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Effect of nitrogen addition and litter removal on understory vegetation, soil mesofauna, and litter decomposition in loblolly pine plantations in subtropical Argentina

C.P. Trentini[a,*], M. Villagra[a], D. Gómez Pámies[a], V. Bernava Laborde[b], J.C. Bedano[c], P.I. Campanello[a,d]

[a] Laboratorio de Ecofisiología y Ecología Forestal, Instituto de Biología Subtropical, Universidad Nacional de Misiones, CONICET, Bertoni 85, 3370 Puerto Iguazú, Misiones, Argentina
[b] Dirección Regional Noreste-Administración de Parques Nacionales, Tres Fronteras 183, 3370 Puerto Iguazú, Misiones, Argentina
[c] Departamento de Geología y Departamento de Ciencias Naturales, FCEFQyN, Universidad Nacional de Río Cuarto, CONICET, Ruta 36, Km. 601, X5804 BYA Río Cuarto, Córdoba, Argentina
[d] Centro de Estudios Ambientales Integrados, Facultad de Ingeniería, Universidad Nacional de la Patagonia San Juan Bosco, CONICET, 9200 Esquel, Chubut, Argentina

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A B S T R A C T

Loblolly pine monocultures have been increasingly expanding in the Atlantic Forest of South America especially in northern Argentina. Pine plantations can modify understory vegetation and soil characteristics due to the management practices and to the dense mulch of pine needles that develop in the forest floor that could affect soil biota and ecosystem processes. Nitrogen (N) addition as expected as atmospheric deposition can also contribute to these changes. The aim of this study was to assess the effect of litter removal and low levels of N addition on understory regeneration, soil mesofauna abundance, and leaf litter decomposition. For this purpose, a completely randomized block design was used. Nitrogen addition had significant effects on understory regeneration promoting creeping herbs, graminoids and shrubs life forms affecting tree establishment and growth. Litter removal treatment showed the same pattern but only promoting the creeping herbs that could also have affected tree species. Decomposition decreased due to litter removal and was slightly increased by N addition. The addition of N decreased the abundance of mesofauna in the mulch, especially Symphypleone (a suborder of Collembola), but the abundance of the soil communities was not affected. Litter removal had a strong impact on these communities because most individuals and species of the mesofauna are present in the litter and not in the soil. This is one of the first studies analyzing the effect of low amounts of N addition and litter removal in subtropical pine plantations and contribute to understand potential impacts of increasing N deposition on biodiversity and soil processes, and to select organisms that may help as bioindicators in assessing impacts on ecological functions in productive ecosystems.

1. Introduction

Tree monocultures have been increasingly expanding in the Atlantic Forest of South America for the last three decades (Izquierdo et al., 2008; Fonseca et al., 2009). In northern Argentina, large areas of these subtropical forests have been replaced by high-yield plantations of loblolly pine (*Pinus taeda* L.). In addition to the well documented effect of tree plantations on understory vegetation and diversity (e.g. Schabenberger and Zedaker, 1999; Thomas et al., 1999; Augusto et al., 2003; Brockerhoff et al., 2003; Ramovs and Roberts, 2003; Cusack and Montagnini, 2004; Zobrist et al., 2005; Andreu et al., 2008), pine plantations can modify soil characteristics such as pH and consequently affect soil biota and ecosystem processes and function including nutrient dynamics (Brand et al., 1986; Binkley et al., 1989; Berthrong et al., 2009). Pine plantations are largely associated with a dense mulch of pine needles on the forest floor that exudes different kinds of organic acids, tannins and phenolic compounds changing soil chemical conditions (Kanerva and Smolander, 2007; Kanerva et al., 2008). Managing practices (e.g., thinning) in tree plantations also affect soil structure by increasing compaction and decreasing water availability in the topsoil (Stogsdili et al., 1992; Zinn et al., 2002; Trentini et al., 2017).

Leaf litter plays an important role in understory regeneration and

* Corresponding author.
E-mail address: carolatrenti@gmail.com (C.P. Trentini).

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soil processes by changing soil microclimate conditions and nutrient availability (Facelli and Pickett, 1991a; Xiong and Nilsson, 1999; Berg and McClaugherty, 2008; Deutsch et al., 2010). In some cases, positive effects on plant establishment are due to better moisture conditions (West, 1979; Fowler, 1986) or by reducing competition with dominant species (Facelli and Pickett, 1991b). Leaf litter can also contribute to plant regeneration by preventing seed predation (Cintra, 1997). However, in coniferous plantations, leaf litter has low water-soluble constituents and high lignin content that slow down degradation processes (Berg and Staff, 1980; Coûteaux et al., 1998; Berg and McClaugherty, 2008; Kanerva et al., 2008). Pine leaf litter accumulates on the ground and acts as a barrier to plant regeneration by delaying or even impeding seed germination (Keever, 1973; Grime, 1979; Sydes and Grime, 1981; Collins and Good, 1987; Persson et al., 1987; Ellenberg, 1988; Facelli and Pickett, 1991a; Bueno and Baruch, 2011).

