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Influence of rootstocks on different sweet cherry cultivars and accumulation of heavy metals in leaves and fruit

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Abstract

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Two seedling rootstocks of Mahaleb cherry (*Prunus mahaleb* L.) from a German type cv. Alpruna marked as No. 2 and No. 6 were selected for their semi-dwarfing properties from biotypes growing at the Rural Experimental Station in Baranowo belonging to the University of Life Sciences in Poznan, Poland. In an orchard experiment in 2012–2013, growth and yield of eight- and nine-year old trees of the cvs Regina, Summit and Vanda were studied. These cultivars were grafted on Mahaleb cherry No. 2 and No. 6 and were compared to the control rootstock Mazzard (*Prunus avium* L.) cv. Alkavo. The Mahaleb cherry biotypes significantly decreased the trunk cross-sectional area and the crown volume of the trees. The cultivars grafted on Mahaleb cherry biotypes No. 2 and No. 6 had more flowers and they gave a higher yield. The yield efficiency for cultivars grafted on these rootstocks was higher than for rootstock Mazzard. Significant differences of the concentration of the elements were found for Fe, Cu, Zn in fruit and for Fe, Cu and Cr in leaves. Presence of Pb and Cr was not detected in sweet cherry fruit.

Keywords: new rootstocks; *Prunus mahaleb*; orchard; fruit tree; flowering; growth; yield

In Poland as well as in other countries a growing interest in sweet cherry trees cultivation can be observed. Fruits of this species are not only characterized by favourable organoleptic attributes but they are also a rich source of vitamins, microelements, unsaturated fatty acids and simple carbohydrates. Cultivation of sweet cherry trees on seedling rootstocks is not easy as genetics makes them vegetatively vigorous. It makes cultivation and harvesting of fruit difficult. Because of these reasons selection of new rootstocks which can limit this strong growth has been carried out. In Poland the most often used rootstock for cultivation of sweet cherry trees is Mazzard (*Prunus avium* L.). It is physiologically compatible with all cultivable cultivars of sweet cherries and it easily propagates from seeds. However, trees budded on this rootstock grow strongly, they create big crowns, are not precocious and are low yielding. Another species which found its application as a rootstock in sweet cherry trees cultivation is Mahaleb cherry (*Prunus mahaleb* L.). It can be propagated from seeds and vegetatively (Garcia et al. 2007). The trees of sweet cherry budded on Mahaleb cherry are better prepared for

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light and dry soils, and their root system is more frost-resistant. Some cultivars of sweet cherries grow weaker on this rootstock, they crop well, have bigger fruit and ripe 2–3 days earlier (Grzyb et al. 2005). In such countries as Bulgaria, Estonia, France, Turkey, Ukraine and Hungary most of cultivars of sweet cherry trees are produced on Mahaleb cherry (Misirli et al. 1996; Lanauskas et al. 2004; Sansavini, Lugli 2008; Şeker 2008). However, some researchers question the validity of Mahaleb cherry use as rootstocks for sweet cherry cultivars because of the possibility of the occurrence of physiological inconsistency (Webster, Looney 1996; Grzyb 2004; Vegvari et al. 2008).

The aim of this experiment was to ascertain the usefulness of newly obtained biotypes of Mahaleb cherry as rootstocks for cultivation of selected sweet cherry cultivars. Other goals of the experiment were to check what amount of heavy metals was present in sweet cherry fruit and to find out whether the used rootstocks and cultivars influence the concentration of selected toxic heavy metals (Cd, Pb, Cr) and metallic microelements (Fe, Zn, Cu, Ni) in leaves and fruit of sweet cherry trees.

MATERIAL AND METHODS

The experiment was conducted in the years 2012 to 2013 at the Rural Experimental Station in Baranowo belonging to the University of Life Sciences in Poznan placed in the distance of 40 meters from a local heavy traffic road. The objects of the study were sweet cherry trees in the eighth and ninth year of cultivation. The cvs Regina, Summit and Vanda were budded on two new biotypes of Mahaleb cherry marked as No. 2 and No. 6. The new rootstocks had been selected from seedlings coming from free pollination of German cv. Alpruna type of Mahaleb cherry. The biotypes were propagated vegetatively through softwood cuttings. Trees growing on cv. Alkavo type of Mazzard obtained from seeds constituted a control group in this orchard experiment.

