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Thinning affects the needlefall nutrient return to soil in a semiarid Aleppo pine afforestation while the nutrient dynamics remain unchanged

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ABSTRACT

For a determination of the impact of silvicultural practices on the biogeochemical cycle, it is crucial to address the forest management in a global-change context, especially in semiarid areas where there is lack of data. In this sense, thinning intensity applied on a *Pinus halepensis* Mill. afforestation was analyzed in the SE of the Iberian Peninsula for three years to ascertain the effects on the monthly dynamics of the needlefall nutrient concentrations (N, P, K, Na, Ca, Mg, Fe, Mn, Zn, and C), and the nutrient amounts returned to soil (kg ha^{-1}), as well as the mean annual inputs (kg ha yr^{-1}) after 8 years from interventions. Mean values of needlefall nutrient concentrations showed statistical differences only among thinning treatments for Na, Mn, and C. The monthly dynamics for needlefall nutrient concentrations had similar trends for all thinning intensities, but marked differences among sampling periods. Mean differences in nutrients returning to soil were found among thinning treatments for all nutrient contents studied, due mainly to differences in the needlefall production, except for Na and Mn. The thinning intensity reduced the amount of nutrients returning to soil for most of the needlefall nutrients, but these differences decreased over the 3 years of the study period. The nutrients returning to the soil are relevant in this semiarid area because they provide data for modeling carbon sequestration (C = 536.5 kg ha^{-1} yr^{-1}) as well as information on the nutrient cycle (N = 6.5 kg ha^{-1} yr^{-1}; P = 0.8 kg ha^{-1} yr^{-1}; K = 1.5 kg ha^{-1} yr^{-1}).

1. Introduction

In a global-change context, knowledge concerning the effect of the management practices on nutrient cycle in forest ecosystems, including afforestation, is critical to anticipate ecosystem changes and to improve climatic resilience (Johnson et al., 2017; Magruder et al., 2013). Foliar macro- and micronutrient concentrations have been considered useful for monitoring the nutritional status of forests because they are sensitive to changes, are indicative of response to functional stress, and are related to ecosystem functions and processes (Bussotti and Pollastrini, 2015). Therefore, changes in seasonal dynamics of these elementary nutrients of forest species reflect ecosystem health and the possible impact of forest-management practices on the nutrient cycle (Berg and McClaugherty, 2008).

A significant proportion of these nutrients is recycled in forests by litterfall. Thus, quantifying the variability in both plant-nutrient composition and litterfall production overtime can provide relevant information about ecosystem dynamics, the productivity and the nutritional state of the forest biomass, soil fertility, and the carbon-cycle model (Miller and Miller, 1976; Ukonmaanaho et al., 2008; Zhang et al., 2014). Global analyses have shown that seasonal patterns of litterfall were influenced by physiological mechanisms as well as environmental variables. Also, effects have been reported regarding topography, water, and nutrient availability, in addition to changes in stand structure at the regional scale (Blanco et al., 2008; Zhang et al., 2014). Moreover, nutrients transferred from the plant to the soil are also determined by litterfall nutrient concentrations.

In conifer forests, the primary litterfall fraction is composed of needlefall, caused mainly by leaf senescence (Blanco et al., 2008; Finér, 1996; Kavvadias et al., 2001). Some studies in Mediterranean areas have demonstrated that climatic phenomena (storm, wind, and drought), and pest outbreaks have significant effects on the litterfall fractions (Navarro et al., 2013). However, needles could be considered the most important nutrient sink and more sensitive to nutrient availability than other litterfall fractions (Berg and McClaugherty, 2008; Blanco et al., 2008). In this way, seasonal fluctuations in needle-

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nutrient concentrations could be reflected in subsequent dynamics of nutrients returning to the soil via needlefall. In addition, retranslocation processes alter the foliar-nutrient concentration over time, while factors such as soil-nutrient availability, climatic and edaphic conditions, and forest-management practices influence needlefall nutrients (Bravo-Oviedo et al., 2017; de las Heras et al., 2016; Fife et al., 2008; Lado-Monserrat et al., 2016).

For example, thinning, considered one of the most important silvicultural practices in Mediterranean areas, has a potential impact on foliar characteristics, changing the microclimate inside the forest by altering light and soil conditions, accelerating decomposition and mineralization in the soil, and increasing the amount of water and nutrients available to plants (Moreno-Gutiérrez et al., 2011; Roig et al., 2005). Thinning also reduces aboveground biomass and consequently the litterfall production, which may decrease the return of nutrients to the soil (Blanco et al., 2008, 2006; Kim et al., 1996). A more exhaustive approach to the thinning effects on the amount of nutrients returning to soil over time can be achieved if the study of the needlefall production is complemented with the evaluation of the dynamics of foliar nutrients and needlefall-nutrient concentrations (Lado-Monserrat et al., 2016).

The thinning impacts on changes in foliar-nutrient concentrations have been reported for different pine species (Blanco et al., 2006; Bravo-Oviedo et al., 2017; Ouro et al., 2001; Primicia et al., 2014). However, the effects on *Pinus halepensis* Mill. foliar nutrients have been poorly analyzed, despite that this species has been widely used for afforestation in Mediterranean areas (Jiménez and Navarro, 2015; López-Serrano et al., 2005; Maestre and Cortina, 2004). In fact, several studies have focused on retranslocation processes or the influence of abiotic, biotic and environmental factors on the nutrient concentrations rather than evaluating the effects of thinning (de las Heras et al., 2016; Párraga-Aguado et al., 2014).