Besides, mulch accumulation in pine plantation can result in favorable conditions for the development of lignin degrading microorganisms such as white rot fungi (Ponge, 1991; Humphrey et al., 2000), and provide refuge and food to meso-decomposers such as springtails (Collembola) and mites (Acari) (Ponge, 1991; Sayer, 2006). Springtails and oribatid mites (suborder Oribatida) are the most dominant taxa among the soil mesofauna, both in abundance and diversity (Vlug and Borden, 1973; Ashford et al., 2013). They influence litter decomposition processes through litter comminution, which increases the surface area for bacterial and fungal activities and facilitates leaching of several compounds, but also feeding on bacteria and fungi, hence controlling their populations and dispersing them (Hansen, 1999; Wall and Moore, 1999; Adl, 2003; Barajas-Guzman and Alvarez-Sanchez 2003; Behan-Pelletier, 2003). Pine plantations can enhance mite and springtail abundances because both taxa respond positively to these typical environmental conditions, e.g. leaf-litter with high moisture contents, high C:N ratios and low soil pH (Robson et al., 2009). Litter removal was observed to affect decomposition rates directly due to the exclusion of decomposers that live in the mulch (Subke et al., 2004) and indirectly modifying soil microclimatic conditions such as temperature and water content (Ponge et al., 1993; Diaz et al., 2005; Ramakrishna et al., 2006; Sayer, 2006) both strongly correlated to litter decay (Berg and McClaugherty, 2008).

Nitrogen (N) addition can affect decomposition rates through changes in soil chemistry and soil biota, but these changes will depend on N enrichment level, litter quality and native soil community (Berg and Matzner, 1997; Knorr et al., 2005). In general, N addition promotes biological activity measured as respiration rate and microbial biomass in the forest floor (Wardle, 1992; Gallardo and Schlesinger, 1994; Berg and Matzner, 1997; Hart and Stark, 1997; Allen and Schlesinger, 2004). Native soil community and the climatic condition can also affect the direction of this effect. A recent meta-analysis performed in temperate forests suggested that N deposition inhibits the decomposition of organic matter especially in N saturated areas (Janssens et al., 2010). But effects of N addition in pine plantations in tropical and subtropical environments with N deficit litter have been less studied (Mo et al., 2006; Mo et al., 2008). In these environments, decomposition may increase when N does not reach saturating values to micro-decomposers (Mo et al., 2006). Litter quality can also affect N addition responses; Jiang et al. (2014) found that decomposition rates of pine needles (low quality) increase in response to N addition while better quality substrates decomposition was slower.

Nitrogen addition can also promote the development of primary productivity (Elser et al., 2007; Stevens et al., 2015), but with negative consequences in plant diversity due to asymmetric competition in favor of fast-growing species, which are adapted to high levels of nutrients (e.g. Vitousek et al., 1997; Bobbink et al., 1998; Stevens et al., 2004; Suding et al., 2005; Pierik et al., 2011; Borer et al., 2014, Humbert et al., 2016). Nitrogen addition can reduce tree growth due to the increase of herbaceous species coverage (Davis et al., 1999; Kraaij and Ward, 2006; Diwold et al., 2010). Besides, nutrient availability can influence plants differently according to their ontogenetic stage (Webb and Peart, 2000), being seedlings and saplings more responsive than small trees (Alvarez-Clare et al., 2013; Fisher et al., 2013; Li et al., 2018). In general, the augment of N in soil has a positive effect on woody species growth especially under high radiation conditions (e.g., Grubb et al., 1996; Kobe, 2006). The increase of plant biomass in response to nutrient availability provides more resources for soil fauna community. N fertilization in forests can increase soil microarthropod abundance (e.g. Berch et al., 2006; Wang et al., 2016), but this has not been always observed (e.g. Maraun et al., 2001; Lindberg and Persson, 2004).

In this study, we assessed the effect of litter removal and low levels of N addition on the understory regeneration, soil mesofauna abundance and leaf litter decomposition in *Pinus taeda* L plantations. Specifically, we aimed to determine the effects on (1) plant cover and life form abundance, (2) tree seedling establishment and growth, (3) microarthropod abundance and (4) pine needle litter decomposition. We hypothesized that litter removal promotes the regeneration of woody plants and tree seedling establishment in the understory, affect negatively meso-decomposers, and decrease pine litter decomposition. Nitrogen fertilization is expected to have a positive effect on plant cover but with a detrimental effect on tree development depending on their size. Larger seedlings will have better advantages in terms of their ability to compete for the lighting resource than smaller seedlings, so they will, therefore, benefit from the addition of N. The positive effect of N addition in plant cover is expected to increase meso-decomposers abundance, and consequently pine needle decay. The study of the effect of the litter on plant regeneration, and on the characteristics and processes occurring in the undergrowth, allows us to understand the impact of needle mulch, and assess the limitations and advantages of potential management strategies. By adding low levels of nitrogen, we intended to predict likely impacts of atmospheric nitrogen deposition on some key processes and biodiversity of plants and on soil mesofauna and litter decomposition in pine plantations.

2. Methods

2.1. Experimental design

A completely randomized block design was used to test the proposed objectives. Pine plantations representing blocks were carefully selected, to have the same stand age, management and similar previous land use and being next to native forests. We only found three plantations fulfilling these conditions (n = 3). Plots were located next to native forest to avoid potential limitation to regeneration by seed arrival. In the study area the abundance and richness of seed rainfall in forest plantations is reduced to less than 20% at a distance of 100 m from the native forest (Vespa et al., 2014). Pine plantations were established in 2006 and were located between 1 km and 5 km apart from each other (see Trentini et al., 2017). Three plots of 45 × 65 m were performed in high intensity thinned stands (50%) where the treatments were randomly assigned after one year of the first thinning procedure as detailed in Trentini et al. (2017). Comparisons were made between treatments plots with N addition (N), needle litter removal (R), and a control plot (C) for both treatments in the three blocks to assess the effects separately. Because we did not intend to study potential understory management under an increment in the atmospheric deposition scenario and another treatment (i.e., litter removal combined with N addition) would decrease statistical power, we preferred no to include a factorial design. Treated and control plots were divided into six 15 × 15 m sub-plots to measure vegetation and meso-decomposers changes, and to perform litter decomposition experiments in order to avoid the hauling roads (see Trentini et al., 2017).