The experiment was set up in a random, complete blocks design, with nine combinations in four replications with 5 trees per plot. Sweet cherry trees on Mazzard rootstock were planted in spacing of 5 × 4 m, and on biotypes of Mahaleb cherry in spacing of 4 × 3 m.

The trees were cultivated in sandy soil. Ground water level stayed at the depth of about 180 cm. The content of organic matter in the arable layer was 12%. The soil was characterized by high concentration of phosphorus, potassium, magnesium and calcium in the arable layer and in the subsoil with right ratio of K:Mg, alkaline pH 7.2 value and salinity within the range of the optimum.

In the years 2012–2013 the trees were fertilized with ammonium sulphate in a dosage of 60 kg N/ha. Mechanical cultivation was kept between the rows. Also in the rows of trees in belts 1 m wide a double herbicide fallow (Roundup 360 SL 3 l/ha + Chwastox 360 SL 2 l/ha based on 2.4-D) was provided. Protection against diseases and pests was carried out according to the binding protection recommendations of sweet cherry trees in orchards. Cutting was mainly based on shortening in summer, after collection of one-year old increments over the fifth leaf (Zahn 1986). During harvest time trees were protected against birds with non-woven fabric. The trees were not watered because annual rainfall was over 600 mm.

During the experiment the following measurements and observations were carried out:

– the circumference of the trunk was measured with a measuring tape 30 cm above the ground. On the basis of this measurement a cross-sectional area (TCSA) of the trunk was calculated:

$$\mathrm{TCSA} = \frac{\pi \times \varphi}{4} \qquad (\mathrm{cm}^2)$$

where:

φ – diameter of the trunk

– the width of the crown was measured in two directions, along and across rows. On the basis of these two measurements and the height of the crown the volume (V) of the crown was calculated:

$$V = \frac{\pi \times h \times B^2}{12} \qquad (\mathrm{m}^3)$$

where:

h – height of the crown from the lowest branch to the top (m)

B – width of the crown (m)

– number of flowers and fruit present on the tree counted according to Baca (1958) recommendations.

Fruit was collected in its high ripening maturity. Fruit from each tree was weighed and counted in-

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Table 1. Concentration of heavy metals in reference material ERM®-CD281 Rye grass

Metal	Rye grass certified content		Wet mineralization (mg/kg)	
	(mg/kg)	+/–	concentration	difference
Cd	0.12	0.007	0.11	0.01
Cr	24.8	1.3	23.93	0.87
Cu	10.2	0.5	9.18	1.02
Fe*	180	–	175.12	4.88
Ni	15.2	0.6	14.44	0.76
Pb	1.67	0.11	1.51	0.16
Zn	30.5	1.1	29.11	1.39

*not certified value

dividually and on this basis the yield of fruit from a tree and mass of one fruit were calculated. Later a calculation of yield efficiency of trees for 1 cm^2 of trunk cross-sectional area and for 1 m^3 of volume crown was conducted. Measurements of trees were carried out after the end of vegetation (the first decade of November) in 2013.

Analysis of leaves and fruit. Samples of leaves were collected in the third decade of June, and samples of fruit in the period of their ripeness. Individual samples consisting of 20 leaves (from long stems coming from the middle part of the crown) and 1 kg of fruit were collected from each tree.

After careful wash in distilled water the plant material (leaves and fruit) was dried in the temperature of 105°C and then mineralized in the mixture of concentrated HNO_3 (ultra clean) and $HClO_4$ (analytically pure) in the ratio of 3:1 (Bosiacki, Roszyk 2010). Next the concentration of heavy metals was determined using the method of atomic absorption spectroscopy with AAS 3 Zeiss apparatus (Carl Zeiss, Jena, Germany).

Accuracy and precision of analytical measurements was checked using the reference Rye Grass ERM®-CD281 material analysis, certified by the European Commission, Joint Research Centre, Institute for Reference Materials and Measurements (IRMM, Geel, Belgium) (Table 1).

