Seasonal pattern of root growth in relation to shoot phenology and 
soil temperature in sweet cherry trees (*Prunus avium*): A preliminary 
study in central Chile

Claudia Bonomelli¹, Carlos Bonilla², Edouard Acuña¹, and Pamela Artacho³

¹Facultad de Agronomía e Ingeniería Forestal, Departamento de Fruticultura y Enología, Pontificia Universidad Católica de Chile. Vicuña Mackenna 4860, Macul, Santiago, Chile.
²Facultad de Ingeniería, Departamento de Ingeniería Hidráulica y Ambiental, Pontificia Universidad Católica de Chile. Vicuña Mackenna 4860, Macul, Santiago, Chile.
³Facultad de Agronomía e Ingeniería Forestal, Programa de Postgrado en Ciencias de la Agricultura, Pontificia Universidad Católica de Chile. Vicuña Mackenna 4860, Macul, Santiago, Chile.

Abstract

C. Bonomelli, C. Bonilla, E. Acuña, and P. Artacho. 2012. Seasonal pattern of root growth in relation to shoot phenology and soil temperature in sweet cherry trees (*Prunus avium*): A preliminary study in central Chile. *Cien. Inv. Agr.* 39(1): 127-136. The period between flowering and harvest in the sweet cherry (*Prunus avium* L.) is shorter than most fruit trees; thus, competition for assimilate and nutrients occurs early in the season. To properly supply water and nutrients during this critical period, optimal growth and root development are necessary. To characterize the root growth pattern of cherry trees in relation to shoot growth and phenology, a study was conducted on a ‘Bing’ cherry orchard on Gisela 6 rootstock at fourth leaf, located in central Chile (34°70' S, 70°43' W). During the 2009-2010 season, the shoot length and fruit diameter were measured on eight trees, and the root length was quantified by installing rhizotrons on two trees. Additionally, a two-tone (black/white) plastic cover was placed in the row over one tree with a rhizotron to analyze the effects of the plastic cover on soil temperature and root growth. The results showed three peaks of root growth during the season. The first peak occurred 43 days after full bloom (DAFB), corresponding to the phenological stages of the fruit turning from green to straw color. This peak occurred at 326 accumulated degree days (ADD) in the soil and 212 ADD in the air. The second peak was observed after harvest at 97 DAFB, when the shoot growth had stopped, and the soil and air had accumulated 932 and 692 degree days, respectively. The third and last peak occurred at 167 DAFB, with 1887 ADD in the soil and 1361 ADD in the air. The plastic cover increased the average soil temperature by approximately 1 °C, thereby increasing the ADD by 105.2 units during the study period. However, this increase was not enough to affect the root growth pattern.

Key words: Accumulated degree days, root growth, root length, soil temperature, sweet cherry.

Introduction

The root system serves diverse functions, including anchorage and water and nutrient uptake. The absorptive portion of the root system is associated with the fine lateral roots, which may be replaced several times per year and represent the most dynamic portion of the root system (Comas *et al.*, 2002). There is no information about root growth patterns for many woody plants, including
cherry trees (*Prunus avium* L.). This information is important for the optimization of soil and nutrient management. However, studies on root systems are scarce because most of the methods used are extremely time-consuming, tedious, and destructive, particularly in large perennial plants such as fruit trees. In general terms, there are five approaches for root growth studies, including whole tree excavation, root sampling methods, observation windows (rhizotrons), root activity measurements, and indirect methods (Black *et al*., 2010). The observation window technique studies the roots through large reinforced glass or plastic windows installed against a vertical soil profile in a trench. This method was first used by Sachs in 1873 and later evolved into root laboratories or simple underground boxes known as rhizotrons (Böhm, 1979). Rhizotrons are among the common methods of observing roots (Futsaether and Oxaal, 2002), and most current knowledge of roots and the rhizosphere still come from experiments with plants growing in rhizotrons and modified rhizotrons (Neuman *et al*., 2009). The main advantage of this type of system is that it allows a continuous study of the roots of the plants during a complete life cycle.

