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ORIGINAL PAPER

EFFECT OF ROOTSTOCK ON LEAF NUTRIENT CONCENTRATION AND PRODUCTIVE VALUE OF 'MUTSU' APPLE TREES*

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Abstract

Various apple rootstock genotypes may affect fruit tree nutrition. The plant nutritional status has a significant impact on the growth and yield of apple trees. The experiment was conducted in 2007-2015, at the Experimental Station in Samotwór near Wrocław, south-western Poland. During the nine-year study, the impact of different rootstocks (M.26, B.7-35, B.396, ARM 18, M.9, B.491, P 16, B.146 and PB-4) on the nutritional status, growth and yield of 'Mutsu' apple trees was investigated. Samples of leaves were collected for the analysis of macro– and microelements in the second half of July in 2009-2011. The study showed an ambiguous influence of rootstock on leaf macro-and microelement composition. This effect differed depending on a year. The results of the average content of the analysed components showed no effect of a rootstock on P, Mg, Mn and Zn concentrations in the leaves. M.26 rootstock resulted in the lower copper level (a significant difference when compared to B.7-35, M.9, B.146 and B.491). Trees on B.491, M.26 and B.7-35 rootstocks were worse stocked in boron than apple trees on ARM-18, M.9 and B.396. In comparison with stronger growing rootstocks, trees on PB-4 were characterised by the low content of calcium. Trees on B.7-35 rootstock grew the most, while the ones grafted on PB-4 showed the weakest growth and had the smallest fruits. The highest number of root suckers was observed for trees grafted on B.7-35 and ARM 18. Until the ninth year after planting, the largest yield was obtained from trees on B.396. In the present study, this rootstock proved to be the best for the 'Mutsu' cultivar.

Keywords: *Malus domestica*, rootstock, macro- and microelements, growth, yield.

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INTRODUCTION

The content of nutrients in the leaves of fruit trees depends on the content of these nutritional elements in the absorption complex of the soil and on the environmental and agrotechnical conditions of cultivation (Zydlik, Pacholak 2006). The type of rootstock has a significant influence on the absorption, transport and accumulation of mineral elements, due to its genetically conditioned absorptive and conductive capacity (Gąstoł, Poniedziałek 2005). The rootstock constitutes an integral part of the tree and the mutual influence of the rootstock and the cultivar modifies the strength of growth of the tree, its yield, and the quality of the fruit (Fallahi et al. 2002). The influence of the rootstock on the growth and yield of the tree may result from a varied pace of mineral elements absorption and transport by the roots of the rootstocks (Kurlus, Ugolik 1999). This is confirmed by the results showing varied contents of nutrients in the xylem of various rootstocks (Fallahi et al. 2002).

In the Polish conditions, the influence of the rootstock on the content of mineral elements in leaves and fruit has been documented by Ben (1999), Andziak et al. (2004), Ben, Kosorz (2005) as well as Pietranek, Jadczuk (2005). The results of the studies on the influence of the rootstock on the state of nutrition of apple tree leaves were presented by Fallahi et al. (2002), Samuolienĕ et al. (2016) and Gjamovski et al. (2017). The results are ambiguous. Some studies indicated an insignificant effect of the rootstock on leaf elemental composition (Joubert et al. 2011), whereas others pointed out the significance of the rootstock (Amiri et al. 2014, Reig et al. 2018). Some authors observed the influence of the weather conditions in a given plant growing season on the content of nutrients in leaves (Słowiński, Sadowski 2001, Pietranek, Jadczuk 2005). Experiments evaluating the suitability of rootstocks from Eastern European countries (Russia, Belarus) for various cultivars of apple trees have been conducted in many countries as well (Domoto, Schroeder 2013, Piestrzeniewicz et al. 2013, Sosna, Gudarowska 2013, Marini et al. 2014, Kviklys et al. 2016, Ryabtseva 2016). Despite numerous experiments relating to cultivars and rootstocks, conducted around the world, no rootstock better than M.9 has been found yet. However, according to Rubauskis, Skrivele (2018), B.396 rootstock may be a better alternative than M.9 in the Baltic states, taking into account the low winter-hardiness of the latter.

