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Early tree growth, productivity, fruit quality and leaf nutrients content of sweet cherry grown in a high density planting system

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Abstract

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From 2008 to 2013 the phenology, early tree growth, precocity, yield, fruit quality attributes and leaf nutrient status of four sweet cherry cultivars (May Early, Germersdorfer, Sunburst and Celeste) were evaluated on Colt rootstock in the Cacak region (Serbia) with 1,250 trees/ha. The soil type was heavy and acidic. The results showed that cv. May Early blossomed and ripened earlier than the other cultivars, and had the highest tree vigour, better yield performance and the poorest fruit physico-chemical attributes. The best fruit quality was found in cv. Sunburst which is categorized as a low precocious cultivar with small yield capacity. Lower tree vigour, good productivity and fruit quality were shown by cv. Celeste. In general, leaf analysis indicated that all cultivars had excessive levels of N and Cu, and in some cases P, whereas K, Ca, Mg, Fe, Mn, Zn and B were deficient in all cultivars. The best balanced nutritional values (ΣDOP) were observed in cv. Sunburst, whereas wider imbalance was observed in cv. Celeste for macronutrients. In contrast, the ΣDOP for micronutrients indicated that cv. Celeste had the best balanced nutritional values, whereas cv. Sunburst had the worst.

Keywords: fruit size; *Prunus avium* L.; macro- and micronutrients; soluble solids; yield

Sweet cherry (*Prunus avium* L.) is a fruit crop with a high economic importance, due to the nutritional, technological and commercial value of its fruits. Because their regular consumption was reported to decrease the risk of arthritis, gout and headaches (Serrano et al. 2005), cherries have recently received increased interest as a healthy foodstuff. The health benefits of cherry fruit are usually attributed to their chemical composition, since they are a good source of antioxidant compounds and other phytochemicals such as sugars, organic acids, minerals, etc. (Nagy et al. 2008; Pérez-Sánchez et al. 2010).

In the past few decades, sweet cherry production has greatly increased worldwide in areas with different agro-climatic conditions. In Serbia, cherry production has also increased, it was however limited by numerous factors, primarily the lack of suitable size-controlling rootstocks and highly productive cultivars. The choice of the best rootstock-scion cultivar combinations for specific climatic conditions and soil types is a very difficult problem for cherry growers worldwide (Moreno et al. 2001; Cantín et al. 2010), including Serbia. In addition, local growing conditions in Serbia require tolerance to cold winters (pro-

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viding min. winter temperature data), and adaptability to heavy and acidic soils which account for over 60% in total Serbian agricultural soils (Glišić et al. 2011). Although the introduction of size-controlling cherry rootstocks, newer cultivars and high density planting (HDP) systems were evident, Serbian cherry growers have little and very poor experience with dwarfing and semi-dwarfing cherry rootstocks and HDP system, especially under non-irrigated conditions.

For these reasons, behaviour of four cherry cultivars grafted on semi-vigorous Colt rootstock with 1,250 trees/ha was evaluated through the phenology, tree growth, productivity, fruit quality and leaf nutrient status in order to identify potential cultivars for cherry production on typical heavy and acidic soil conditions in the Cacak region, Western Serbia.

MATERIAL AND METHODS

The orchard was established in Prislonica village (43°33'N, 16°21'E, 300 m a.s.l.) near Cacak city, Western Serbia. The long-term (1965–2010) average annual temperature was 11.3°C, with an average air temperature during the growing cycle of 17.0°C, and total annual precipitation was 690.2 mm. In the period April–October from 2009 to 2013, mean monthly air temperatures were considerably higher than long-term averages, while rainfall had lower values in general, especially in July and August (data not shown). Soil is a typical heavy vertisol (also called “smonitza”) with 2.46% organic matter, 0.21% total N (N_{TOT}), 35.25 mg/kg P_2O_5, 107.50 mg/kg K_2O, 0.07% Ca and 1.04% Mg. Soil analysis also indicated 3.5% Fe, 1,370 mg/kg Mn, 30 mg/kg Cu, 61 mg/kg Zn and 1.1 mg/kg B. Levels of organic matter and N_{TOT}, Cu, Mn and Zn were moderate to high, whereas levels of available P, K, Ca, Mg, Fe and B were low. Soil texture is clay-loam with very low pH (4.71 in 0–30 cm depth).

One-year-old nursery trees of two old and traditional (cvs May Early and Germersdorfer), and two newly [cvs Sunburst and Celeste (syn.: Sumpaca)] sweet cherry cultivars grafted on Colt (*P. avium* L. × *P. pseudocerasus* Lindl.) rootstock, were planted in autumn 2008 and trained in a Zahn Vertical Axis, with distances of 4 m between rows and 2 m between trees (1,250 trees/ha). The trial was established in a randomized block design with four replications of five trees per plot of each rootstock-cultivar combination (n = 20). Tree vigour was controlled by early summer pruning according to the principles of Zahn’s system of tree pruning (Zahn 1991). Also, pruning was accompanied with regular branch bending by 80° to 90° during the first three years to stimulate development of flower buds. Standard cultural practices were applied, except irrigation. Each year, starting in 2010 (2nd leaf) 400 kg calcium ammonium nitrate (containing 27% N_{TOT}) per ha was applied before the onset of growth.

