



## Research paper

# Net primary productivity and allocation to fine-root production in field-grown sweet cherry trees under different soil nitrogen regimes

P. Artacho<sup>a,\*</sup>, C. Bonomelli<sup>b</sup>

<sup>a</sup> Programa de Doctorado en Ciencias de la Agricultura, Facultad de Agronomía e Ingeniería Forestal, Pontificia Universidad Católica de Chile, P.O. Box 306-22, Santiago, 78204360, Chile

<sup>b</sup> Departamento de Fruticultura y Enología, Pontificia Universidad Católica de Chile, 78204360, Chile

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## ABSTRACT

Fine-roots have a high replacement rate or turnover during growing season, constituting an important sink for C allocation and a substantial metabolic cost for trees. However, studies in fruit-bearing trees are scarce. Here we report the annual net primary production (NPP) and relative allocation to seasonal fine-root production in field-grown sweet cherry trees (*Prunus avium* L. cv 'Bing' on Gisela<sup>®</sup> 6) fertilized with two N rates (0 and 60 kg ha<sup>-1</sup>). Seasonal fine-root production and total tree NPP were estimated combining destructive and non-destructive methods. Vegetative growth variables, fruit yield, and air/soil variables were also monitored. N fertilization hastened the turnover rates of fine-roots, resulting in an increased absolute amount of fine-root biomass production, on average 70% higher than in control trees. Total NPP was unchanged, but the relative fraction of annual NPP accounted by fine-roots was higher in N-fertilized trees (24% versus 17%), which did not affect the fruit yield and quality. However, the relative C allocation to leaves and shoots was diminished, suggesting that N-fertilized trees preferentially allocated the fixed C into fruits and fine-roots at the expense of vegetative canopy growth. Inputs from fine-roots to soil organic cycle were 22 kg N ha<sup>-1</sup> and 690 kg C ha<sup>-1</sup> in control trees; while, 42 kg N ha<sup>-1</sup> and 1170 kg C ha<sup>-1</sup> in N-fertilized trees. Our results demonstrate that fine-root growth represents a major C cost for young sweet cherry trees, as well as an important contribution of C and nutrients to soil cycling.

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## 1. Introduction

Fine-roots in woody species are usually non-woody, small-diameter ( $\leq 2$  mm), short-lived (lifespan  $< 1$  year), mainly short, and highly branched, with the uptake of water and nutrients as major function (Fitter, 2002; Rytter, 2013; Wells and Eissenstat, 2003). An important consequence of the short life of fine-roots is the high rate of root replacement or turnover during growing season. In forest species, the turnover rates of fine-roots vary from 0.4 to 2.8 yr<sup>-1</sup>, but the rates may be faster (1.2 to 12 yr<sup>-1</sup>) if only very fine-roots ( $< 1$  mm diameter) are considered (Fukusawa et al., 2013; Gill and Jackson, 2000; King et al., 2002; McCormack et al., 2014; Rytter, 2013). In temperate fruit trees, practically there is no information about turnover rates. However, most of fine-roots emerging each year turn brown or senesce before the end of their first growing season, and their median lifespan, i.e., days to 50% mortality of a root population, typically ranges between 30 to 100 days (Bouma

et al., 2001; Psarras et al., 2000; Wells and Eissenstat, 2001; Wells et al., 2002).