The objective of the analysis was to evaluate the influence of different vigour rootstocks on the content of selected micro- and macronutrients in the leaves and on the productive value of 'Mutsu' apple trees.

MATERIAL AND METHODS

The experiment was conducted at the Experimental Station in Samotwór near Wrocław, Poland (51°06′12″N; 16°49′52″E) in 2007-2015. The orchard was located on lessive soil consisting of slightly sandy, light clay over medium clay and representing the 3rd class in the Polish economic soil classification. The plant material included maiden trees of ‘Mutsu’ cultivar on seven rootstocks, mainly of Eastern European origin. The trees were planted in the spring 2007, in rows spaced at 3.5 m. The within-row tree spacing varied according to the expected rootstock vigour: 0.8 m for PB-4 and B.146 (3571 trees ha^{-1}), 1.2 m for B.491, P 16 and M.9 (2381 trees ha^{-1}) – a group of dwarf rootstocks with M.9 as a standard, and 1.7 m for B.7-35, B.396, ARM 18 and M.26 (1681 trees ha^{-1}) – a group of semi-dwarf rootstocks with M.26 as a standard. The experiment was established in four replications, with five trees per plot. The trees were annually pruned soon after flowering, starting from the fourth year following the orchard establishment. No irrigation was applied, and fruitlets were not thinned. The orchard floor management system consisted of herbicide fallow (Glifosate + MCPA) in the tree rows and sward in the alleyways — both set up in the year of the tree planting. The chemical protection was carried out according to up-to-date recommendations of the Orchard Protection Programme. Nitrogen fertilizer in the form of ammonium nitrate was applied in a single dose of 50 kg N ha^{-1} every year. Only this fertilizer was used in 2009-2011.

Samples of leaves were collected for an analysis of macro- and microelements in 2009-2011, in the second half of July, in three replications. A sample of 100 leaves from the middle part of long shoots (3-4 leaves each) was collected from all trees in one replication. Total content of P, K, Mg and Ca as well as Cu, Mn, Zn, Fe and B in the leaves was determined. The leaves were dried at a temperature of 45-50°C and then ground. The content of phosphorus was determined with the colorimetric method with ammonium molybdate, and the content of Mg was assayed with the help of titanium yellow. The concentrations of potassium and calcium were determined with the flame photometric method. The content of microelements was determined following dry mineralisation of the leaves at a temperature of 480°C applied for 8 hours. The ash was evaporated with nitric acid, and then diluted to the volume of 25 cm^3. Elements were determined with the use of acetate-absorption spectrometry on a Varian SpectrAA 220 apparatus, while maintaining the correct measurement parameters for each of the microelements.

For the purpose of data collection, each cultivar was harvested following a single-picking schedule, and the fruit from each tree were collected into separate boxes. To determine external crop quality, a sample of 20 fruits per tree was taken and weighed. Each year, in mid-October, the extent of vegetative growth was evaluated by measuring the trunk circumference

20 cm above the bud union (tailor's tape measure) and calculating the trunk cross sectional area (TCSA) values as well as their two-year increments. In autumn 2015, the tree height and canopy width in two directions were recorded. The volume of canopy was calculated using a formula for the cone volume. The last set of TCSAs together with the 2008–2015 fruit yield sums were used to calculate yield efficiency coefficients achieved at the end of the study. In this study, the published results concerning the productive value of 'Mutsu' apple trees are based on data obtained during 9 years of research.

The collected experimental data underwent statistical analysis based on the analysis of variance (ANOVA) approach involving a model appropriate for a randomised block design. Significant differences at the α=0.05 level were detected using the Duncan's multiple range test.

RESULTS AND DISCUSSION

The years in which the nutritional status was analysed were warmer in comparison with the long-term period and were characterised by a higher volume of precipitation in May and July. The years 2009-2011 were characterised by lower amounts of rainfall in April, same as June in 2011, while August and September in 2009 and 2011 were drier (Table 1).