The study was based on 24 traits, describing agronomic (3) and fruit quality (11) traits and leaf nutrient content (10) of sweet cherry genotypes (Table 1).

Blossoming dates (first, full, end) were determined according to the methodology proposed by Baggiolini (1952). Blossoming observations were made every 2–3 days.

The following parameters were measured and/or calculated: trunk circumference at 10 cm above the graft union, the yield per tree and yield efficiency. Trunk circumferences were converted into trunk cross-sectional areas (TCSA). Cumulative yield per tree and yield efficiency of each cultivar were computed from the harvest data. The yield efficiency was expressed as the ratio of total cumulative yield per final TCSA.

Fruit analyses covered fruit weight, fruit dimensions and fruit size (geometric mean diameter), sphericity, stone weight, flesh/stone ratio (pulp yield), content of soluble solids, titratable acidity and ripening index value (soluble solids/acidity ratio) according to Milošević et al. (2013). These analyses were recorded on 20 cherries in four replicates (n = 80) from each cultivar at full maturity stage (S14) according to fruit colour and size (Serrano et al. 2005).

Leaf samples for macro- and micronutrient determination were collected from the middle part of current season non-bearing shoots (30–50 cm long) of the evaluated cultivar trees at 60 days after full bloom (DAFB). The deviation from optimum percentage (DOP index) for nutritional status of trees (Montañés et al. 1993) was calculated from leaf chemical analysis at 60 DAFB by the following mathematical formula:

$$\mathrm{DOP} = \left(\frac{C_n}{C_o} - 1\right) \times 100$$

where:

C_n – foliar content of the tested nutrient [dry matter basis (d.b.)]

C_o – critical optimum nutrient content for sweet cherry (d.b.)

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Table 1. Agronomic traits, fruit quality attributes and leaf nutrient status of sweet cherry cultivars

Evaluated variables	Unit	Abbreviations
A. Agronomic features		
1. Blossoming date (first, full, end): date when 10 and 80% were opened, respectively; and, when 90% calyx failed	date	BD
2. Harvest date: the date when fruits have full (commercial) maturity stage (S4) (Serrano et al. 2005)	date	HD
3. Yield: determined for each tree accession by ACS System Electronic Scale (Zhejiang, Suzhou, China)	kg/tree	Y
B. Fruit quality attributes		
4. Fruit weight: measured by scale FCB 6K 0.02B (Kern & Sohn, GmbH, Belingen, Germany)	g	FW
5. Stone weight: measured by scale FCB 6K 0.02B	g	SW
6. Pulp yield (flesh rate): calculated by subtracting the stone weight from the whole fruit weight	%	*Py*
7. Fruit length (L, polar diameter): measured by caliper Starrett 727 (Athol, North York, USA)	mm	L
8. Fruit width (W, suture diameter): measured by caliper Starrett 727	mm	W
9. Fruit thickness (T, equatorial diameter): measured by caliper Starrett 727	mm	T
10. Fruit geometric mean diameter or fruit size (D_g): calculated using equation: $D_g = \sqrt[3]{LWT}$ (Mohsenin 1980)	mm	D_g
11. Sphericity (φ): calculated using equation: $\varphi = D_g/L$ (Mohsenin 1980)	ratio	*Sp*
12. Soluble solids content: determined by refractometer Milwaukee MR 200 (ATC, Rocky Mount, USA)	°Brix	SSC
13. Titratable acidity was measured by neutralization to pH 8.1 with 0.1 mol/l NaOH	%	TA
14. Ripeness index was calculated as the ratio of SSC/TA	ratio	RI
C. Leaf nutrient composition		
15. Nitrogen: determined by Kjeldahl analysis (Vapodest 50s; Gerhardt, Königswinter, Germany)	%	N
16. Phosphorus: analyzed spectrophotometrically (Hewlett Packard 8452A, Ontario, CA)	%	P
17. Potassium: determined by flame photometer Flapho 4 (Carl Zeiss, Jena, Germany)	%	K
18. Calcium: determined with absorption spectroscope Pye Unicam SP 191 (Pye Unicam Ltd., Cambridge, UK)	%	Ca
19. Magnesium: determined with absorption spectroscope Pye Unicam SP 191	%	Mg
20. Iron: determined with absorption spectroscope Pye Unicam SP 191	mg/kg	Fe
21. Manganese: determined with absorption spectroscope Pye Unicam SP 191	mg/kg	Mn
22. Cooper: determined with absorption spectroscope Pye Unicam SP 191	mg/kg	Cu
23. Zink: determined with absorption spectroscope Pye Unicam SP 191	mg/kg	Zn
24. Boron: determined colorimetrically using kinalizarin on colorimeter MK 6/6 (Carl Zeiss, Jena, Germany)	mg/kg	B

The C_o was taken from optimum values for sweet cherry proposed by Leece (1975). Besides, it provides the general nutritional status of nutrients through the ΣDOP index, obtained by adding the values of DOP indices irrespective of sign. The lower the ΣDOP, the greater is the intensity of balance among nutrients.