Similarly, the effects of thinning on the monthly dynamics of litterfall production of *P. halepensis* have been poorly studied (García-Plé et al., 1995; Jiménez and Navarro, 2016; Lado-Monserrat et al., 2016; Navarro et al., 2013). According to previous results, the maximum peak in needle production in *P. halepensis* stands occurs in summer, as reported for other pine species (Kavvadias et al., 2001; Kurz et al., 2000; Roig et al., 2005; Sardans et al., 2005).

Therefore, it appears that thinning could modulate the nutrient return to the soil through the litterfall fractions. However, most of the results reported could be more related to the effects on litterfall production than to the direct impacts on the needlefall-nutrient concentrations in *Pinus* sp. In a recent study in a natural Aleppo pine regenerated forest, Lado-Monserrat et al. (2016) found that: (i) in general, the soil type affected the nutrient concentration (C, N, P, K, Ca, Mg) of senescent needles more than the tree-removal intensity, and (ii) the treatments applied reduced the nutrient return to soil via litterfall, which was related to their intensities. For Blanco et al. (2008), the site quality and the season, rather than thinning treatments, were the factors affecting the nutrient concentration (N, P, K, Ca, and Mg) in *P. sylvestris* needlefall. On the other hand, Klemmedson et al., (1990) determined that silvicultural treatments, including thinning, affected the nutrient transfer via litterfall (C, N, P, S, Ca, Mg, K and Na) in a *P. ponderosa* forest. Also, changes in the amount of *P. resinosa* nutrients (N and P) returning to the soil were observed depending on the levels of canopy removal (Kim et al., 1996). However, in the case of N, the low inputs of that macronutrient were attributed to N concentration rather than to litter production. Finally, Roig et al. (2005) found that the differences in *P. pinaster* needlefall production among thinning intensities disappeared 5 years after the treatments. Although differences in the concentration of some nutrients (N, P) between months and seasons were reported, the thinning effects on needlefall-nutrient concentrations were not analyzed.

In summary, little is known about the effects of thinning on needlefall nutrient dynamics in semiarid afforested areas for *P. halepensis*. In earlier studies, we have addressed the effects of thinning on monthly foliar-nutrient concentrations (Jiménez and Navarro, 2015), and on monthly litterfall production (Jiménez and Navarro, 2016; Navarro et al., 2013), highlighting that more data are needed to establish the effects of thinning on foliar nutrients. Moreover, Jiménez and Navarro (2016) reported that thinning clearly affects *P. halepensis* litterfall production. Moreover, the differences in the needlefall production among thinning treatments persisted after 8 years.

In the present work, we studied the effect of four thinning intensities on *P. halepensis* afforestation in the SE Iberian Peninsula after 8 years of the intervention. Our hypotheses were: (1) monthly needlefall nutrient concentrations are more affected by the sampling time than by thinning; (2) monthly needlefall nutrient return to the soil is related to monthly needlefall production; and (3) the greatest differences in the needlefall nutrient return to soil are found between the most intense thinning and non-thinned stands. On this basis, our aim was to study the effect of thinning intensities on needlefall nutrient concentrations and nutrients return to soil via needlefall.

2. Material and methods

2.1. Study area

The study area was located at the Cortijo del Conejo, in the Guadix-Baza Basin (Granada province, SE Iberian Peninsula, 37°26′N and

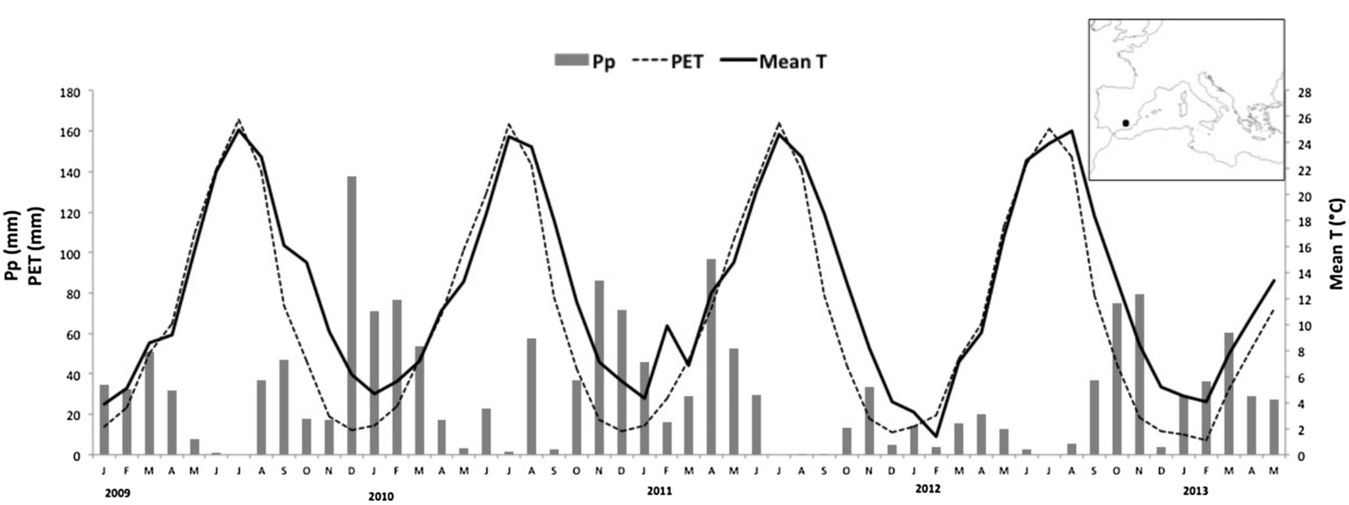

Fig. 1. Mean monthly temperature (T, °C), monthly rainfall (Pp, mm), and monthly potential evapotranspiration (PET, mm) in the study area from January 2009–May 2013. Meteorological station: Rambla de Becerra (37 °26′N; 3 °05′W). Experimental area location is shown in the upper right corner.