The average results of the content of macro- and microelements showed that the rootstock did not influence the content of P, Mg, Mn and Zn in leaves of 'Mutsu' trees (Tables 2-3). Similar results were obtained by Ershadi, Talaie (2001). Szewczuk et al. (2009, 2011) and Gjamovski et al. (2017) did not observe significant differences in the content of microelements in the leaves of young apple trees and of macroelements in older ones. The study conducted by Kurlus, Ugolik (1999) showed a lack of influence of the M.26 and M.9 rootstocks on the K content in the apple tree leaves and an increase in the Mg content in the leaves of trees grafted on the M.26 semi-dwarf rootstock. The results of the research conducted by Pietranek, Jadczuk (2005) proved that the rootstock did not influence the content of P and Mg in apple tree leaves. Gąstoł, Skrzyński (2006) did not observe any influence of the rootstock and other methods of dwarfing the growth of apple trees on the concentrations of Fe, Zn and Cu in the leaves. Different results were obtained in Iran, where apple trees on M.9 rootstock had the highest leaf Mg, Zn, Fe and Mn concentrations (Amiri et al. 2014). A higher content of Fe and lower of K and B in leaves of 'Fuji' apple trees grafted on M.9 in comparison with M.26 were demonstrated by Reig et al. (2018). The apple cultivar 'Ligol' on rootstocks M.26 and B.396 was better supplied with P and Mg than trees on M.9 (Samuolienė et al. 2016). In our study, M.26 rootstock caused the lowest content of P in the apple tree leaves but the difference compared to other rootstocks was insignificant. A low concentration of P in apple tree leaves on M.26 rootstock was also determined

Table 1

Average monthly temperature and precipitation in the plant growing seasons 2009-2011 in comparison with the means for period 1971-2000 at the Experimental Station in Samotwór near Wrocław

Monthly rainfall and temperature in vegetative season	April	May	June	July	August	September
Monthly precipitation in long period 1971-2000 (mm)	36.9	57.1	78.7	90.8	64.0	50.6
Monthly rainfall in 2009	21.5	87.7	115.9	132.5	58.0	6.5
In relation to long period	- 15.4	+30.6	+37.2	+41.7	- 6.0	-44.1
Monthly rainfall in 2010	33.2	107.5	84.0	127.4	110.2	109.5
In relation to long period	-3.7	+50.4	+5.3	+36.6	+46.2	+ 58.9
Monthly rainfall in 2011	26.7	66.0	49.3	141.0	44.5	21.0
In relation to long period	-10.2	+8.9	-29.4	+50.2	-19.5	-29.6
Monthly temperature in long period 1971-2000 (°C)	8.2	13.5	16.3	18.1	17.8	13.6
Monthly temperature in 2009	13.8	15.8	17.0	21.0	21.3	16.9
In relation to long period	+5.6	+2.3	+0.7	+2.9	+3.5	+3.3
Monthly temperature in 2010	10.0	14.1	18.7	23.0	20.6	14.1
In relation to long period	+1.8	+0.6	+2.4	+4.9	+2.8	+0.5
Monthly temperature in 2011	12.2	15.1	19.8	19.2	19.9	16.9
In relation to long period	+4.0	+1.6	+3.5	+1.1	+2.1	+3.3

