3.68	0.50	6.28	0.32	0.44	0.08
Ratios							
2017	Beni Shogun (Fuji)	1.00	0.17	1.91	0.06	0.11	0.03
	Gala Schniga	1.00	0.23	2.42	0.12	0.15	0.03
	Ligol	1.00	0.25	2.42	0.04	0.13	0.04
2018	Beni Shogun (Fuji)	1.00	0.10	1.38	0.12	0.12	0.02
	Gala Schniga	1.00	0.10	1.81	0.07	0.14	0.01
	Ligol	1.00	0.08	1.04	0.06	0.10	0.01
Mean	Beni Shogun (Fuji)	1.00	0.14	1.65	0.09	0.12	0.03
	Gala Schniga	1.00	0.17	2.12	0.10	0.15	0.02
	Ligol	1.00	0.17	1.73	0.05	0.12	0.03
	2017	1.00	0.22	2.25	0.07	0.13	0.03
	2018	1.00	0.09	1.41	0.08	0.12	0.01
	2017+2018	1.00	0.16	1.83	0.08	0.13	0.02

* Values in columns for years 2017 and 2018 followed by different letters are significantly varied, ** mean values for cultivars followed by different letters are significantly varied, *** values for years followed by different letters are significantly varied.

Table 9

Mean content of metallic microelements (mg kg^{-1} d.m.) and their mutual ratios (in relation to Fe as 1.00) in apple fruits

Year	Cultivar	Fe	Mn	Zn	Cu
	content				
2017	Beni Shogun (Fuji)	13.20 *a**	1.950 *a*	8.350 *a*	5.268 *a*
	Gala Schniga	13.23 *a*	2.433 *b*	8.588 *a*	5.668 *a*
	Ligol	13.50 *a*	2.375 *b*	9.100 *a*	5.300 *a*
	CV (%)	5.0	11.6	7.9	7.3
2018	Beni Shogun (Fuji)	14.450 *a*	0.400 *a*	4.825 *a*	2.100 *a*
	Gala Schniga	15.400 *a*	0.550 *b*	6.300 *b*	2.350 *a*
	Ligol	15.025 *a*	0.475 *ab*	5.025 *a*	2.250 *a*
	CV (%)	7.3	17.5	12.9	11.8
Mean	Beni Shogun (Fuji)	13.825 *a***	1.175 *a*	6.588 *a*	3.875 *a*
	Gala Schniga	17.000 *a*	1.988 *a*	7.950 *a*	4.475 *a*
	Ligol	14.263 *a*	1.425 *a*	7.063 *a*	3.775 *a*
	2017	13.31 *a****	2.25 *b*	8.68 *b*	5.41 *b*
	2018	14.96 *b*	0.48 *a*	5.38 *a*	2.23 *a*
	2017+2018	14.13	1.36	7.03	3.82
Ratios					
2017	Beni Shogun (Fuji)	1.00	0.15	0.63	0.40
	Gala Schniga	1.00	0.18	0.65	0.43
	Ligol	1.00	0.18	0.67	0.39
2018	Beni Shogun (Fuji)	1.00	0.03	0.33	0.15
	Gala Schniga	1.00	0.04	0.41	0.15
	Ligol	1.00	0.03	0.33	0.15
Mean	Beni Shogun (Fuji)	1.00	0.09	0.48	0.28
	Gala Schniga	1.00	0.11	0.53	0.29
	Ligol	1.00	0.11	0.50	0.27
	2017	1.00	0.17	0.65	0.41
	2018	1.00	0.03	0.36	0.15
	2017+2018	1.00	0.10	0.50	0.28

* Values in columns for years 2017 and 2018 followed by different letters are significantly varied, ** mean values for cultivars followed by different letters are significantly varied, *** values for years followed by different letters are significantly varied.

Differences in the nutrient content resulted in varying proportions between nutrients, with greater differences observed for macronutrients. For examples, the N : K ratio in 2017 was identical in cv. Gala Schniga and Ligol (1.00 : 2.42), while this ratio was markedly reduced to 1.00 : 1.91 in cv.