Root growth and development are controlled by genetic and environmental factors, such as temperature, water availability, nutrients, oxygen and the physical properties of the soil (Ang *et al*., 2009). Additionally, root growth is related to the growth of shoots and fruit during the season and to the interaction between the rootstock and the scion (Sitarek *et al*., 2005). For example, in peach trees (*Prunus persica* L.), low rates of fruit growth have been observed to coincide with the highest rates of root growth, while a rapid increase in the rate of fruit growth during stage III is associated with a low rate of root growth (Abrisqueta *et al*., 2008). Other authors have reported that the presence of fruit reduces the shoot length and the dry weight of the shoots and leaves in peach trees (Grossman and Dejong, 1995). This is extremely important because in *Prunus* species, the formation of fruit has priority over other organ sinks (Flore and Layne, 1999). Additionally, Honorato *et al*.(1990) demonstrated that the equilibrium between above- and below-ground components was fundamental to the productivity of vineyards. The most productive vineyards had the largest root volume and thus, the largest organic reserves and shoot growth. The least productive vineyards showed a restricted root and shoot growth and a lower level of organic reserves.

Among the soil factors that influence root growth, temperature is one of the most important due to its strong effect on nutrient uptake and plant growth (Baghour *et al*., 2003). In this context, one of the main benefits associated with the use of plastic mulches is a higher root zone temperature (Lamont, 2005), which has been effective in increasing the dry matter of roots in broccoli plants (*Brassica oleracea* L.) (Díaz-Pérez, 2009) and root growth and the accumulated dry matter of the shoots in black currants (*Ribes nigrum* L.) (Larsson and Jensen, 1996). However, this practice would be more useful in regions where low soil temperature is a limiting factor. Additionally, other cultural practices, such as grafting, also affect above- and below-ground plant relationships. Cherry rootstocks influence the performance of the scion, including fruit quality (Jiménez *et al*., 2004), tree growth and yield (Moreno *et al*., 2001), and floral and foliar nutrition (Neilsen and Kappel, 1996; Jiménez *et al*., 2007). Newly planted cherry orchards in Chile and worldwide have been mainly established in high densities, in which are necessary dwarfing rootstocks to reduce tree vigor. In these rootstock types, the critical stage when the fruits and shoots compete with the roots has not been established. Therefore, the objectives of this study were to quantify the relationship between the aerial and root growth of trees in a high-density cherry orchard and to determine the effects of ground cover on soil temperature and root growth rate.
Materials and methods

Relationship between shoots, fruit and root growth

The study was conducted in an experimental sweet cherry orchard, cv. ‘Bing’ on Gisela 6 rootstock, located in central Chile (34°07′55″ S and 70°43′15″ W). The climate in the area is warm temperate with a long dry season. The average monthly temperatures are approximately 19.5 °C in the summer months (January and February) and 7.5 °C in the winter (June and July). Precipitation is concentrated in the May-September period, and there are seven months (October to April) with an average monthly precipitation lower than 40 mm (Gastó et al. 2008). The soil is classified as Fluventic Haploxerolls, according to Soil Taxonomy-USDA, with a clay-loam texture, flat topography, moderate depth (75-100 cm) and good drainage (CIREN, 1996). The main chemical and physical characteristics are shown in Table 1.

Table 1. Physical and chemical soil properties in the study site (0-30 cm).

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay (%)</td>
<td>29.5</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>44.0</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>26.5</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>3.2</td>
</tr>
<tr>
<td>N (mg kg⁻¹)</td>
<td>17</td>
</tr>
<tr>
<td>P-Olsen (mg kg⁻¹)</td>
<td>32</td>
</tr>
<tr>
<td>K (mg kg⁻¹)</td>
<td>161</td>
</tr>
<tr>
<td>Ca (meq L⁻¹)</td>
<td>12.5</td>
</tr>
<tr>
<td>Electrical conductivity in suspension (mS cm⁻¹)</td>
<td>0.15</td>
</tr>
<tr>
<td>pH in suspension</td>
<td>7.27</td>
</tr>
</tbody>
</table>

The orchard was established in August 2006, with a plant density of 889 plants ha⁻¹ (4.5 x 2.5 m) on raised ridges (1.5 m wide x 0.2 m high). The trees were approximately trained to the Vogel Spindle system, and the Black Tartarian cultivar was used as pollinator in a proportion of 11%. Irrigation was applied through a double drip line system with 4 L h⁻¹ emitters located every 0.9 m along the row.