by Kurlus, Ugolik (1999). Among the dwarf rootstocks, the trees on rootstock B.491 were characterised by the lowest content of B and the highest content of Cu, while PB-4 rootstock caused the lowest content of Ca and highest of Fe in the leaves of 'Mutsu' apple trees. The low concentration of Ca in leaves of trees on PB-4 was observed in all years of the study, but especially in 2011. Słowiński, Sadowski (2001) determined a lower content of P both in the leaves of PB-4 rootstock and in the leaves of a cultivar grafted thereon. In a Dutch study, apple trees on B.491 were characterised by higher levels of Ca in fruits and leaves (Maas, Wertheim 2004). In the present study, a low content of Ca was observed for this rootstock only in the first year of chemical analysis. In the subsequent year, B.491 rootstock showed the highest concentration of Ca in 'Mutsu' apple tree leaves. A higher content of Ca in leaves of apple trees grafted on dwarf rootstocks in comparison with semi-dwarf rootstocks was proved by Kurlus, Ugolik (1999). In an experiment conducted in Lithuania, more dwarfing rootstocks brought about a higher concentration of leaf Ca and a lower content of leaf Mg (Kviklys et al. 2017). On the other hand, in an experiment conducted by Gąstoł, Poniedziałek (2005), no difference in the content of calcium in the leaves was demonstrated that would depend on a rootstock. Compared with standard

Table 2

Macroelement content in ‘Mutsu’ leaves as affected by a rootstock (2009-2011)

Rootstock	P (g kg^{-1} d.m.)	K (g kg^{-1} d.m.)	Mg (g kg^{-1} d.m.)	Ca (g kg^{-1} d.m.)
	2009			
M.26 - standard	0.8 *a**	14.2 *a*	6.3 *ab*	6.9 *bc*
B.7-35	1.0 *ab*	15.1 *ab*	6.7 *b*	6.8 *bc*
B.396	0.9 *ab*	16.2 *a-c*	6.3 *ab*	6.9 *bc*
ARM 18	0.9 *ab*	13.5 *a*	6.3 *ab*	7.9 *c*
M.9 - standard	1.1 *ab*	16.3 *a-c*	6.0 *a*	6.0 *ab*
B.491	1.2 *b*	16.1 *a-c*	6.4 *ab*	5.5 *a*
P 16	0.9 *ab*	14.7 *ab*	5.9 *a*	6.3 *ab*
B.146	1.1 *ab*	20.1 *c*	6.0 *a*	5.3 *a*
PB-4	1.0 *ab*	18.6 *bc*	6.8 *b*	5.6 *a*
	2010			
M.26 - standard	1.8 *a*	15.5 *b*	3.2 *cd*	7.5 *ab*
B.7-35	2.0 *a*	15.4 *b*	2.7 *ab*	7.0 *ab*
B.396	1.8 *a*	15.3 *b*	2.8 *a-c*	7.0 *ab*
ARM 18	2.8 *b*	14.6 *ab*	3.2 *cd*	7.1 *ab*
M.9 - standard	2.5 *ab*	14.9 *ab*	3.6 *d*	7.2 *ab*
B.491	1.8 *a*	13.7 *a*	3.3 *cd*	7.9 *b*
P 16	2.1 *ab*	15.2 *b*	2.8 *a-c*	7.0 *ab*
B.146	2.4 *ab*	15.4 *b*	3.2 *b-d*	6.5 *a*
PB-4	1.9 *a*	15.0 *b*	2.6 *a*	6.7 *a*
	2011			
M.26 - standard	0.5 *a*	18.4 *ab*	1.2 *a*	9.3 *b*
B.7-35	0.9 *bc*	19.0 *ab*	0.8 *a*	9.7 *b*
B.396	1.2 *c*	17.9 *ab*	3.0 *b*	9.3 *b*
ARM 18	0.8 *a-c*	17.1 *a*	3.7 *c*	9.1 *b*
M.9 - standard	0.5 *a*	18.8 *ab*	4.2 *cd*	9.1 *b*
B.491	0.6 *ab*	17.9 *ab*	4.3 *d*	9.5 *b*
P 16	0.5 *a*	19.5 *b*	4.1 *cd*	9.0 *b*
B.146	0.6 *ab*	18.9 *ab*	4.0 *cd*	9.3 *b*
PB-4	0.6 *ab*	16.8 *a*	3.9 *cd*	7.6 *a*
	Mean for 2009-2011			
M.26 - standard	1.0 *a*	16.0 *ab*	3.6 *a*	7.9 *b*
B.7-35	1.3 *a*	16.5 *ab*	3.4 *a*	7.8 *b*
B.396	1.3 *a*	16.5 *ab*	4.0 *a*	7.7 *b*
ARM 18	1.5 *a*	15.1 *a*	4.4 *a*	8.0 *b*
M.9 - standard	1.4 *a*	16.7 *ab*	4.6 *a*	7.4 *ab*
B.491	1.2 *a*	15.9 *ab*	4.7 *a*	7.6 *ab*
P 16	1.2 *a*	16.5 *ab*	4.3 *a*	7.4 *ab*
B.146	1.4 *a*	18.1 *b*	4.4 *a*	7.0 *ab*
PB-4	1.2 *a*	16.8 *ab*	4.4 *a*	6.6 *a*