Statistical differences between the experimental factors were verified using ANOVA. When the

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Table 2. Phenological characteristics of four sweet cherry cultivars. Data are the means for the period 2010–2013

Cultivar	Blossoming			Harvest date		Fruit development period
	first	full	end	beginning	full	
May Early	8 April	10 April	14 April	9 May	13 May	29
Germersdorfer	21 April	23 April	29 April	12 June	15 June	50
Sunburst	17 April	19 April	27 April	14 June	16 June	56
Celeste	20 April	23 April	28 April	7 June	10 June	45

F-test was significant, means were compared with the LSD test at $P \leq 0.05$. Analyses were performed using the Microsoft Office Excel software (Microsoft Corporation, Redmond, USA).

RESULTS AND DISCUSSION

Phenological characteristics

The phenological characteristics are presented in Table 2. Cv. May Early had the earliest first blossoming, whereas cvs Celeste and Germersdorfer had the latest first blossoming, and cv. Sunburst showed an intermediate first blossoming date. On average, full and end of blossoming occurred 2–3 and 6–10 days, respectively, after the first blossoming date. Cv. May Early had the shortest blossoming period (6 days), while cv. Sunburst had the longest blossoming period (10 days). These results are in accordance with data of Milošević (1997) and Kazantzis et al. (2011) who all reported similar blossoming date tendencies for cvs May Early and Germersdorfer. Contrary to our results, cv. Celeste blossomed relatively early under Bulgarian (Lichev et al. 2004) and Serbian (Milatović et al. 2013) conditions, whereas Kappel et al. (1998) noted that the bloom period of this cultivar is late in Canada, which confirmed our results. These data suggest that cultivar effects on blossoming can be of importance when deciding on pollinizers for new orchards with self-incompatible cultivars (Gratacós et al. 2008). Also, blossoming time and duration are important in cherry cultivar selection for planting on spring frost-prone sites. Beside cultivars, most of authors reported that season (year) importantly influenced blossoming date (García-Montiel et al. 2010). In addition, climatic conditions can affect fruit set with both low and high temperatures having negative effects. Low temperatures at blossoming reduce pollen tube growth and may shorten the effective pollination period (Sanzol, Herrero 2001), whereas high pre-blossom temperatures (≥ 27°C) can negatively affect ovule longevity and pollination effectiveness (Postweiler et al. 1985).

The cultivar which ripened earliest was May Early, followed by Celeste and Germersdorfer, whereas cv. Sunburst ripened latest of all (Table 2). The full ripened stage (S14) occurred 2−4 days after first harvest. Harvest dates for a cultivar may be modified by rootstock effects and climatic conditions in the growing season (Menzies 2004). Generally, our harvest date for the same cultivars is in agreement with observations of other authors (Kazantzis et al. 2011; Milatović et al. 2013). Otherwise, early and late ripening is considered a desirable trait in sweet cherry (Lichev et al. 2004).

The period of fruit development was the shortest in cv. May Early at 29 days, and the longest in cv. Sunburst at 59 days. Our results for cv. May Early closely agree with the results of Bulatović (1992) who reported that cv. May Early had a 28-day period of fruit development. Besides genotype and rootstock, the fruit development depends on the cultivar chilling requirements and temperature sums from blossoming to harvest period in general. However, Alburquerque et al. (2008) stated that in the many cases, harvest time was not related to the blossoming time, as later−flowering cultivars may be harvested earlier than earlier-flowering cultivars.

Tree vigour and yield performance

Tree growth, as measured by TCSA, was significantly influenced by cultivar, starting from the second year (2010) after planting (Fig. 1). Tress of cv. May Early grew vigorously, tress of cvs Sunburst and Celeste grew slowly, while trees of cv. Germersdorfer grew moderately. Lichev et al. (2004) noted

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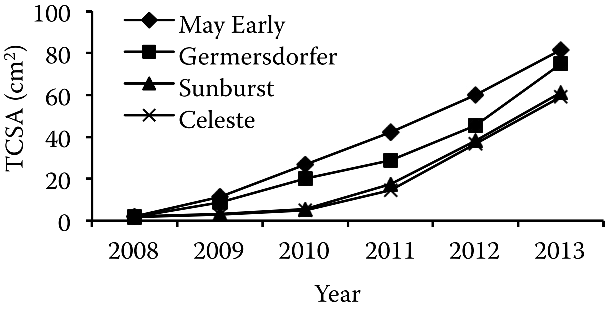

Fig. 1. Effect of cultivar on trunk cross-sectional area (TCSA) from the first (2008) to the sixth (2013) year after grafting