Soil analysis. From each field (5 trees) one mixed sample consisting of 15 individual samples (4 × 15 = 60 single samples) was taken from the soil layer of 0–30 cm. Soil samples were taken in the first decade of August. Microelements (Fe, Cu, Zn, Ni) and toxic heavy metals (Cd, Pb, Cr) were extracted from the soil with modified Lindsay solution containing: 5 g ethylenediaminetetraacetic acid ($C_{10}H_{16}N_2O_8$); 9 cm^3 25% solution ammonium hydroxide (NH_4OH); 4 g citric acid ($C_6H_8O_7{\cdot}H_2O$); 2 g calcium acetate $Ca(CH_3COO)_2{\cdot}2H_2O$ in 1 dm^3 (Nowosielski 1988). Next they were determined using the method of atomic absorption spectroscopy AAS (FASS) with AAS 3 Zeiss apparatus. Salinity was determined with conductometric analysis as electrolytic conductivity of the soil, and pH with potentiometric analysis (soil-water ratio 1:2) (Golcz 2011).

Statistical analysis. Two-factor variance analysis was used to calculate the results of the experiment. Only for yield efficiency one-factor variance was used. A separate analysis was carried out for each individual tested feature: trunk cross-sectional area, volume of crown, number of flowers, number of fruit, percentage of fruit in ratio to flowers, mass of one fruit, yield of fruit, productivity index for trunk cross-sectional area, productivity index for crown volume and concentration of heavy metals in sweet cherry leaves and fruit. Percentage values were transformed using Bliss. Difference in significance among combinations was estimated on the basis of confidence intervals using the Duncan's test, with probability level $P < 0.05$.

RESULTS AND DISCUSSION

Growth and yield

Trees of studied sweet cherry cultivars grew the strongest on Mazzard rootstock. It is consistent with the opinions of Kloutvor (1991) and Godini et al. (2008). New rootstocks of Mahaleb cherry No. 2 and No. 6 significantly limited the trunk cross-sectional area in comparison with Mazzard rootstock (Table 2).

Hrotkó et al. (2009) observed a differentiated growth of cv. Carmen sweet cherry trees budded on different rootstocks of Mahaleb cherry of Hungarian selection. It is also confirmed by previous reports (De Salvador et al. 2005; Hilsendegen 2005; Bujdoso, Hrotkó 2007; Usenik et al. 2008). However, in the experiment of Balmer (2008) trees of cv. Regina budded on cv. SL405 Mahaleb cherry grew very strongly and they had the biggest TCSA among all checked rootstocks. Independently from the used rootstocks, trees of cvs Regina and Summit were characterized by a bigger

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Table 2. Trunk cross-sectional area, volume of crown, number and number of fruits of flowers, flower:fruit ratio and fruit mass of sweet cherry trees depending on type of rootstock and cultivar