* Means indicated by the same letter within the columns and year do not significantly differ at α=0.05 according to Duncan’s *t*-test.

Table 3

Microelement content in 'Mutsu' leaves as affected by a rootstock (2009-2011)

Rootstock	Cu (mg kg^{-1} d.m.)	Mn (mg kg^{-1} d.m.)	Zn (mg kg^{-1} d.m.)	Fe (mg kg^{-1} d.m.)	B (mg kg^{-1} d.m.)
	2009				
M.26 - standard	5.41 *a**	70.00 *a*	22.93 *a*	54.60 *c*	16.43 *ab*
B.7-35	6.51 *cd*	112.93 *b*	27.83 *ab*	57.60 *d*	16.87 *bc*
B.396	5.66 *ab*	70.53 *a*	32.37 *b*	52.50 *ab*	17.97 *b-e*
ARM 18	6.67 *d*	147.10 *c*	30.10 *b*	57.90 *d*	17.33 *b-d*
M.9 - standard	6.51 *cd*	116.50 *b*	47.73 *c*	59.00 *d*	18.93 *de*
B.491	6.58 *d*	163.87 *d*	28.70 *ab*	53.50 *bc*	14.90 *a*
P 16	6.22 *c*	244.57 *e*	47.50 *c*	51.00 *a*	19.10 *e*
B.146	6.38 *cd*	163.33 *d*	43.00 *c*	54.00 *bc*	18.53 *c-e*
PB-4	5.81 *b*	156.53 *d*	72.50 *d*	57.47 *d*	19.10 *e*
	2010				
M.26 - standard	5.54 *ab*	437.33 *a-c*	80.97 *cd*	50.23 *d*	18.07 *a-c*
B.7-35	5.62 *a-c*	480.83 *c*	77.90 *bc*	48.37 *cd*	18.30 *a-d*
B.396	5.39 *a*	442.17 *bc*	82.53 *cd*	45.73 *bc*	19.97 *e*
ARM 18	5.43 *a*	548.00 *d*	97.27 *e*	42.43 *ab*	19.30 *c-e*
M.9 - standard	6.62 *c*	479.50 *c*	82.70 *d*	48.93 *cd*	19.70 *de*
B.491	6.03 *bc*	484.00 *c*	82.93 *d*	45.53 *bc*	16.93 *a*
P 16	5.85 *a-c*	381.83 *a*	67.93 *a*	40.83 *a*	17.80 *a-c*
B.146	6.04 *c*	410.40 *ab*	73.20 *b*	47.63 *cd*	17.63 *ab*
PB-4	5.61 *a-c*	480.83 *c*	81.57 *cd*	57.00 *e*	18.60 *b-e*
	2011				
M.26 - standard	5.24 *a*	108.80 *e*	19.07 *a*	57.23 *b*	17.00 ab
B.7-35	6.15 *d*	124.10 *f*	24.53 *bc*	59.40 *bc*	16.23 a
B.396	6.06 *cd*	93.97 *c*	26.30 *c*	50.97 *a*	18.60 bc
ARM 18	5.56 *a-c*	84.87 *b*	19.80 *a*	56.00 *ab*	20.93 d
M.9 - standard	5.44 *ab*	85.13 *b*	21.37 *ab*	56.60 *b*	18.87 c
B.491	6.44 *d*	105.47 *d*	22.23 *ab*	55.77 *ab*	17.00 ab
P 16	6.06 *cd*	108.37 *e*	18.70 *a*	55.90 *ab*	19.07 c
B.146	6.35 *d*	75.40 *a*	21.10 *ab*	63.00 *c*	17.20 ab
PB-4	6.05 *b-d*	102.40 *d*	18.73 *a*	55.30 *ab*	18.00 bc
	Mean for 2009-2011				
M.26 - standard	5.40 *a*	205.38 *a*	40.99 *a*	54.02 *ab*	17.17 *ab*
B.7-35	6.09 *b*	239.29 *a*	43.42 *a*	55.12 *ab*	17.13 *ab*
B.396	5.70 *ab*	202.22 *a*	47.07 *a*	49.73 *ab*	18.85 *c*
ARM 18	5.89 *ab*	259.99 *a*	49.06 *a*	52.11 *ab*	19.19 *c*
M.9 - standard	6.19 *b*	227.04 *a*	50.60 *a*	54.84 *ab*	19.17 *c*
B.491	6.35 *b*	251.11 *a*	44.62 *a*	51.60 *ab*	16.28 *a*
P 16	6.04 *ab*	244.92 *a*	44.71 *a*	49.24 *a*	18.66 *bc*
B.146	6.26 *b*	216.38 *a*	45.77 *a*	54.88 *ab*	17.79 *abc*
PB-4	5.82 *ab*	246.59 *a*	57.60 *a*	55.59 *b*	18.57 *bc*