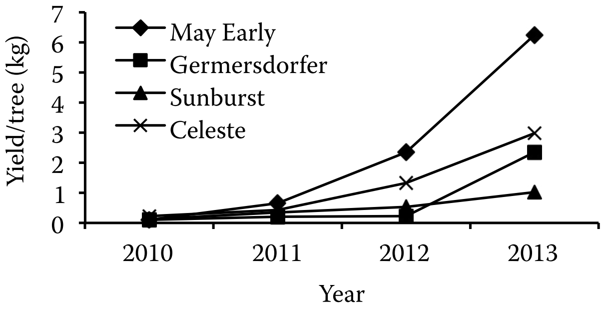

Fig. 2. Effect of cultivar on precocity and yield per tree from the second (2010) to the fifth (2013) year after planting

that cv. Celest had moderate tree dimensions when compared with seven commercial cultivars grown under Bulgarian conditions. The vigorous and upright growth habit of cv. Germersdorfer was also reported previously by Kazantzis et al. (2011). The final TCSA values in 2013 showed that cv. May Early had the most vigorous trees, significantly different from the other cultivars (Table 3). The high vigour of cv. May Early may be beneficial when planting on poor soils or under replanting conditions (Milošević 1997). Because both cvs Celeste and Sunburst on Colt had a better capacity to control vigour, these scion-rootstock combinations may be more suitable for closer within-row planting.

Colt rootstock in dry conditions reduced tree vigour by about 20–30% compared to Mazzard (Perry 1987). However, tree vigour, as measured by TCSA, of cv. Lapins grafted on 12 dwarfing, semi-vigorous and invigorating rootstocks, including Mazzard seedlings, was the highest on Colt (Godini et al. 2008), and TCSA of cvs Kordia, Těchlovan and Vanda also on Colt was much higher as compared to P-HL-A rootstock (Blažková, Drahošová 2012).

In the first two bearing years (2010–2011), yields were very low (< 0.2 kg/tree), and there were no significant cultivar differences (Fig. 2). In 2012 and 2013, yields of all cultivars, except cv. Sunburst, increased. These data are in accordance with the results of Moreno et al. (2001) and Wociór (2008) who reported that on average, sweet cherry started to produce two years after planting and production increased in the 3rd and 4th years. In other studies, cherry started to produce between the 3rd and 6th year (Godini et al. 2008). In our study, the most precocious cultivar is May Early, followed by Celeste and Germersdorfer, while Sunburst consistently had very low yields, thus being classed as a low precocious cultivar, as previously reported by Gliŝić et al. (2011) in conditions similar to ours.

Significant differences among cultivars for final yield per tree, cumulative yield and yield efficiency became evident, being the highest in cv. May Early, and the lowest in cv. Sunburst (Table 3). The high vigour and yield shown by cv. May Early were reported previously (Bulatović 1992), and could be explained by its good adaptation to a typical heavy and acidic soil. The better adaptation of this cultivar to the growing conditions may also explain larger fruit retention, and thus a better overall performance in yield (Godini et al. 2008; Cantín et al. 2010). Low yield efficiency was found in cv. Germersdorfer, which is in agreement with the results of Kazantzis et al.

Table 3. Tree growth and yield attributes of four sweet cherry cultivars (mean ± SE)

Cultivar	Final TCSA (cm^2) (2013)	Yield (kg/tree) (2013)	Cumulative yield (kg/tree) (2010–2013)	Yield efficiency (kg/cm^2) (2013)
May Early	81.46 ± 1.82^a	6.23 ± 0.24^a	9.33 ± 0.01^a	0.08 ± 0.00^a
Germersdorfer	74.88 ± 0.20^b	2.35 ± 0.15^b	2.89 ± 0.02^c	0.03 ± 0.00^c
Sunburst	61.18 ± 1.50^c	1.02 ± 0.10^c	2.02 ± 0.01^d	0.02 ± 0.00^c
Celeste	59.07 ± 0.58^d	2.98 ± 0.11^b	4.95 ± 0.01^b	0.05 ± 0.00^b

cultivar means in the same column followed by the same letter are not significantly different according to the LSD test ($P \leq 0.05$); TCSA – trunk cross-sectional area

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Table 4. Fruit physical attributes of four sweet cherry cultivars grafted onto Colt rootstock. Data are the mean ± SE for 2012 and 2013

Cultivar	Fruit weight (g)	Fruit length (mm)	Fruit width (mm)	Fruit thickness (mm)	Geometric mean diameter (mm)	Sphericity	Stone weight (g)	Pulp yield (%)
May Early	3.14 ± 0.11^{d}	15.64 ± 0.14^{d}	14.78 ± 0.14^{d}	17.03 ± 0.20^{d}	15.78 ± 0.13^{d}	1.01 ± 0.01^{c}	0.16 ± 0.00^{d}	94.61 ± 0.27^{d}
Germersdorfer	9.18 ± 0.17^{b}	22.76 ± 0.19^{b}	25.04 ± 0.21^{b}	20.76 ± 0.14^{b}	22.79 ± 0.16^{b}	1.00 ± 0.00^{d}	0.34 ± 0.00^{a}	96.32 ± 0.08^{c}
Sunburst	11.36 ± 0.18^{a}	23.71 ± 0.17^{a}	27.14 ± 0.38^{a}	22.31 ± 0.19^{a}	24.30 ± 0.21^{a}	1.02 ± 0.01^{b}	0.24 ± 0.00^{b}	97.88 ± 0.06^{a}
Celeste	7.80 ± 0.18^{c}	20.41 ± 0.18^{c}	23.44 ± 0.22^{c}	19.93 ± 0.13^{c}	21.21 ± 0.15^{c}	1.04 ± 0.00^{a}	0.20 ± 0.00^{c}	97.36 ± 0.08^{b}

means in the same column followed by the same letter are not significantly different according to the LSD test ($P \leq 0.05$)