Beni Shogun (Fuji). In the next year, it was greatly narrowed in all the varieties. Also, the relationship between N and P in the consecutive years of the study was broadened from 1.00 : 0.22 to 1.00 : 0.08. Moreover, other proportions were also varied (e.g. K : Ca, N : Ca). Relationships between metallic micronutrients (Fe : Mn : Zn : Cu) in the case of the investigated varieties were similar and on average amounted to 1.00 : 0.17 : 0.65 : 0.41 (in 2017), with distinct changes found in 2018 (on average 1.00 : 0.03 : 0.36 : 0.15) at relatively small differences observed between the varieties. Generally, the variability in the micronutrient content was smaller than in the case of macronutrients, and it may be considered as limited (CV>20%). It was the smallest for Fe (CV 5.02 and 7.3%, for 2017 and 2018, respectively), while being the biggest for Mn (CV 11.6 and 17.5%). Similarly to macronutrients, the assayed content of micronutrients in leaves was distinctly higher than in fruit (from an average 3.2-fold for Cu to as much as over 44-fold for Mn).

Apples are valuable sources of nutrients in the diet, while differences in their contents between individual varieties may influence the eating value and flavour of fruits (Nour et al. 2010). These fruits also constitute quite rich sources of micronutrients and trace elements (Grembecka, Szefer 2013). However, the chemical composition of fruits may be affected by several factors, e.g. apple tree varieties (Nour et al. 2010), plant nutrition and plant age (Pacholak et al. 2004) or the applied cultivation measures (Kiczorowska, Kiczorowski 2005).

N is a nutrient determining sugar accumulation (Campeanu et al. 2009) and fruit acidity (Jivan, Sala 2014), with a significant impact on the process of sugar accumulation and fruit quality exerted by the N : P ratio. In this study the determined N content ranged from 2.35 to 3.53 g kg^{-1} d.m. in 2017 and within 4.20-5.18 g kg^{-1} d.m. in 2018, being significantly differentiated by the variety factor. The variety-dependent differentiation in nutrient content was confirmed by Nour et al. (2010). In turn, Kowalczyk et al. (2017), in their investigations on the effect of nitrogen nutrition, recorded generally comparable concentrations of this nutrient in apple fruits. The results of this study also are positively correlate with the data reported by Campeanu et al. (2009), who stated a significant effect of a variety on the content of N and K. However, in contrast to the results of this study, those authors indicated a modifying effect of a variety on the P content. K is a nutrient which most effectively accumulates in fruit (Nour et al. 2010), and this is confirmed by our results. However, the content of this nutrient assayed by the aforementioned authors was found within a wider range of values from 0.82% (for cv. Mutzu) to 1.60% (for cv. Florina). An insufficient content of potassium in fruit may contribute to problems with their quality, particularly during long-term fruit storage (Campeanu et al. 2009). Generally, the content of N and K in apples assayed in this study was comparable to the ranges given by Campeanu et al. (2009) N 1.1-6.7 and K 4.0-7.5 g kg^{-1}, at a simultaneous markedly lower P content: 1.5-2.35 g kg^{-1}.

The balance of sugars/acidity in apples is an index specific to the cultivar and it may be modified by certain growth conditions, particularly the nutrition application rate (Hecke et al. 2006). Dris, Niskanen (2004) found fluctuations in N, P, K, Ca and Mg contents in apple leaves and fruits during the vegetation period and fruit development, respectively. They found a significant positive correlation between nutrient concentrations in the early and normally harvested fruits only for P and Ca. Mean K concentration was slightly higher in early harvested fruits.

In our study, there were no significant differences between the varieties in terms of the P content, and a similar level of this element (0.38-0.59 g kg^{-1}) was reported by Kiczorowska, Kiczorowski (2005) in fruit of cv. Szampion. In turn, the content of this nutrient in apple fruits determined by Kowalczyk et al. (2017) was markedly greater. The range of P levels assayed by Nour et al. (2010) in apple fruits were much more varied, ranging from 0.37 to 1.7 g kg^{-1} P (for cv. Aura and Florina, respectively) at the mean for all the analyzed cultivars (0.74 g kg^{-1} of P) similar to the value recorded in this study. At the same time, Pacholak et al. (2004) reported that the P content in fruit is by approximately 30% lower than the K content; in this study, these differences were much greater in both years of the study. In our study, the nutrient levels assayed in fruit were relatively consistent with the values given by Kowalczyk et al. (2017) in the case of N (2.14-3.38 g kg^{-1} d.m.), K (6.70-7.80 g kg^{-1} d.m.) and Mg (0.30-0.36 g kg^{-1} d.m.). Nevertheless, they were definitely lower than those presented by the quoted authors for P and Ca.