With fast turnover rates and low C/N ratios (mainly C/N  $< 50$ ; Gordon and Jackson, 2000; Pregitzer et al., 1995), the fine-root tissues constitute a high dynamic pool of soil carbon (C) and nutrients. In forest soils, fine-root decomposition contributes to organic matter pools with 0.7 to 1.9 t C ha<sup>-1</sup> yr<sup>-1</sup> (McClougherty et al., 1982); and return nitrogen (N) to the soil in amounts between 29 to 255 kg N ha<sup>-1</sup> yr<sup>-1</sup> (Nadelhoffer et al., 1985; Vogt et al., 1986). Additionally, the fine-root turnover plays an important role in whole-plant C budget, constituting a major sink for C allocation and a substantial metabolic cost for trees, especially considering that little, if any, retranslocation of nutrient occurs before the fine-root senescence (Gill and Jackson, 2000). Therefore, the fine-root production and turnover accounts for an important fraction of net primary production (NPP) in tree ecosystems, i.e., 20 to 75% in forests, although fine-roots often represent less than 10% of the tree standing biomass (Fukusawa et al., 2013; Jackson et al., 1997; Nadelhoffer et al., 1985; Tateno et al., 2004; Vogt, 1991). In one of the few existing studies with fruit trees, Zanotelli et al. (2013) reported that the fine-root production in an apple orchard (9 yr-

\* Corresponding author.

E-mail addresses: [pnartach@uc.cl](mailto:pnartach@uc.cl), [pamelaartacho@gmail.com](mailto:pamelaartacho@gmail.com) (P. Artacho).

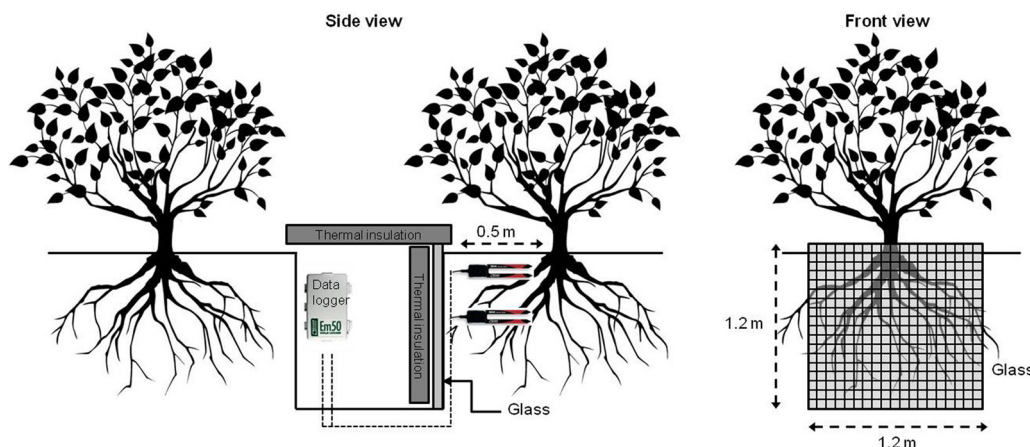


Fig. 1. Scheme of the rhizotron used in the study and the location of the soil sensors.

**Table 1**

Coefficients and goodness-of-fit parameters for the allometric equations established between the trunk diameter ( $X$ ; mm) and the biomass in woody organs ( $Y$ ; g tree<sup>-1</sup>) in trees of sweet cherry 'Bing' on Gisela® 6. Allometric relations described by  $Y = Y_0 \exp(kX)$ .

Organ	$Y_0$	$k$	$R^2$	$Sy.x$	$n$
Trunk	206.3	0.03260	0.98	400.9	12
Rootstock	87.85	0.03046	0.96	189.3	12
≥1-yr-old branches	287.7	0.02938	0.92	807.9	12
Spurs	6.366	0.03698	0.96	20.14	11
Coarse roots	214.6	0.03159	0.98	369.1	12

$Y$  is the estimated biomass of woody organs (g tree<sup>-1</sup>),  $X$  is the trunk diameter (mm),  $Y_0$  is the  $Y$  value when  $X$  is zero (g tree<sup>-1</sup>), and  $k$  is the rate constant (mm<sup>-1</sup>).  $Sy.x$  is the standard deviation of the residuals.

old trees 'Fuji' on M9) represented 14% of the yearly NPP, while the fruits almost 50%. Similarly, Panzacchi et al. (2012) found that 13% of NPP of apple trees (10 yr-old trees 'Gala' on EMLA9) was allocated to annual fine-root production, and fruits accounted only for a 29%.