(2011) who reported that this cultivar gave only moderate yields. After cv. May Early, cv. Celeste possesses good yield performance, especially yield efficiency due to its low vigour and relatively high productivity (Lichev et al. 2004). Our results for yield per tree and yield efficiency at the same tree age were however much lower for cv. Celeste on Colt than those obtained by Milatović et al. (2013) in similar conditions. The differences between our results and those of the above authors could be explained by differences in the tree shape and size and in the pruning regimes. Several studies distinguished problems related to poor yields, which are frequently found in some sweet cherry cultivars (García-Montiel et al. 2010). For example, Godini et al. (2008) reported that cumulative sixth year yields of cv. Lapins ranged from a min. of 2.5 kg/tree to a max. of 45.5 kg/tree, depending on the rootstocks.

Fruit physical features

All fruit physical features were very different among cultivars (Table 4). The highest values were found in fruits of cv. Sunburst, and the lowest in cv. May Early. Fruit weight, dimensions and size are the most important indicators of sweet cherry fruit quality and just one criterion used in choosing a cultivar (Menzies 2004). For most European countries, fruit weight of sweet cherry should be between 11 and 12 g (Kappel et al. 1996). In the present study, however, only cv. Sunburst had fruit weight >11 g, which is in agreement with a previous study on sweet cherry (Milatović et al. 2013). For cv. Celeste, Lichev et al. (2004) noticed that its fruits are large (9.9 g in average), which was not the case in our trial. For cv. Germersdorfer, Keserović et al. (2007) and Kazantzis et al. (2011) noted intermediate to large fruit sizes as compared with other new cultivars. It is important to note that many aspects of growing cherries such as pruning, rootstocks, pollination and irrigation can modify or overcome some of these cultivar characteristics (Menzies 2004). In the very early cultivar (May Early) fruit weight and size were very small, therefore this cultivar is admitted into the first category of quality with fruits at least 16 mm in width and a weight of at least 5 g (Sîrbu et al. 2012). However, this cultivar may be of interest to growers primarily due to its early maturity and high productivity.

Although weight is an important external fruit quality trait, fruit size and fruit diameter are essential

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for commercial market value (Whiting et al. 2005). Thus, sweet cherry cultivars with large fruits (in both weight and width) are increasingly valued at the international level. For example, fruits of 26 mm in width are admissible into the first quality category, regardless of the ripening period (UNECE Standard 2007). These category ranges varied among countries, i.e. 25 mm in Spain to 29–30 mm in Canada (Whiting et al. 2005). Generally, consumers prefer sweet cherries with short peduncles, fruit diameter ≥ 24 mm and with bright red colour (Crisosto et al. 2003).

The sphericity of the fruits is an index of its roundness (Mohsenin 1980). In our study, all cultivars, except cv. Germersdorfer, had slightly elongated heart-shaped fruits, so sphericity values were slightly over 1 (Table 4). Kappel et al. (1998) noted that fruits of cv. Celeste are symmetrical and kidney shaped. Differences in the fruit form are interesting, since a flattened sweet cherry seems to be more tempting than a lengthened one (Pérez-Sánchez et al. 2010).

In the present study, cv. Germersdorfer had the highest stone weight, and cv. May Early the lowest (Table 4). Sweet cherry stones are used in genotype identification and their characters were found to be very variable among them (Blažková 1988). This author also reported that stone weight relative to fresh fruit weights ranged between 3.7% and 8.4%, values which are similar to our results in general. By evaluating data of all cultivars, we showed that the pulp yield or flesh/stone ratio was cultivar-dependent (Schoedl et al. 2009), the best value being found in cv. Sunburs, and the poorest in cv. May Early. Consumers prefer sweet cherries with high pulp yield.

Fruit chemical characteristics

The soluble solids content (SSC) (consisting mostly of sugars) varies between 11 and 25°Brix in sweet cherry (Serrano et al. 2005). In general, American consumers preferred sweet cherries with SSC > 16% (Crisosto et al. 2003).

In the present study, mean SSC ranged between 14.1 and 16.2°Brix. Fruits of cv. Sunburst had the highest SSC, followed by cv. Celeste, the lowest were cvs Germesdorfer and May Early with similar SSC levels (Table 5). Keserović et al. (2007) reported that cv. Germesdorfer also contained lower SSC as compared with other commercial cultivars grown in similar environment, but similar to our data. For cv. Celeste, our result was lower as compared to the data of Kappel et al. (1998), but higher than those obtained by Milatović et al. (2013) at the same tree age and grafted onto Colt rootstock in conditions like ours. Neri et al. (2005) showed that cv. Celeste under an Italian environment had the lowest level of SSC (13.2°Brix) as compared with eight other cultivars such as cvs Van, Durone Nero II, etc. This level is lower than those mentioned in our study, probably due to different local environment, farming practice and rootstock used.

