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Monthly foliar-nutrient pattern in a semiarid Aleppo pine plantation five years after thinning

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ABSTRACT

Foliar-nutrient concentrations in tree species have traditionally been used to assess the nutrient status of forests. Monitoring these parameters in artificial forest plantations could be crucial to planning the best silvicultural practices as a basic strategy for improving stand resilience. This work examines the monthly patterns of foliar-nutrient concentrations over a 13-month period in a *Pinus halepensis* plantation five years after four different thinning regimes were applied (T0 treatment: control plots; T75, T60, and T48 treatments: 75%, 60%, and 48% of mean basal area was removed, respectively). Mean leaf-nutrient concentrations reported were among the normal and adequate ranges shown in the literature for *P. halepensis*, with the exception of Ca (higher), as well as K and Zn (lower). Thinning did not affect the leaf P or K concentrations in any case or sampling period. Moreover, we found no clear differences between thinned and control stands for other nutrients. Only B was higher in control stands and Zn in thinned stands. Exceptionally, N, Mg, Fe, Zn, and Ca concentrations proved higher in the most intense thinning (T75), for specific sampling periods. Patterns of foliar-nutrient concentrations were similar among thinned treatments and control. All nutrient concentrations decreased over the study period except the Ca concentration (and Mg in T75), which increased. Foliar-nutrient concentrations showed a positive linear correlation between nutrients (especially N–P, P–B and N–B), except K–Ca, K–Mg, and Fe–Ca, which proved negative. Partial correlations (month by month) among nutrient concentrations differed from the general patterns. Foliar-nutrient concentrations and paired relationships were influenced mainly by the sampling period, suggesting the importance of standardized leaf-sampling designs in studies analyzing and comparing foliar-nutrient concentrations.

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1. Introduction

Forest plantations have expanded dramatically worldwide in recent decades (5 million hectares per year between 2000 and 2010), and now account for an estimated 7% of the total forest area in the world, or 264 million hectares (FAO, 2010). These forests are artificially shaped by humans and can be considered emerging ecosystems in which species assemblages that are novel in both composition and abundance result from human activity (Hobbs et al., 2006). It is known that these artificial plantations show low resilience to environmental alteration (Fitzgerald and Lindner, 2013), and therefore it becomes a priority to learn how these new forestlands will respond to global change and the provision of ecosystem services (Bauhus et al., 2010). For example, in Mediterranean areas, pine plantations have been associated with (1) high fire risk, (2) high levels of pests and diseases, (3) high rainfall interception, and (4) high density-associated mortality. These drawbacks are being increasingly exacerbated by climate change (Moriondo et al., 2006; Sarris et al., 2010; Vicente-Serrano et al., 2010; Molina and Del Campo, 2012; Sánchez-Salguero et al., 2012). Thus, monitoring the health status of these novel ecosystems could be a key to planning the best silvicultural practices (proactive adaptive management) as a basic strategy to improve stand resilience (Lindner et al., 2010; Ungar et al., 2013; Del Campo et al., 2014).

Foliar-nutrient concentrations in tree species have routinely been used to assess the nutrient status of forests (Adams and Allen, 1985). Intensive monitoring programs use changes in the foliar-nutritional state as a development index for forests and as a means to diagnose atmospheric and edaphic patterns or disturbances (Rautio et al., 2010). Leaf-nutrient concentrations can also provide additional information on the physiological status of the trees and could be used as an indicator of stand development and health status (Ingestad, 1987; Jones et al., 1991; López-Serrano et al., 2005). Despite the importance of this, nutrient-concentration data is lacking in the literature concerning forest plantations and their temporal variation, as well as regarding the effects of stand

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age, and silvicultural practices, especially in semiarid Mediterranean environments.

Aleppo pine (*Pinus halepensis* Mill.) is a native tree of the western and central Mediterranean Basin, covering more than 25,000 km^2 and dominating forest formations in semiarid and dry sub-humid areas (Quezel, 2000). This species has been extensively used for afforestation and reforestation schemes in drier Mediterranean areas for many decades (Maestre and Cortina, 2004; Omary, 2011). Its drought tolerance and fast growth (pioneer species) have led to its use outside its range in high-density plantations for controlling soil erosion in degraded lands and to facilitate succession toward later-successional communities or species such as oaks (Pausas et al., 2004; Prévosto et al., 2011).

Several studies have investigated the foliar nutrients in *P. halepensis* nursery-grown seedlings (Jones et al., 1991; Díaz Roldán, 2000; Royo et al., 2001; Puértolas et al., 2003; Oliet et al., 2004; Mañas et al., 2010; Inclán et al., 2011), after outplanting under different field experiments (Díaz and Roldán, 2000; Valdecantos et al., 2006, 2011; Fuentes et al., 2007; Querejeta et al., 2008; Oliet et al., 2009), or regenerated saplings under post-fire natural conditions (Sardans et al., 2004, 2005). However, few studies refer to leaf-nutrient concentrations in adult *P. halepensis* trees, especially in plantations and examining fluctuations over time.