To study the root growth, rhizotrons were installed in two representative trees (R1 and R2), at 0.5 m from the trunk. Rhizotrons are glass front observation boxes that allow root development along the transparent walls (Böhm, 1979). In this study, the rhizotrons were 1.2 m wide by 1.2 m long and 1.2 m deep, with a glass of 1.10 m wide, 1.15 m long and 8 mm thick. Additionally, the soil temperature and volumetric water content were measured every 15 min at 20 cm depth using an EC-TM sensor (Decagon Devices Inc., Washington, USA) that was connected to an EM50 data logger (Decagon Devices Inc., Washington, USA). The air temperature was recorded using a sensor located 1 m above the ground that was connected to a WatchDog 450 data logger (Spectrum Technologies Inc., Illinois, USA).

From September 2009 to May 2010, the length of the absorptive roots (white roots) was weekly quantified from digital images captured from the rhizotrons, following procedures outlined by Sotomayor et al. (2009). Using AutoCAD® 2007 (Autodesk Inc., California, USA), the extension of each white root in the glass was marked with digital lines, and the total length was recorded. White roots (youngest) were selected because they exhibit a considerably higher nutrient absorptive capacity and respiration rate than pigmented (brown) roots (Baldi et al., 2010; Volder et al., 2005). It is known that tree roots transit by visually identifiable stages during their lifetime. New roots are white and turn brown several weeks or months later. This color change has been associated with marked physiological changes resulting in differences in nutrient uptake, respiration rate and anatomy (Comas et al., 2000, Wells and Eissenstat, 2001; 2003). To characterize the growth of shoots and fruits during the season, eight trees were selected, including the trees with the rhizotrons. The growth of four apical shoots per tree were measured weekly, each one from representative branches. At the same time, the fruit growth was assessed by measuring the equatorial diameters in four fruits per tree using a digital caliper (Digimess, Buenos Aires, Argentina).
Additionally, the tree growth and development were related to the air and soil temperature accumulation expressed as accumulation of degree days (ADD):

\[ \text{ADD} = \sum_{n,} (T_z - T_b) \]  

where \( n \) is the number of days after full bloom (DAFB) to reach each phenological event or until the end of the evaluated period, \( T_z \) is the average daily soil or air temperature, and \( T_b \) is the base temperature (10°C). These calculations were performed for different soil depths and for trees with and without the plastic cover.

**Effect of plastic cover**

The effect of soil temperature on root growth was evaluated by placing a two-tone plastic cover (black on the surface in contact with the ground/white on the upper surface) in the row over five trees, including one tree with a rhizotron. The other tree with a rhizotron was left uncovered. The plastic cover was 60 microns thick and 8 m long by 1.4 m wide and was installed in the spring (early September, 2009). To complement the soil measurements from the rhizotrons, the soil temperature was recorded weekly at a 10-cm depth using a solid digital thermometer (CHY, 505 RTD Thermometer, Taiwan) in five covered and uncovered trees. The effect of the plastic cover on the soil temperature was analyzed from November to January by repeated measures analysis of variance, and the means were compared using a Tukey-test in STATISTICA 7.0 software (Steel et al., 1997).

**Results and discussion**

**Relationship between root, shoot, and fruit growth**

During the season under study, the first bearing season, three peaks of root growth were recorded. The first peak of root growth coincided with the rapid vegetative and reproductive growth (Figure 1) between 36 and 49 days after full bloom (DAFB) when the fruit color changed from green to straw-tone. During this period, the shoots grew at a rate of approximately 5 cm per week. Gil (1999) mentioned that the first period of root growth is short when the initial growth of shoots is vigorous. When the shoots are not vigorous, the first period of root growth is longer and there is an early initiation of the second period of root growth. At the beginning of the growing season, the competition for photosynthates between aerial and root components affects the peaks of white root growth; the first peak is lower than the second and third peaks, which was observed in this study (Figure 1). The vegetative growth started on October 21, two weeks after the emergence of the first white roots. This was evidence of early competition between the aerial and root parts of the tree during this period. On December 12, the shoot growth rates diminished, and shoot growth stopped approximately two weeks later. At the same time, white root production rapidly increased, peaking for the second time two weeks later. Additionally, a third peak was reported early in the spring, followed by a second peak immediately after harvest. In their work, a first peak occurred early in the spring, followed by a second peak immediately after harvest. Additionally, a third peak was reported in October, just before the beginning of winter in the Northern Hemisphere. In contrast, the date of the first two peaks in our study differed from those described by Gratacós et al. (2008) for the same cultivar and rootstock in central Chile. They mentioned that root activity started in September, with the main peak in October and with a moderate growth for the rest of the season. Nevertheless, the pattern of root growth reported on Gisela 5 in that study is similar to that observed in the present study, with a first peak of root growth in late October, followed by the second and main peak between late December and early January, and the third peak in the second half of March
In this study, a decrease in production of new roots was observed in the last phase of fruit growth, reflecting a competition for resources between fruit and root (Figure 1). It is known that cherry productivity depends on the supply and storage of photosynthates, as well as on the ability to transport photosynthates to the reproductive structures (Flore and Layne, 1999, Ayala and Lang, 2004), and that these processes can modulate the competition level between aerial and root components.