Malic acid is the principal metabolic substrate together with sugars (Westwood et al. 1973), and was present in cherry fruits in higher contents than other organic acids. In our study, similarly to SSC, fruits of cv. Sunburst had the highest titratable acidity (TA) levels, and cv. May Early had the lowest (Table 5). The other two cultivars had intermediate TA levels. Our data were similar to the results previously reported for cvs Celeste (Milatović et al. 2013), Germersdorfer (Keserović et al. 2007) and Sunburst (Glišić et al. 2011). Variability in total acidity levels among sweet cherry cultivars was also previously reported (García-Montiel et al. 2010).

The ripening index (RI) is commonly used as a quality index for sweet cherry, and higher ratios are usually preferred (Cantín et al. 2010). Interestingly, although cv. May Early is an early ripening cultivar, its fruits had the highest RI value (Ta-

Table 5. Soluble solids content, titratable acidity and ripening index for mature fruits of four sweet cherry cultivars grafted onto Colt rootstock (mean ± SE for 2012 and 2013)

Cultivar	Soluble solids content (°Brix)	Titratable acidity (%)	Ripening index
May Early	14.10 ± 0.20^{c}	0.41 ± 0.01^{d}	35.37 ± 1.15^{a}
Germersdorfer	14.17 ± 0.12^{c}	0.53 ± 0.01^{b}	27.17 ± 0.64^{c}
Sunburst	16.18 ± 0.16^{a}	0.57 ± 0.01^{a}	28.49 ± 0.47^{bc}
Celeste	14.99 ± 0.26^{b}	0.49 ± 0.01^{c}	30.73 ± 0.97^{b}

means in the same column followed by the same letter are not significantly different according to LSD test ($P \leq 0.05$)

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ble 5), probably due to its lower acidity content. In contrast, statistically the lowest value was found in cv. Germersdorfer, whereas the other two cultivars had intermediate values. Milatović et al. (2013) reported higher RI values for cv. Celeste than those in our data. Additionally, SSC, which is easily measured in contrast to TA, is the major contributor to the SSC/TA ratio (RI), and therefore, to consumer acceptance (Crisosto et al. 2003).

Leaf nutrient composition at 60 DAFB

According to Betrán et al. (1997), the standard sampling time for cherry foliar diagnosis is usually assessed at mid-summer, i.e. approximately at 120 days after full bloom (DAFB). However, at this time, most of cherry cultivars have been already harvested. For these reasons, leaf analysis of mineral content at 60 DAFB would allow the diagnosis of potential deficiencies or excesses in time to be corrected with more efficiency (Moreno et al. 1996).

In the present study, all leaf nutrients significantly varied among cultivars (Table 6). Regarding leaf macronutrients, the highest N level was found in cv. Celeste, and the lowest in cv. Germersdorfer. Cvs May Early and Celeste had similar and higher P amount as compared with the other two cultivars. Three cultivars (Germersdorfer, Sunburst and Celeste) contained statistically similar and higher K levels than cv. May Early, whereas cv. Sunburst had higher Ca level than other cultivars. Cvs May Early and Sunburst had identical and the highest leaf Mg as compared to others. Our data are partially in accordance with the results obtained by Neilsen et al. (2010) who reported that there were no cultivar differences in leaf N content and inconsistent differences in leaf P. However, results of others authors confirmed the great variability of leaf mineral composition due to genotype, year, rootstock and environment (Ystaas, Frøynes 1995; Roversi et al. 2008). Nagy et al. (2008) reported that cv. Germersdorfer under Hungarian conditions contained higher levels of leaf K and Ca as compared with our results.

Similarly to the macronutrients level, leaf micronutrients also significantly varied among cultivars (Table 6). Cv. May Early is the cultivar with the highest levels of leaf Fe, Mn, Cu and Zn, whereas cv. Germresdorfer had the highest level of leaf B. Cv. Sunburst together with cv. Germresdorfer, had the lowest capacity to accumulate micronutrients. Jiménez et al. (2007) and Stochl et al. (2008) also reported cultivar differences in leaf micronutrients level.