In this sense, the European Forest Foliar Coordinating Centre (FFCC) published the foliar macro- and micronutrient analyses for different European tree species, including *P. halepensis* (see Stefan et al., 1997). Sardans et al. (2011) evaluated factors affecting the macronutrient concentration and stoichiometry of *P. halepensis* and other forest trees in northeastern Spain, while Sardans and Peñuelas (2014) analyzed the nutrient concentrations for various taxonomical groups (including *P. halepensis*) and the elemental allocation to different aboveground organs as a characterization of the biogeochemical niches of the species. However, none of these studies have differentiated between native forests, plantations, sampling period, or stand age. On the contrary, Alifragis et al. (2001) studied the leaf-macronutrient composition of Aleppo pine trees in planted stands of 23, 48, 70, and >100 years old (in Greece) and found significant differences among stands. Other authors have investigated the nutrient cycling and foliar status for macro- and micronutrients in an urban forest of Aleppo pine in Athens (Michopoulos, 2007). Recently, Omary (2011) analyzed the leaf-macro- and micronutrient concentration of semiarid Aleppo pine plantations under different aspects and slope positions in Jordan.

In any case, all these works have analyzed the foliar nutrients in different sampling periods of the year, which also might complicate their comparisons. Furthermore, none of these studies took into consideration the possible effects of stand density on leaf-foliar concentrations. In fact, there is also little information concerning the effects of different silvicultural practices on nutrition status of *Pinus* species in forest stands (for an exception, see Ouro et al., 2001; Blanco et al., 2006; Primicia et al., 2014), and unfortunately this has been scarcely researched for *P. halepensis*. We found only the data provided by López-Serrano et al. (2005), who examined the effects over time of different silvicultural practices (thinning, scrubbing, pruning) on nutrition status of *P. halepensis* saplings in young post-fire forest stands (5 years old).

According to Blanco et al. (2009), with the reduction in stem density by thinning reductions in nutrient competition could be expected and consequently increases in nutrient availability. Taking all of this information into consideration, we hypothesize that the monthly leaf-nutrient concentration will change over the year and this will be affected by thinning treatments. To test this, we studied the foliar nutrients of a *P. halepensis* plantation with the following objectives: (i) to document the leaf-nutrient concentration and dynamics over a 13-month period under the semiarid conditions of southeastern Spain; (ii) to assess how thinning treatments can influence foliar nutrients; (iii) to analyze the monthly leaf-nutrient dynamics and the interaction with thinning treatments, and (iv) to determine the relationships among foliar nutrients and their dynamics over time.

2. Material and methods

2.1. Study area

The experiment was conducted in the Altiplano del Conejo (Guadix-Baza Basin, Granada), in the SE Iberian Peninsula (37°25′11″N and 3°05′16″W) at 1032 m a.s.l. The climate is semi-arid Mediterranean with cold winters and hot, dry summers. Mean annual precipitation is 318 mm, with high inter-annual variability. In fact, during the study period (March 2010–February 2011), annual precipitation was 30% higher than the average (416 mm). The minimum and maximum mean monthly temperatures are −2 °C in January and 33 °C in July. In winter, the minimum temperature can drop to as low as −19.3 °C (January 2005) and in summer can reach 39.6 °C (August 2012). Climatic data of the study area belong to the nearby meteorological station (Cortijo Becerra, 37°25′58″N, 3°06′05″W; 972 m a.s.l.), which has been recording data since 1998. Data registered during the study period are shown in Fig. 1. The soil is a petric calcisol (IUSS Working Group, 2006) and is also very homogeneous throughout the sampling area, having a petrocalcic horizon with a high $CaCO_3$ content (40–60%) situated at 35–40 cm in depth. Approximate values of organic carbon ranges between 1% and 4%, exchangeable K between 0.045 and 0.070 mg g^{-1}, and it is calcium saturated. The study area was a tilled agricultural zone until 1993, when the land was bought by the Andalusian regional government and plowing ceased. In 1994–1995 an area of 1200 ha of this degraded agricultural land was planted with Aleppo pines to a density of about 1500 trees per ha.

2.2. Experimental design

In the spring of 2005, 10 years after planting, three different thinning regimes were applied to 16 randomly established 20 × 20 m plots (4 per treatment + 4 control plots) by regular overstory thinning and pruning of the remaining trees, eliminating branches to 1 m in height. These thinning treatments consisted of removing 75% of the mean basal area (T75), 60% (T60), and 48% (T48). In the control plots (T0), only pruning was performed using the same procedure. Density (trees ha^{-1}) just after thinning treatments (2005) for T75, T60, T48, and T0 was 325 (±39.5 SE), 513 (±38.9 SE), 681 (±34.4 SE), and 1444 (±129.2 SE), respectively. Diameter measured at breast height (DBH) and height of trees of the different stands 5 years after thinning treatment (2010) are shown in Table 1. The basal area of the different stands just after the treatment application (2005) and five years later (2010) are shown in Fig. 2. The plots were located within the afforestation area with similar abiotic conditions including aspect, slope, and soil characteristics. A minimal distance of 10 m was established between plots to avoid edge effects.

Needle samples were taken every month for a one-year period (March 2010–March 2011). We followed the methodology proposed by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) expert panel on foliage and litterfall (Rautio et al., 2010), since this standardized process of foliar sampling can facilitate comparisons with other studies. One composite sample of needles per plot was randomly collected, pooling the needles of four pines. Samples were taken at mid-height of the tree canopy, combining all the needles of four distal shoots, one per orientation (N, W, S, and E) discarding the tips of the shoots and damaged needles (4 treatments × 4 replicates × 13 months = 208 samples). Composite samples were made

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