* For explanation see Table 2.

M.26 and M.9, the tested rootstocks had little influence on the content of macro- and microelements in the leaves of ‘Mutsu’ trees. Significant differences were observed only for Cu and B. More copper was found in apple trees on rootstock B.7-35, more boron for B.396 and ARM 18, and less of this element in leaves of trees grafted on B.491. There was no clear relationship between the content of elements in ‘Mutsu’ apple tree leaves and the growth of the examined rootstocks.

In the undertaken research, the content of specific macro- and microelements varied significantly in the individual years of study (Tables 2-3). In a study by Zydlik, Pacholak (2006), the course of the weather did not affect the concentration of P and K in apple tree leaves, although it influenced the content of Mg and Ca. The magnesium concentration decreased with the increase of temperature during the vegetation period and it had a positive correlation with the amount of precipitation. Other correlations were observed by the researchers in the case of calcium, the level of which was higher in warmer and drier vegetation seasons. In the present study, the highest levels of K and Ca, and the lowest of P and Mn in ‘Mutsu’ leaves were noted in 2011, which has less precipitation. In turn, higher concentrations of P, Mn and Zn were found in the rainy year 2010. A large amount of precipitation in that year did not influence the content of Cu, Fe and B in apple tree leaves, regardless of the rootstock applied. The content of calcium and potassium in the leaves depended not only on the course of the weather in a given year, but also on the level of fruiting. The highest concentration of the mentioned elements was found in 2011, when trees yielded relatively poorly, and was the lowest in 2009, when trees yielded abundantly. This can be explained by the fact that calcium, and especially potassium, occur in large amounts in the apples. According to Słowiński, Sadowski (2001), it is difficult to find a connection between the content of mineral elements in the leaves of rootstocks in stool beds or in a nursery and in the cultivars grafted thereon in an orchard. This may result from the fact that the content of mineral elements in leaves of apple trees depends on many different factors, such as the concentration of these elements in the soil, the course of the weather, the level of yielding and the age of the trees as well as on the conditions of cultivation prior to tree planting (Jarociński 2005, Zydlik et al. 2011). Probably these factors also contributed to such large differentiation in the results obtained from the chemical analysis of apple leaves in our study.