The effect of soil N availability on fine-root production has been subject of a number of studies involving almost exclusively forest species. Some of them have reported increases in length or biomass with an improved soil N availability (Adams et al., 2013; King et al., 2002, 1999; Kubiske et al., 1998; Majdi, 2001; Noguchi et al., 2013; Pregitzer et al., 2000, 1995, 1993). While, other studies have reported null effects (Phillips et al., 2006; Rytter, 2013) or even the opposite results (Jia et al., 2010; Rytter, 2013). Different hypotheses have been formulated to explain such variety of responses, most of them resulting in absolute and proportionally lower fine-root biomass on fertile sites (Nadelhoffer, 2000; Nadelhoffer et al., 1985; Rytter, 2013; Vogt et al., 1986). However, if the fine-root turnover becomes faster as a consequence of higher N concentration in roots, the fine-root production could increase in absolute terms. Moreover, the metabolic demand of greater root growth and nutrient uptake should be met by an increased availability of photosynthates resulting from a higher N concentration in leaves (Nadelhoffer, 2000).

In fruit-bearing trees, the relationship between the fine-root production with soil N availability is highly untested, and might be less straightforward than in forest species due to the presence of fruits. Carbon allocation in fruit trees depends on complex rules linking source and sink organs, and fruits generally have the highest sink strength and priority (Flore and Layne, 1999; Génard et al., 2008; Grossman and DeJong, 1995). In fact, an important number of studies have shown that fruiting reduces the root growth, especially during the final stage of fruit growth (Abrisqueta et al., 2008;

Basile et al., 2007; Glenn and Welker, 1993; Grossman and DeJong, 1995; Mimoun and DeJong, 2006; Morinaga et al., 2003; Williamson and Coston, 1989).

In this context, the aim of this study was to estimate annual net primary production (NPP) and relative allocation to fine-root production in field-grown sweet cherry trees (*P. avium* cv 'Bing' on Gisela® 6 rootstock) fertilized with different N rates. The hypothesis was that a non-limiting N availability in soil will increase the absolute amount of biomass, as well as the relative fraction of annual NPP accounted by the fine-root production without affecting fruit production.

## 2. Materials and methods

### 2.1. Study site and plant material

The study was conducted in a 5-yr-old sweet cherry orchard cv. 'Bing' on Gisela® 6 rootstock located in Chile's central region (34°08' S and 70°43' W). The orchard was planted in August 2006 as part of a wider N optimization experiment (Bonomelli and Artacho, 2013) with trees spaced 2.5 m apart within rows and 4.5 m apart between rows. According to the Köppen–Geiger Climate Classification (Kottek et al., 2006), the climate of the area is warm temperate with dry and warm summer. The soil is classified as Fluventic Haploxeroll according to Soil Taxonomy-USDA; it presents a clay-loam texture, is more than 1.5 m in depth and exhibits no physical limitations. All nutrients in the soil, except N, were at sufficient levels and did not limit the growth or fruit production of the trees. For further details, see Artacho and Bonomelli (2016).

### 2.2. Experimental design

The net primary productivity (NPP) of sweet cherry trees was estimated during the 2011/12 growing season, combining data of tree biomass from destructive harvests in 2006/07, 2007/08, 2008/09 (Bonomelli and Artacho, 2013), and 2012/13 seasons, with data of fine-root biomass production from an intensive campaign of soil coring during 2011/12, and with data of length-based fine-root growth from rhizotrons during 2011/12 (Artacho and Bonomelli, 2016).

The basal experiment was established in 2006 as a four-replicate completely randomized design with three treatments (0, 60, and 120 kg N ha<sup>-1</sup>) with experimental units corresponding to a group of nine trees (Bonomelli and Artacho, 2013). In the present study, two treatments were used (0 and 60 kg N ha<sup>-1</sup>) in a three-replicate completely randomized design, which were ongoing since orchard

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