In turn, Heghedűș-Mîndru et al. (2014) presented a K content (1.5 g kg^{-1}) markedly lower than the levels assayed in our study, at a similar Mg content in 2017 (0.28 g kg^{-1}) and an evidently lower Na content. In contrast, the content of K and Mg in fruit consistent with our figures was reported by Kiczorowska, Kiczorowski (2005) – 5.37-6.20 g kg^{-1} and 0.28-0.30 g kg^{-1}, respectively and Kowalczyk et al. (2017) – 6.7-7.8 g kg^{-1} K and 0.3-0.36 g kg^{-1} Mg. In turn, a much higher Mg content (within the range of 0.52 - 1.18 g kg^{-1} Mg; mean 0.79 g kg^{-1}) was determined by Nour et al. (2010).

Ca plays an important role in apple production and its adequate content in tissue is required for the production of quality fruits (Conway et al. 2002), while deficiency of this nutrient results in increased susceptibility to storage diseases even under controlled atmosphere storage conditions (Wójcik 2007). The Ca content assayed in fruit in this study varied and ranged from 0.13 to 0.30 g kg^{-1} d.m. (2017) and from 0.34 to 0.50 g kg^{-1} d.m. (2018). At the same time, in 2017 it was lowest among all macronutrients, which confirms the thesis by Nour et al. (2010); however, this dependence was not confirmed in the next year, when on average the lowest level was assayed for P. In turn, Kiczorowska, Kiczorowski (2005) found the content of this nutrient in fruit that was even several-fold greater than in our study. The Ca content in fruit reported by Kowalczyk et al. (2017) fell within the range of 0.3-4.6 g kg^{-1} (modified). Similarly, Nour et al. (2010) gave an approximately twice as high the calcium content in fruit as herein, with the cultivar Prima having the highest content of this nutrient (8.7 g kg^{-1} Ca). Also Pacholak et al. (2004) recorded more Ca in apple fruit than determined in this study.

The literature presents relatively limited data concerning micronutrient content in fruit. This study showed significant variability between the cultivars in the content of Mn (in 2017 and 2018) and Zn (2018). Compared to our results, much less Fe and Mn in fruit – at markedly more varied proportions between these micronutrients ranging from 1.00:0.11 (for cv. Arlet and Ionagold) to 1.00:0.29 (Granny Smith) – were assayed by Nour et al. (2010). Those authors found distinctly greater varietal differentiation in the Fe content, which ranged from 1.9 mg kg^{-1} – Ionagold to 4.0 mg kg^{-1} – Cadel and Early Red (Nour et al. 2010). Our determinations of the Mn content in 2017, at 2.575-3.342 mg kg^{-1} d.m., were comparable to ones provided by Kiczorowska, Kiczorowski (2005), while in the successive year of the study it did not exceed 0.55 mg kg^{-1} d.m. (Gala Schniga). In turn, the Fe and Mn content recorded by Hegheduş-Mîndru et al. (2014) in apples sold in Romania was much lower than the levels in this study. At the same time, Nour et al. (2010) found the Zn content to be much lower (mean 1.9 mg kg^{-1} d.m.) than in the varieties we investigated.

Sodium influences tissue hydration. Its contents did not differ between the varieties in 2017, but was significantly affected by the cultivars in the successive year. A distinctly higher content of this element (on average 0.38 g kg^{-1}) in fruit was assayed by Nour et al. (2010).

In this study the variety with the highest total content of macronutrients and sodium in 2017 turned out to be Beni Shogun (Fuji), while it was the lowest for Ligol (the content lower by 19.1%). However, these trends were not confirmed in 2018, in which the greatest content was found in Gala Schniga and the lowest one was in Beni Shogun (Fuji). In turn, for metallic micronutrients their total content in 2017 was by 4.98% lower in Beni Shogun (Fuji) than in Ligol; however, in 2018 it was highest for Gala Schniga and lowest for Beni Shogun (Fuji) (a decrease by 11.5%).