DOP and ΣDOP indexes

According to Montañés et al. (1993), the DOP index is the relative content of assessed nutrients and is used to indicate if an element tends to be deficient (DOP < 0), optimal (DOP = 0), or in excess (DOP > 0). In the present study, leaf N was higher than normal in all cultivars (Table 7), and was attributed to excessive N-fertilization (Leece 1975). This situation can be also linked to relatively high

Table 6. Leaf macro- and micronutrients composition for sweet cherry trees of four cultivars based on mid-shoot leaves sampled at 60 days after full bloom (mean ± SE for 2012 and 2013)

Cultivar	N	P	K	Ca	Mg
May Early	3.18 ± 0.06^{b}	0.27 ± 0.01^{a}	0.99 ± 0.06^{b}	1.11 ± 0.02^{b}	0.41 ± 0.00^{a}
Germersdorfer	2.55 ± 0.03^{d}	0.20 ± 0.01^{b}	1.15 ± 0.02^{a}	0.96 ± 0.05^{b}	0.28 ± 0.02^{b}
Sunburst	2.88 ± 0.02^{c}	0.21 ± 0.00^{b}	1.13 ± 0.02^{a}	1.54 ± 0.01^{a}	0.41 ± 0.00^{a}
Celeste	3.42 ± 0.03^{a}	0.27 ± 0.01^{a}	1.03 ± 0.03^{a}	0.94 ± 0.05^{b}	0.30 ± 0.01^{b}
	Fe	Mn	Cu	Zn	B
May Early	172.37 ± 1.25^{a}	49.07 ± 0.77^{a}	20.60 ± 0.27^{a}	23.50 ± 0.46^{a}	20.27 ± 1.01^{b}
Germersdorfer	118.59 ± 1.80^{c}	24.03 ± 1.57^{c}	12.66 ± 0.17^{b}	14.06 ± 0.80^{c}	22.67 ± 0.78^{a}
Sunburst	124.69 ± 3.24^{c}	15.00 ± 0.31^{d}	13.28 ± 0.24^{b}	16.09 ± 0.29^{bc}	19.24 ± 0.41^{b}
Celeste	139.34 ± 0.34^{b}	30.31 ± 1.21^{b}	12.16 ± 0.32^{b}	17.50 ± 0.33^{b}	20.70 ± 0.69^{ab}

means in the same column followed by the same letter are not significantly different according to the LSD test ($P \le 0.05$)

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Table 7. The DOP index and SDOP determined from leaf macro- and micronutrients content at 60 DAFB of four sweet cherry cultivars (mean for 2012 and 2013)

Cultivar	N	P	K	Ca	Mg	ΣDOP
May Early	+32.50	+10.20	−56.96	−51.48	−25.45	176.59^{b}
Germersdorfer	+6.25	−18.37	−50.00	−49.47	−49.09	173.18^{b}
Sunburst	+20.00	−14.29	−50.87	−18.95	−25.45	129.56^{c}
Celeste	+42.50	+10.20	−55.22	−50.53	−45.45	203.90^{a}
	Fe	Mn	Cu	Zn	B	ΣDOP
May Early	−1.50	−50.93	+96.19	-32.86	-49.23	230.71^{b}
Germersdorfer	−32.23	−75.97	+20.57	−59.83	-43.32	231.92^{b}
Sunburst	−28.75	−85.00	+26.48	−54.03	-51.90	246.16^{a}
Celeste	−20.38	−69.69	+15.81	−50.00	-48.25	104.13^{c}

leaf composition standards for sweet cherry based on mid-shoot leaves sampled at 60 DAFB (Leece 1975); (–) lower content than optimum; (+) higher content than optimum; the different letters in last column indicate significant differences among ΣDOP indexes within each cultivar at $P \leq 0.05$ by the LSD test; DAFB – days after full bloom; DOP – deviation from optimum percentage

N_{TOT} content in the soil. Leaf N level in cv. Germersdorfer tended to be closer to the optimum N level ($DOP_N \approx 0$). All these data imply that cv. Germersdorfer and other cultivars evaluated on Colt rootstock could be less susceptible to N deficiency in these conditions.

The DOP_P for cvs May Early and Celeste was positive and closer to the optimal level, whereas in other two cultivars this index was negative. These results indicated that cvs May Early and Celeste on Colt rootstock were more adaptive to heavy and acidic soil with low available P (Beutel et al. 1978), as compared with cvs Germersdorfer and Sunburst on the same rootstock. Also, the P reduction in cherry leaves may be explained by the antagonistic interaction of Cu with P, i.e. the P level decreased with increasing amount of Cu, as previously reported (Milošević et al. 2013). However, deficiency of P is rare in fruit crops (Beutel et al. 1978).

The negative DOP_K, DOP_{Ca} and DOP_{Mg} indicated the tendency of K, Ca and Mg deficiency in all cultivars on heavy and acidic soil (Leece 1975). Decreased leaf K for cherry was previously associated with heavier cropping rootstocks (Neilsen, Kappel 1996), and probably cultivars. However, except for cv. May Early, yields were small to intermediate, implying that factors other than crop load were affecting leaf K. It seems that the low leaf K level in cherries on Colt rootstock might indicate that they could be susceptible to K deficiency, especially when grown in areas with lower soil K (Moreno et al. 1996), which is the case in our trial. Although deficiencies of Ca and Mg are rarely seen in fruit orchards, this tendency in sweet cherry previously reported (Usenik et al. 2005) as well as in the current study can be related to the very low levels of these nutrients in the soil. Ca is classified as an immobile element in plant tissue (Clarkson 1984), whereas Mg deficiency may be explained by the antagonism with Ca or K (Leece 1975). Ca deficiency can also be induced by drought conditions, reducing the movement of Ca through the soil solution (Pilbeam, Morely 2007). Interestingly, Moreno et al. (1996, 2001) reported that sweet cherries on Colt grown on heavy and calcareous soil showed deficiency or close to deficiency values for N and K, and values higher than normal for Ca and Mg at 60 DAFB. On this line, Betrán et al. (1997) stated that sweet cherries on Colt rootstock appear less suitable for heavy and calcareous soils.