By the ninth year after planting, the rootstocks covered by the study had a significant effect on the vegetative growth of ‘Mutsu’ trees (Table 4). The strongest growth was observed in the case of trees grafted on B.7-35. They had thicker trunks as compared with those grafted on M.26 rootstock. Trees grafted on B.396 grew similarly to those on M.26 rootstock, with the exception of the volume of canopies, which were significantly smaller and similar to ones grown by trees on M.9. In other studies (Univer et al. 2010, Skrivele et al. 2011, Marini et al. 2014, Kviklys et al. 2016, Piestrzeniewicz

Table 4

Vegetative growth of 'Mutsu' apple trees depending on a rootstock

Rootstock	TCSA (cm^2)		Canopy volume (m^3) autumn 2015	Total number of root suckers per tree 2007-2015
	autumn 2015	increment 2013-2015		
M.26 – standard	56.6 *d*	14.8 *e*	5.1 *ef*	0.1 *a*
B.7-35	82.3 *e*	23.2 *f*	5.9 *f*	95.8 *b*
B.396	48.2 *d*	11.6 *de*	3.6 *d*	0.1 *a*
ARM 18	52.6 *d*	14.8 *e*	4.7 *e*	77.0 *b*
M.9 – standard	36.1 *c*	9.9 *cd*	3.2 *cd*	0.2 *a*
B.491	22.3 *b*	5.5 *b*	2.3 *b*	6.0 *a*
P 16	25.4 *b*	6.9 *b*	2.6 *bc*	3.0 *a*
B.146	17.0 *ab*	3.6 *ab*	1.4 *a*	2.9 *a*
PB-4	11.5 *a*	1.4 *a*	1.2 *a*	0.9 *a*

* Means indicated by the same letter within the columns do not significantly differ at α=0.05 according to Duncan's *t*-test.

et al. 2018), trees on this rootstock were characterised by a growth similar to that on M.9 and were classified as dwarf trees. In the present study, trees on PB-4 showed a very weak growth, which was confirmed in other reports (KUKHTO 2010, UNIVER et al. 2010, PIESTRZENIEWICZ et al. 2013, KVIKLYS et al. 2016, RYABTSEVA 2016). Trees grafted on B.146 and B.491 rootstocks had also thinner trunks and smaller crowns than trees on M.9. Similar results were obtained by SOSNA, GUDAROWSKA (2013) and PIESTRZENIEWICZ et al. (2018). The highest number of root suckers was formed by the most vigorous trees on B.7-35 and ARM 18. Other tested rootstocks were characterised by a similar, very small number of suckers, which was also confirmed by CZYNCZYK et al. (2010) and DOMOTO, SCHROEDER (2013).

Until the ninth year after planting, significantly the largest amount of fruit was harvested from trees on B.396 (Table 5). The high productivity of trees on this rootstock was also proved by SKRIVELE et al. (2011), SOSNA, GUDAROWSKA (2013), KVIKLYS et al. (2016) and SAMUOLIENĖ et al. (2016). Trees on ARM 18 yielded like ones on M.26. Apple trees on PB-4 were characterised by the lowest crops, which was also confirmed by other researchers (UNIVER et al. 2010, RYABTSEVA 2016, PIESTRZENIEWICZ et al. 2018). In the present study, 'Mutsu' cultivar on B.491 and P 16 rootstocks fruited at a level similar to that on the standard rootstock M.9. After the conversion of the yield into the unit area, trees growing on B.396 appeared to have the highest yields, too, but the difference was not significant compared to P 16, B.146 and M.26 rootstocks. Trees on other rootstocks fruited at a level similar to those on M.26 and M.9. The calculated crop efficiency coefficients were differentiated and generally higher for the group of dwarf rootstocks. Compared with the standard M.26, a higher coefficient was recorded for B.396

Table 5

Yield, productivity, fruit weight and survivability of 'Mutsu' apple trees depending on a rootstock