Rootsctock	Cultivar			Mean for rootstock
	Regina	Summit	Vanda	
Trunk cross-sectional area (cm^2) (autumn 2013)				
Mazzard cherry	46.3[e]	39.3[d]	36.5[c]	40.7[b]
Mahaleb cherry No. 2	28.4[ab]	31.2[b]	27.1[a]	28.9[a]
Mahaleb cherry No. 6	29.0[ab]	31.4[b]	27.7[a]	29.4[a]
Mean for cultivar	34.6[b]	34.0[b]	30.4[a]	
Crown volume (m^3) (autumn 2013)				
Mazzard cherry	19.6[e]	20.4[e]	14.3[d]	18.1[b]
Mahaleb cherry No. 2	5.1[a]	8.2[bc]	9.7[c]	7.7[a]
Mahaleb cherry No. 6	6.7[ab]	7.4[b]	7.5[b]	7.2[a]
Mean for cultivar	10.5[a]	12.0[b]	10.5[a]	
Number of flowers (mean values 2012–2013)				
Mazzard cherry	4,866.7[c]	6,230.0[d]	3,268.0[a]	4,788.2[a]
Mahaleb cherry No. 2	3,980.0[b]	5,206.0[c]	6,826.7[e]	5,337.6[b]
Mahaleb cherry No. 6	4,896.0[c]	6,296.0[d]	7,473.3[f]	6,221.8[c]
Mean for cultivar	4,580.9[a]	5,910.7[b]	5,856.0[b]	
Number of fruits (mean values 2012–2013)				
Mazzard cherry	1,163.3[a]	2,533.3[e]	1,918.0[c]	1,871.5[a]
Mahaleb cherry No. 2	1,200.0[ab]	1,731.7[c]	3,853.3[g]	2,266.7[b]
Mahaleb cherry No. 6	1,448.7[b]	2,180.6[d]	3,492.7[f]	2,374.0[b]
Mean for cultivar	1,270.7[a]	2,148.5[b]	3,088.0[c]	
Flower:fruit ratio (%) (mean values 2012–2013)				
Mazzard cherry	24.0[a]	427[d]	59.9[f]	41.8[b]
Mahaleb cherry No. 2	29.5[b]	33.3[bc]	54.1[e]	38.8[a]
Mahaleb cherry No. 6	29.6[b]	34.6[c]	45.7[d]	36.5[a]
Mean for cultivar	27.7[a]	36.8[b]	53.3[c]	
Average fruit mass (g) (mean values 2012–2013)				
Mazzard cherry	8.0[cd]	8.7[bcd]	6.4[a]	7.4[a]
Mahaleb cherry No. 2	8.0[cd]	8.2[d]	8.8[e]	8.3[b]
Mahaleb cherry No. 6	7.8[cd]	7.2[b]	7.6[bc]	7.5[a]
Mean for cultivar	7.9[b]	7.7[ab]	7.6[a]	
Yield of fruits (kg) (mean values 2012–2013)				
Mazzard cherry	9.3[a]	19.4[e]	12.3[b]	13.7[a]
Mahaleb cherry No. 2	14.6[bc]	16.2[cd]	33.4[g]	21.4[b]
Mahaleb cherry No. 6	15.3[c]	18.7[de]	26.2[f]	20.1[b]
Mean for cultivar	13.1[a]	18.1[b]	24.0[c]	

means followed by the same letter do not differ significantly at $P < 0.05$

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TCSA area than cv. Vanda. A different result was obtained by Chełpiński (2007), who measured the biggest TCSA for cv. Vanda.

The biggest crown volume was noted for trees budded on Mazzard rootstock, over two times smaller on Mahaleb cherry rootstocks No. 2 and No. 6. It was observed that the studied cultivar also influenced the volume of the tree crown. The biggest crown volume was found for cv. Vanda, next for cvs Regina and Summit trees (Table 2).

According to many authors (Simon et al. 2004; Bujdoso, Hrotkó 2005; Hrotkó 2007; Gratacos et al. 2008; Stachowiak 2012) sweet cherry trees budded on weakly growing rootstocks blossom and fruit more abundantly than trees budded on stronger growing rootstocks. It is also confirmed by the results of the conducted experiment (Table 2). On the basis of the mean values of results obtained from two years' observations, a significant influence of rootstock on the number of flowers was noticed. Trees budded on Mazzard rootstocks had much fewer flowers than those growing on Mahaleb cherry rootstock. The best result was obtained for Mahaleb cherry No. 6, and next No. 2. Trees of cvs Summit and Vanda blossomed the most intensively (Table 2).

Trees budded on biotypes of Mahaleb cherry rootstock had the larger amount of fruit. Much less fruit was collected from trees growing on Mazzard, which is also confirmed by earlier experiments of Chełpiński (2007) and Stachowiak (2012). Among the studied cultivars the largest number of fruit was collected from cvs Vanda and Summit, the smallest from cv. Regina (Table 2).

The highest percentage of fruit compared to the number of flowers was obtained from trees of cv. Vanda budded on the Mazzard rootstock (Table 2).