The general deficiency values for all leaf micronutrients, except Cu, are indicated by the negative DOP indexes. While leaf Fe of cv. May Early tended to have a DOP value close to the optimum level ($DOP_{Fe} \approx 0$), lower levels of leaf Fe than normal were found for other cultivars showing no acute symptoms of chlorosis. This can be connected with the low soil Fe content. Also, Fe:P, Fe:Cu, Fe:Mn or Fe:(Cu+Mn) antagonisms may have contributed to leaf Fe deficiencies (Tisdale, Nelson 1966). Al-

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though overall Fe levels were very deficient, the Fe present may have been quite active physiologically (Leece 1975). This author also noted that, based on low leaf Ca values and from soil analyses, the observed Fe deficiency was not lime-induced, which is the case in our trial. Synthetic iron chelates applied to soil or foliage were more effective in correcting Fe deficiency than applying inorganic iron to the soil (Johnson, Uriu 1989).

The negative DOP_{Mn} indicated a very high Mn deficiency in sweet cherry leaves, although the Mn soil level is very high. Mn is not mobile in plant tissues (Mengel et al. 2001) and deficiencies can be associated with its lack of solubility or losses in a vertisol with low pH value, as previously reported by Milivojević et al. (2011). Also, Mn insufficiency could be due to the poor uptake of this element form this soil type (Moreno et al. 2001).

Generally, Cu deficiency is extremely rare in cherry and other fruit orchards (Leece 1975; Johnson, Uriu 1989), and Cu levels may be close to optimum (Moreno et al. 1996; Jiménez et al. 2007). In contrast, excessive leaf Cu levels observed in some sweet cherry orchards, including our trial, probably represent accumulated levels of inactive Cu (Leece 1975) or may result applications of Cu fungicides to control diseases. Cv. May Early is the cultivar with the highest DOP_{Cu} value as compared to other cultivars, probably due to the higher root uptake efficiency of Colt rootstock when grafted with this cultivar in heavy and acidic soil.

Although Zn content in our soil was relatively high, DOP_{Zn} value showed a tendency to Zn deficiency. Other authors also reported slight Zn insufficiency in cherry orchards on heavy and calcareous soils (Moreno et al. 1996, 2001; Jiménez et al. 2007). Tisdale and Nelson (1966) reported a very high Zn insufficiency on an acidic soil, indicating that the inhibition of Zn uptake was not due to soil alkalinity. Dormant applications of Zn help to correct deficiencies but are less satisfactory or practical than are foliar sprays (Beutel et al. 1978). Also, annual maintenance applications of Zn are desirable in areas of severe deficiency, which is the case in our trial.

According to Johnson and Uriu (1989), most B in soils is unavailable to plants. Also, B is often deficient in most acidic soils like ours because most of this nutrient adsorbed onto clay minerals, hydrous metal oxides, and organic matter in soils (Nagy et al. 2008). Deficiencies of B can be corrected by soil applications of borax or by foliar sprays of boric acid, which give control of B deficiencies for one or more years (Beutel et al. 1978; Nagy et al. 2008). In addition, the low level of B in the leaf tissue of the cherries on Colt rootstock suggests this scion-rootstock combination may be appropriate for the use in areas with B toxicity problems.

ΣDOP indexes for macro- and micronutrients balance showed statistically significant differences among cultivars (Table 7). For macronutrients, the best balanced nutritional values were found in cv. Sunburst, whereas the widest imbalance was observed in cv. Celeste. For micronutrients, the situation was reversed, with cv. Celeste being the best balanced and cv. Sunburst the worst.

CONCLUSION

We observed that phenology, tree growth, precocity, productivity, and fruit quality of sweet cherry significantly varied among cultivars. These results highlight the important relationships between plant adaptability and development and the major factors of productivity and fruit quality.

The accumulation of leaf nutrients was cultivar-dependent, but inconsistent, and resulted in nutrient deviations from normal values. Nutrient imbalances were observed in all cultivars, suggesting that inadequate fertilization was employed in this study. The specific nature of this soil necessitates not only N-fertilization but also the use of some macro- and micronutrient fertilizers with adequate elements content. Liming is another operation required for this soil due to its low pH.

With more controlled fertilization and irrigation, productivity, fruit quality and nutritional status of leaves of sweet cherries on Colt rootstock grown in a high density planting system on heavy and acidic soil could be improved. Finally, cvs Celeste and Sunburst, and to a lesser extent Germersdorfer, had lower tree vigour, good yield performance and fruit quality attributes, so these cultivars can be recommended for growing under similar conditions.

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