Apple quality is influenced not only by the absolute content of individual nutrients, but also by their quantitative ratios (Casero et al. 2010). In fruits free from bitter pit the Ca content is higher at the simultaneous decrease in the N : Ca and K : Ca ratios (Fallahi et al., 2006). In turn, an increase in the content of N, P and K in relation to Ca may result in an acceleration of metabolic processes, which cause fruit softening (Casero et al. 2010). The series of nutrient content in apples, developed from the results of this study, was as follows (averages) for 2017: K > N > P > Mg > Ca > Na > Fe > > Zn > Cu > Mn, being similar in 2018: K > N > Mg > P > Ca > Na > Fe > > Zn > Cu > Mn. In turn, Nour et al. (2010) reported that the series of nutrient content in apple fruits regardless of a variety was K>Mg>P >Ca> Na>

> Fe> Zn> Cu> Mn> Cr> Sr> Al. The N : P : K : Ca : Mg ratios calculated in our study were markedly different than those reported by Pacholak et al. (2004). The series of content based on the cited research was K>P>Ca>Mg>N. In turn, Nachtigall, Dechen (2006) claimed that the total nutrient quantities accumulated in dry fruits and removed from orchards during harvest followed a decreasing order: cv. Gala: K> N> P> Mg = = Ca> Fe> Mn> B> Cu> Zn; cv. Golden Delicious: K> N> Mg = P> Fe> Ca> > B > Mn> Cu> Zn; and cv. Fuji: K> N> P> Mg> Ca> Fe> B> Cu> Mn> Zn. These trends concerning cv. Gala and Fuji, particularly for micronutrients, were different than in this study.

Summing up, it may be stated that both the plant growing season and variety influenced the plant growth and yielding. The highest uniformity in yielding was observed for the variety Beni Shogun (Fuji), while Gala Schniga and Ligol showed greater fluctuations of yielding. Tree growth and yielding were significantly dependent on the mineral content in leaves. A variety was found to have a significant effect on the content of most macronutrients (apart from P and S) as well as Mn and Cu in leaves, at the simultaneous absence of such an effect in the case of K, Fe, Zn and Na. Moreover, significant variability was observed in the years of the study (for means from the varieties) in the content of N, P, Ca, Mg, Na, Fe, Mn, Zn and Cu in fruit, without such an effect on the K content. A variety significantly modified the K content in fruit (for the mean of the 2 years of the study). Interestingly for consumers, in 2017, when the sum of precipitation was clearly higher, the content in N, Ca, Mg, Mn, Zn and Cu was higher than in 2018. At the same time, in 2017, the content of P, Fe and Na was higher in the next year of research. This indicates changes in the biological value of fruits expressed in their elemental composition depending on the growing season and the prevalent climatic conditions. In order to further improve the quality of produced yields and their biological value, research needs to be continued on the effect of climatic conditions on the growth and yielding of apple trees, and on the optimization of their nutrition.

CONCLUSIONS

1. Significant variation was observed in tree growth manifested in TCSA and leaf area.

2. The highest uniformity of yielding was found in cv. Fuji Benishogun. Gala Schniga and Ligol demonstrated greater fluctuations of yielding.

3. Tree growth and their yielding were significantly dependent on the nutrient content in leaves.

4. A significant effect of a variety on the content of N, K, Ca, Mg, Mn and Cu in leaves was observed, at the simultaneous lack of such an effect on P, Fe, Zn and Na.

5. Significant variation in the years of the study was found (for means from the varieties) in the content of N, P, Ca, Mg, Na, Fe, Mn, Zn and Cu in fruit, with no effect observed on the K content.

6. A variety significantly modified the K content (for the mean from the 2 years of the study) in fruit, at the simultaneous lack of such an effect on the content of N, P, Ca, Mg and Na, Fe, Mn, Zn and Cu.

7. The series of nutrient concentrations in fruit in 2017 was as follows (on average): K > N > P > Mg > Ca > Na > Fe > Zn > Cu > Mn, and it was comparable in 2018: K > N > Mg > P > Ca > Na > Fe > Zn > Cu > Mn.

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