According to De Salvador et al. (2005), Grzyb et al. (2008), and Wociór (2008) a rootstock influences the mass of fruit. A higher mass was obtained from trees budded on biotype Mahaleb cherry rootstock No. 2. A lower mass was obtained from trees budded on rootstocks Mazzard and Mahaleb cherry No. 6. Also De Salvador et al. (2005), Godini et al. (2008) and Hrotkó et al. (2009) reported the higher mass of sweet cherry fruit from trees budded on Mahaleb cherry rootstocks. It can be concluded that Mahaleb cherry selections coming from different scientific centres positively influence the mass of sweet cherry fruit. The highest mass of fruit, as in the previous years (Stachowiak 2012), was collected from cv. Regina trees (Table 2).

Rootstock frequently significantly influences yielding of sweet cherry trees (Robinson et al. 2008; Sitarek et al. 2008). It is also confirmed in the considered experiment. The higher mean 2-year-crop from one tree was obtained from Mahaleb cherry rootstocks No. 2 and No. 6. The crop from trees growing on Mazzard rootstock was significantly lower (Table 2).

Low yields of trees budded on Mazzard rootstock was also reported by Grzyb et al. (2005, 2008). Furthermore, the experiments of other authors (Simon et al. 2004; Godini et al. 2008) confirm that trees budded on Mahaleb cherry cv. SL64 produced higher crop. From all rootstocks examined in the experiment cv. Vanda gave the highest fruit yields, next was cv. Summit, and the weakest yielding cultivar was Regina (Table 2). Similar results were found in Europe and Chile (De Salvador et al. 2005; Godini et al. 2008; Hrotkó et al. 2009).

Yield efficiencies of sweet cherry trees grafted on new Mahaleb cherry rootstocks were significantly higher than those on Mazzard rootstock (Table 3), which implies that this index is not positively correlated with tree vigour, as was observed by other authors (Simon et al. 2004; Balmer 2008; Godini et al. 2008; Grzyb et al. 2008; Hrotkó et al. 2009). The current experiment found that higher yield efficiency for trees on Mahaleb cherry rootstocks No. 2 and No. 6 results from better yielding and weaker growth.

Heavy metals content

According to the Commission Regulation (EC) No. 1881:2006 setting maximum levels for certain

Table 3. Yield efficiencies for trunk cross-sectional area (TCSA) and crown volume (kg/m^3), of sweet cherry trees depending on the type of rootstock (mean value years 2012–2013)

Rootstock	Yield efficiencies	
	TCSA (kg/cm^2)	crown volume (kg/m^3)
Mazzard cherry	0.22^a	0.48^a
Mahaleb cherry No. 2	1.90^b	2.86^c
Mahaleb cherry No. 6	1.90^b	2.28^b

means followed by the same letter do not differ significantly at $P < 0.05$

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contaminants in foodstuffs, a permissible content of fresh mass mg/kg for Pb is 0.10 and for Cd 0.05.

The mean water content in fruit amounted to 86.1% for cv. Regina, 84.8% for cv. Summit, 85.4% for cv. Vanda. Taking 85.4% as the mean value of water content for studied cultivars, a permissible amount was recalculated to the content allowed in the dry mass and it amounted to 0.69 mg/kg for Pb and 0.34 mg/kg for Cd. The concentration of cadmium in sweet cherry trees leaves oscillated from 0.97 to 1.27 mg/kg of dry mass (d.m.) (Table 4).

A lower concentration of cadmium was found in fruit and it amounted from 0.02 to 0.05 mg/kg of dry mass; thus it did not exceed a permissible norm. No significant influence of cultivars and rootstocks on the concentration of this metal in leaves and fruit was found. The amount of lead in leaves was from 0.26 to 0.76 mg/kg d.m. and it did not depend on the cultivar and rootstock (Table 4). However, a level of chromium in leaves amounted from 0.02 to 0.10 mg/kg d.m. The highest amount of this metal was found in leaves of cv. Regina budded on Mahaleb cherry No. 2 and No. 6, and the lowest in leaves of cv. Vanda budded on Mazzard.

In the conducted experiments the concentration of iron in fruit fluctuated from the level of 6.80 to 19.73 mg/kg d.m. and it was higher than in leaves (Table 5). The highest amount of Fe was found in fruit of cv. Summit budded on Mahaleb cherry No. 6, and it was 2.9 times higher than the smallest value found in fruit of cv. Vanda budded on Mazzard. Comparing the influence of a rootstock on the concentration of iron in fruit, separately for each examined cultivar, it was found that rootstock No. 6 had a significant influence on accumulation of this metal in fruit. The concentration of Fe in leaves oscillated from the level of 5.40 to 8.80 mg/kg d.m. The highest concentration of Fe was found in leaves of cv. Regina budded on Mahaleb cherry No. 6, and the lowest in leaves of cv. Vanda budded on rootstock Mazzard.