Relationship between root growth and accumulated degree days

Accumulated degree days (ADD) have been used to study and to forecast flowering, harvest and other phenological events in fruit crops. For example, Alburquerque et al. (2008) mentioned that mid-season cherry cultivars are very similar regarding their ADD requirement from dormancy to 50% flowering. Other authors have used this parameter to develop predictive models to estimate the number of days between full bloom and harvest in Prunus species (Day et al., 2008). However, there is no known evidence linking ADD with peak root growth in cherry or other fruit trees. In this study, the first root growth peak occurred at 43 days after full bloom (DAFB), with 326 ADD in soil at 20 cm depth and 212 ADD in the air (Table 2). This peak coincided with the time of fruit color change, which is easily observed in the field. If these events are usually correlated for the variety/rootstock and edaphoclimatic combinations, fruit color change could be used as an indicator to recognize the occurrence of the first maximum root growth. Hence, it is important to evaluate these observations under variable conditions, such as colder climatic conditions and vigorous rootstocks. The second maximum root growth took place at 97 DAFB, with 932 ADD in the soil and 692 ADD in air, and the third and final root growth peak was observed at 167 DAFB, with 1887 ADD in the soil and 1361 ADD in the air. There was a high correlation between air and soil ADD at 20 cm depth ($R^2 = 0.999$). The soil and air ADD for other phenological events are presented in Table 2.

![Figure 1](image-url)

Figure 1. Root (0-90 cm soil depth), shoot and fruit growth of cherry cv. ‘Bing’ on Gisela 6 during the 2009-2010 growing season in central Chile. 1 = flowering, 2 = petal fall, 3 = fruit color change from green to straw, 4 = fruit coloring, 5 = harvest.
**Effect of plastic cover**

The temperatures from November to January at a 10-cm and 20-cm soil depth in trees with and without the plastic cover are shown in Figure 2. The average temperature at the 10-cm depth during the period under study (13 measurements) was significantly higher in the soil with the cover than without the cover (21.7 °C versus 20.9 °C, respectively; \( F_{1, 6} = 7.5, P = 0.03 \)). At the 20-cm soil depth, a similar difference was observed, with average temperatures of 21.1 °C and 20.2 °C, respectively, for the soil with and without the cover. There was also a significant effect of time (\( F_{12, 72} = 40.35, P \leq 0.0001 \)) showing an increasing trend towards the summer (Figure 2). The cover x time interaction was also significant (\( F_{12, 72} = 2.18, P = 0.02 \)), with soil temperatures without the cover initially higher than those for the soil with the cover. However, the opposite effect occurred from mid-November onwards. Higher soil temperatures at the 20-cm depth with the plastic cover from November to January resulted in an increase of 105.2 degree days compared to the bare soil (Figure 2). Similar results have been reported by Ibarra et al. (2008) in cucumbers and by Díaz-Pérez (2009) in broccoli, when comparing temperatures between bare soil and a soil covered

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**Table 2.** Relationship between cherry phenological stages and accumulated degree days in soil at a 20-cm depth and in air for trees without the plastic cover.