Rootstock	Cumulative yield 2008-2015		Mean fruit weight 2009-2015 (g)	Yield efficiency 2007-2015 (kg cm^{-2})	Trees destroyed by the storm in 2015 (%)
	(kg tree^{-1})	(t ha^{-1})			
M.26 – standard	163.2 *f**	274.5 *b-d*	247 *cd*	2.88 *b*	5
B.7-35	133.2 *de*	223.7 *ab*	247 *cd*	1.62 *a*	0
B.396	191.7 *g*	321.8 *d*	249 *cd*	3.98 *cd*	60
ARM 18	154.1 *ef*	258.7 *bc*	250 *d*	2.93 *bc*	20
M.9 – standard	108.9 *cd*	259.0 *bc*	235 *bc*	3.02 *bc*	0
B.491	103.4 *bc*	246.0 *bc*	226 *b*	4.64 *d*	35
P 16	120.8 *cd*	287.4 *cd*	232 *b*	4.76 *d*	5
B.146	79.1 *b*	282.2 *cd*	225 *b*	4.65 *d*	45
PB-4	48.7 *a*	173.9 i	201 *a*	4.23 *d*	45(10)**

* For explanation see Table 4

** Including 10% of dead trees due to bark and wood fungal diseases

and a lower one for B.7-35. The highest yield efficiency was observed for trees on dwarf rootstocks P 16, B.146, B.491 and PB-4, which was confirmed by Sosna, Gudarowska (2013), Marini et al. (2014) and Piestrzeniewicz et al. (2018). Like in the experiment of Czynczyk et al. (2010), the crop efficiency of 'Mutsu' on P 16 was significantly higher than that on M.9. The tested rootstocks had little influence on the mean fruit weight. Compared with the standard M.9 and M.26, only apples from trees growing on PB-4 rootstock were significantly smaller, which was confirmed by other researchers (Kukhto 2010, Univer et al. 2010, Piestrzeniewicz et al. 2013). Some authors found that rootstocks did not affect the mass of harvested apples. Fruits with roughly the same size as fruits from trees grafted on M.9 and M.26 were observed for trees on B.396 (Rubauskis, Skrivele 2018), as well as on B.491, B.146 and P 16 (Czynczyk et al. 2010, Sosna, Gudarowska 2013, Bielicki, Pąśko 2018, Piestrzeniewicz et al. 2018).

A violent storm with a hurricane wind and heavy hail, which passed over the Experimental Station in Samotwór at the end of July 2015 provided us with a chance to assess the connection status between 'Mutsu' apple trees and the tested rootstocks. Many trees were broken off at the place of budding. The weakest union with the 'Mutsu' cultivar was observed for B.396 rootstock, where most trees (60%) were broken off. For the same reason, relatively many trees (35-45%) were destroyed among the ones grafted on dwarf B.491, PB-4 and B.146 rootstocks. Apple trees on the other rootstocks survived very well and the number of dead trees was not high (Table 5).

CONCLUSIONS

The study has shown that the influence of a rootstock on the state of nutrition of trees with macro- and microelements cannot be determined unambiguously. This influence differed in individual years of the study. The average content of the analysed elements showed that the rootstock did not influence the concentrations of P, Mg, Mn and Zn in the ‘Mutsu’ cultivar leaves. M.26 rootstock resulted in a lower level of copper (a significant difference compared with B.7-35, M.9, B.146 and B.491). Trees on B.491, M.26 and B.7-35 rootstocks were worse stocked in boron than apple trees on ARM-18, M.9 and B.396. In comparison with the stronger-growing rootstocks, trees on PB-4 were characterised by a low content of calcium. Concentrations of some macro- and microelements in apple tree leaves were also influenced by the course of the weather, in particular the amount of precipitation in the plant growing season.

Trees on B.7-35 rootstock grew the most, while trees grafted on PB-4 showed the weakest growth and had the smallest fruits. Apples from trees on stronger growing rootstocks were characterised by bigger mass. The highest number of root suckers was observed for trees grafted on B.7-35 and ARM 18. Trees on other rootstocks produced very few root suckers. Until the ninth year after planting, the highest yield was obtained from trees on B.396. In the present study, this rootstock has proved to be the best for the ‘Mutsu’ apple tree cultivar.

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