According to Grembecka and Szefer (2013) the concentration of Fe in fruit of charry (gean black) amounted from 0.37 to 0.66 and of cherry (gean) from 1.08 to 1.32 mg/100 g d.m.; however the content of water in fruit of cherry (gean black) amounted to 84.7% and those of cherry (gean) to 82.0%. Recalculating the results into dry mass, the concentration of Fe in fruit of cherry (gean black) amounted from 24.05 to 42.9 and in fruit of cherry (gean) from 59.94 to 73.26 mg/kg d.m.

Table 4. Concentration of Cd, Pb and Cr (mg/kg d.m.) in sweet cherry leaves and fruit depending on cultivar and rootstock (mean values 2012–2013)

Metal	Cultivar	Rootstock		
		Mahaleb cherry		Mazzard cherry
		No. 2	No. 6	
Cd	**leaf**			
	Regina	1.12[a*]	1.13[a]	1.08[a]
	Summit	1.05[a]	1.05[a]	1.27[a]
	Vanda	0.97[a]	1.10[a]	1.14[a]
	fruit			
	Regina	0.05[a]	0.05[a]	0.05[a]
	Summit	0.02[a]	0.02[a]	0.05[a]
	Vanda	0.04[a]	0.05[a]	0.05[a]
Pb	**leaf**			
	Regina	0.51[a]	0.57[a]	0.26[a]
	Summit	0.66[a]	0.76[a]	0.68[a]
	Vanda	0.45[a]	0.66[a]	0.55[a]
	fruit			
	Regina			
	Summit		not detected	
	Vanda			
Cr	**leaf**			
	Regina	0.10[b]	0.10[b]	0.05[a]
	Summit	0.05[a]	0.04[a]	0.05[a]
	Vanda	0.05[a]	0.05[a]	0.02[a]
	fruit			
	Regina			
	Summit		not detected	
	Vanda			

homogeneous groups separately for leaves and fruit were identified with the Duncan's test, $P < 0.05$, values denoted with identical letters do not differ significantly

The level of copper in leaves amounted from 1.35 to 2.05 mg/kg d.m. (Table 5). The highest concentration of Cu was found in leaves of cv. Regina budded on rootstock Mahaleb cherry No. 2, and the lowest in leaves of cv. Summit budded on Mahaleb cherry No. 2. The fruit was characterized by higher concentration of Cu than leaves. The level of this metal in fruit oscillated from 2.22 to 6.06 mg/kg

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Table 5. Concentration of Fe, Cu, Zn and Ni (mg/kg d.m.) in sweet cherry leaves and fruit depending on cultivar and rootstock (mean values 2012–2013)

Metal	Scion	Concentration (mg/kg) Mahaleb cherry No. 2	Mahaleb cherry No. 6	Mazzard cherry
		leaf		
Fe	Regina	7.00[ab]	8.80[c]	5.80[ab]
	Summit	6.45[ab]	7.35[bc]	6.70[ab]
	Vanda	6.40[ab]	6.68[ab]	5.40[a]
		fruit		
	Regina	8.50[ab]	17.60[e]	7.91[ab]
	Summit	15.17[d]	19.73[f]	9.29[b]
	Vanda	8.15[ab]	11.40[c]	6.80[a]
		leaf		
Cu	Regina	2.05[c]	1.85[bc]	1.65[ab]
	Summit	1.35[a]	1.55[a]	1.45[a]
	Vanda	1.50[a]	1.55[a]	1.60[ab]
		fruit		
	Regina	3.27[a]	5.75[c]	2.22[a]
	Summit	5.12[bc]	5.50[c]	5.10[bc]
	Vanda	3.56[ab]	6.06[c]	2.25[a]
		leaf		
Zn	Regina	1.75[a]	1.35[a]	1.30[a]
	Summit	1.75[a]	1.35[a]	1.45[a]
	Vanda	1.50[a]	1.55[a]	1.45[a]
		fruit		
	Regina	4.91[e]	4.35[d]	2.00[ab]
	Summit	3.74[c]	5.35[f]	5.35[f]
	Vanda	2.27[b]	5.45[f]	1.70[a]
		leaf		
Ni	Regina	2.35[a]	2.40[a]	2.35[a]
	Summit	2.45[a]	2.40[a]	2.50[a]
	Vanda	2.40[a]	2.50[a]	2.35[a]
		fruit		
	Regina	1.05[a]	1.15[a]	1.10[a]
	Summit	1.25[a]	1.10[a]	1.25[a]
	Vanda	1.10[a]	1.20[a]	1.00[a]