<table>
<thead>
<tr>
<th>Date (dd-mm-yr)</th>
<th>DAFB</th>
<th>Phenological stage</th>
<th>Soil ADD</th>
<th>Air ADD</th>
</tr>
</thead>
<tbody>
<tr>
<td>06-10-2009</td>
<td>0</td>
<td>Full Bloom</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14-10-2009</td>
<td>8</td>
<td>Petal fall</td>
<td>71</td>
<td>40</td>
</tr>
<tr>
<td>11-11-2009</td>
<td>36</td>
<td>Fruit color change from green to straw</td>
<td>259</td>
<td>161</td>
</tr>
<tr>
<td>18-11-2009</td>
<td>43</td>
<td>First root growth peak</td>
<td>326</td>
<td>212</td>
</tr>
<tr>
<td>24-11-2009</td>
<td>49</td>
<td>Fruit coloring</td>
<td>361</td>
<td>247</td>
</tr>
<tr>
<td>18-12-2009</td>
<td>73</td>
<td>Harvest</td>
<td>620</td>
<td>461</td>
</tr>
<tr>
<td>26-12-2009</td>
<td>81</td>
<td>Shoot growth end</td>
<td>720</td>
<td>540</td>
</tr>
<tr>
<td>11-01-2010</td>
<td>97</td>
<td>Second root peak</td>
<td>932</td>
<td>692</td>
</tr>
<tr>
<td>22-03-2010</td>
<td>167</td>
<td>Third root peak</td>
<td>1887</td>
<td>1361</td>
</tr>
</tbody>
</table>

DAFB, days after full bloom; ADD, accumulated degree days (base temperature = 10 °C).

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**Figure 2.** Effect of plastic cover on soil temperature at (a) 10 cm \((n = 5)\) and (b) 20 cm depth.
by a bicolor plastic. Figure 3 shows the effect of the plastic cover on soil water content during November, the period with the highest competition between aerial and root activity. It was noted that the soil moisture content at a 20-cm depth in soil with the plastic cover was higher than in bare soil. These results were consistent with other studies reporting a reduction of soil evaporation when a plastic cover was placed over soil (Anikwe et al., 2007, Larsson and Jensen, 1996).

In relation to root growth in soil with and without a plastic cover, the first peak occurred one week earlier in bare soil (November 18) than in soil with the plastic cover (November 26) (Figure 4). Interestingly, the second growth peak was on January 11, 2010, for both treatments, despite the fact that this second root flush began earlier in the soil without the plastic cover compared to the covered soil. Therefore, even though the plastic cover significantly increased the soil temperature for most of the season and consequently increased the accumulated degree days in the soil and the soil moisture in comparison with bare soil, the root growth pattern was not noticeably affected. The root growth pattern was most likely not affected because the temperatures prevailing during the growing season in the soil were above the minimum requirements for root growth. Specifically, the soil temperature was always in a suitable range for root growth, that is, above 14 °C and below 28 °C. This might not be the case for other cherry growing regions, such as the northern United States and Europe. Furthermore, the use of clear plastic covers under central Chile growing conditions could generate excessively high soil temperatures that can have negative effects on root growth (Bonomelli et al., 2009).

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Resumen

temprano en la estación. Para asegurar un suministro adecuado de agua y nutrientes durante este periodo crítico, se requiere un crecimiento y desarrollo radical óptimos. Para caracterizar el patrón de crecimiento radical en árboles de cerezo en relación al crecimiento y fenología de su parte aérea, se realizó un estudio en un huerto de cerezo ‘Bing’ sobre el portainjerto Gisela 6 en su cuarta hoja, ubicado en Chile central (34°70’ S, 70°43’ O). Durante la estación 2009-2010, se midió el largo de brotes y diámetro de frutos en ocho árboles, y se cuantificó el largo de raíces blancas a través de la instalación de rizotrones en dos árboles. Adicionalmente, se instaló una cubierta plástica de dos tonos (negro/blanco) sobre la hilera en un árbol con un rizotrón para analizar su efecto sobre la temperatura de suelo y el crecimiento radical. Se observaron tres picos de crecimiento radical durante la estación. El primero ocurrió 43 días después de plena flor (DDPF), correspondiendo al estado fenológico de cambio de color del fruto desde paja a coloreado. Este pico ocurrió con 326 días grados acumulados (DGA) en el suelo y con 212 DGA en el aire. El segundo pico se observó después de la cosecha (97 DDPF), cuando el crecimiento de brotes se había detenido y se habían acumulado 932 y 692 días grados en el suelo y aire, respectivamente. El tercer y último pico se produjo 167 DDPF, con 1887 DGA en el suelo y 1361 DGA en el aire. La cubierta plástica aumentó la temperatura promedio del suelo en aproximadamente 1°C, aumentando los DGA en 105,2 unidades durante el período estudiado. Sin embargo, esto no fue suficiente para modificar el patrón de crecimiento radical.

**Palabras clave:** Cerezo dulce, crecimiento radical, días grados acumulados, largo de raíces, temperatura de suelo.

**References**


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