homogeneous groups separately for leaves and fruit were identified with the Duncan's test $P < 0.05$, values denoted with identical letters do not differ significantly

d.m. Mahaleb cherry No. 6 showed a higher concentration of copper in fruit in all examined cultivars.

Similarly as in case of iron, results of copper concentration obtained by Grembecka and Szefer (2013) were recalculated for a concentration of copper in dry mass. The authors found on average 0.001 mg of copper/100 g d.m. in fruit of cherry (gean black), after recalculating 0.065 mg/kg d.m., and 0.06 mg/100 g d.m. in fruit of cherry (gean), after recalculating 33.3 mg/kg d.m.

The concentration of zinc in leaves was in the range of 1.30 to 1.75 mg/kg d.m., however, in fruit it was from 1.70 to 5.45 mg/kg d.m. (Table 5). A higher concentration of this metal was found in fruit than in leaves. No significant influence of cultivar and rootstock on the concentration of zinc in leaves was observed. Significant differences were obtained in fruit. Mahaleb cherry No. 2 influenced the highest concentration of Zn in fruit of cv. Regina. In fruit of cv. Vanda the highest concentration of Zn was found in plants budded on Mahaleb cherry No. 6. Cv. Summit budded on Mahaleb cherry No. 6 and on Mazzard was characterized by the highest concentration of this metal in fruit.

Grembecka and Szefer (2013) found the concentration of Zn from 0.02 to 0.11 mg/100 g of wet weight (w.w.) in fruit of charry (gean black) and charry (gean). After recalculating into dry mass, the concentration of Zn in fruit of charry (gean black) amounted from 1.30 to 7.17 and in fruit of charry (gean) from 1.11 to 6.11 mg/kg d.m..

The level of Ni in leaves amounted from 2.35 to 2.50 mg/kg d.m., however, in fruit it was from 1.00 to 1.25 mg/kg d.m. (Table 5). No significant influence of cultivar and rootstock on the concentration of this metal in leaves and fruit was observed. Grembecka and Szefer (2013) observed the concentration of nickel from 0.004 to 0.01 mg/100 g d.m. in fruit of charry (gean black), after recalculating into dry mass it was from 0.26 to 0.65 mg/kg, but in fruit of charry (gean) it was from 0.01 to 0.03 mg/100 g d.m., after recalculating into dry mass it was from 0.55 to 1.67 mg/kg.

All the conducted experiments made it possible to arrange a series of mean values of the concentration of analysed metals: Fe > Ni > Cu > Zn > Cd > Pb > Cr in leaves, and Fe > Cu > Zn > Ni > Cd in fruit.

The concentration of phytotoxic forms of heavy metals in soil is affected by soil physicochemical properties such as granulometric composition, pH, organic substance content, sorption properties and

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Table 6. Concentration of heavy metals (mg/kg of d.m.) in upper layer of the soil (0–30 cm) in sweet cherry orchard

Cultivar	Rootstock	Year	Heavy metals (mg/kg)							pH (H_2O)	EC (mS/cm)
			Cd	Pb	Cr	Fe	Cu	Zn	Ni		
Regina	Mahaleb cherry No. 2	2012	0.08	2.20	0.21	109.71	2.81	12.70	0.24	6.98	0.08
		2013	0.12	2.31	0.24	101.23	2.63	11.23	0.21	7.11	0.08
	Mahaleb cherry No. 6	2012	0.09	2.38	0.22	92.51	2.14	11.00	0.26	7.21	0.08
		2013	0.12	2.35	0.21	98.12	2.33	12.76	0.30	7.18	0.08
	Mazzard cherry	2012	0.09	2.28	0.23	107.52	1.90	11.01	0.28	7.11	0.08
		2013	0.11	2.31	0.21	99.89	2.10	12.53	0.26	7.15	0.08
Summit	Mahaleb cherry No. 2	2012	0.12	2.42	0.23	98.00	2.53	11.10	0.27	6.93	0.07
		2013	0.10	2.38	0.24	95.43	2.30	10.76	0.26	7.14	0.08
	Mahaleb cherry No. 6	2012	0.14	2.69	0.21	95.21	2.00	9.80	0.25	7.19	0.08
		2013	0.12	2.47	0.26	97.34	2.01	10.52	0.31	7.09	0.08
	Mazzard cherry	2012	0.15	243	0.25	96.44	2.11	12.76	0.33	7.24	0.09
		2013	0.14	2.38	0.28	99.45	2.10	13.31	0.29	7.14	0.09
Vanda	Mahaleb cherry No. 2	2012	0.15	2.49	0.21	94.91	2.20	11.10	0.31	7.29	0.07
		2013	0.10	2.44	0.24	94.11	2.01	12.42	0.33	7.23	0.07
	Mahaleb cherry No. 6	2012	0.16	2.28	0.26	106.52	1.73	12.28	0.27	7.23	0.09
		2013	0.15	2.17	0.27	103.45	1.94	11.76	0.31	7.18	0.09
	Mazzard cherry	2012	0.13	2.10	0.22	103.41	2.25	12.01	0.29	7.16	0.08
		2013	0.17	2.11	0.28	105.23	2.10	12.30	0.30	7.11	0.08

oxidoreductive potential (Fergusson 1990; Kabata-Pendias, Pendias 2001).

Polish law regulates binding limits of heavy metals concentration in the Minister's of Environment Regulation of September 9, 2002 on soil and ground quality standards. According to this regulation in a 0–30 cm layer of soil a permissible concentration of metals expressed in mg/kg of soil dry mass amounts to: Cd 4, Pb 100, Cr 150, Cu 150, Zn 300 and Ni 100. The current experiments found that min. and max. concentrations ranged from: Cd 0.08–017, Pb 2.10–2.69, Cr 0.21–0.28, Fe 92.51–109.71, Cu 1.73–2.81, Zn 9.80–13.31, Ni 0.21–0.33 mg/kg of soil dry mass (Table 6).

The form of existence and availability of heavy metals for plants is mainly dependent on pH of the soil (Kabata–Pendias, Pendias 2001). Soil acidity leads to an increase in forms available for plants (Alloway, Ayres 1999; Blake, Goulding 2002). In the conducted experiments pH values (in H_2O) amounting from 6.93 to 7.29 and EC (mS/cm) amounting from 0.07 to 0.09 were indicated (Table 6).

CONCLUSION

– Trees budded on new biotypes of Mahaleb cherry No. 2 and No. 6 were characterized by a weaker vigour in comparison with sweet cherry trees budded on Mazzard rootstock. Trees of cv. Vanda cultivar grew stronger than the two remaining cultivars.

– Sweet cherry trees budded on Mahaleb cherry rootstocks No. 2 and No. 6 had more flowers, fruit and gave a higher yield. Also yield efficiency for cultivars budded on these rootstocks was the higher.

– Sweet cherry trees budded on Mahaleb cherry rootstock No. 2 and cv. Regina had the higher mass of fruit.

– Analysing the influence of rootstock and cultivar on the concentration of heavy metals significant differences were observed for Fe, Cu and Zn in fruit, and for Fe, Cu and Cr in leaves.

– In sweet cherry fruit, the presence of Pb and Cr was not detected; the permissible concentration of cadmium was not exceeded.

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– The highest concentration of Cd, Pb, Cr and Ni was found in leaves of sweet cherry, the highest amounts of Fe, Cu and Zn were observed in fruit.

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