Eco. Env. & Cons. 28 (1) : 2022; pp. (78-85)
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ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i01.011

Effect of *Pinus halepensis* reforestation on soil fertility in the forest of Beni Sohane (Ribat Al Kheir Region - Morocco)

Khalid Benarchid, Mohammed Khatori and Said Hilali

co-Design, Energy, Environment and Innovation Laboratory
Faculté des Sciences et Techniques, Université Hassan 1er, Settat, Morocco

(Received 7 May, 2021; Accepted 2 July, 2021)

ABSTRACT

The purpose of this study is to determine the effect of reforestation of *Pinus halepensis* on soil fertility in the Beni Sohane forest. The Physico-chemical analysis was carried out on 24 soil samples collected at two depths of 0-10 cm and 10-30 cm. The soil samples were collected from 45-year-old reforested plots and native forest controls. The results revealed that reforestation with *P. halepensis* did not affect the pH, while it had negative effects on the content of all other nutrients, especially for Olsen phosphorus and boron, whose levels were significantly lower than those recorded in the native forest. The negative impact of reforestation was most accentuated in the topsoil layer of 0-10 cm. At this layer, the average content of all nutrients was -39% lower than the average content of the native forest, while at a depth of 10-30 cm it was only -18%. It seems that the sustainable restoration of degraded lands would depend on the prevalence of ecological considerations, favoring native forest species rather than expansionist exotic species such as *P. halepensis*.

Key words : *Reforestation, Pinus halepensis, Exotic species, Soil fertility, Soil acidification.*

Introduction

Fighting soil erosion is one of the main challenges for the protection of forests and agro ecosystems in the Mediterranean. Throughout the twentieth century, considerable efforts have been made to reforest large areas, the main purpose of which is to protect the soil from erosion and improve soil fertility. Converting degraded or marginal lands into forests can help reduce its disturbance and ensure the sustainability of vegetation cover, thereby providing a variety of ecosystem services (Sauer *et al.,* 2012).

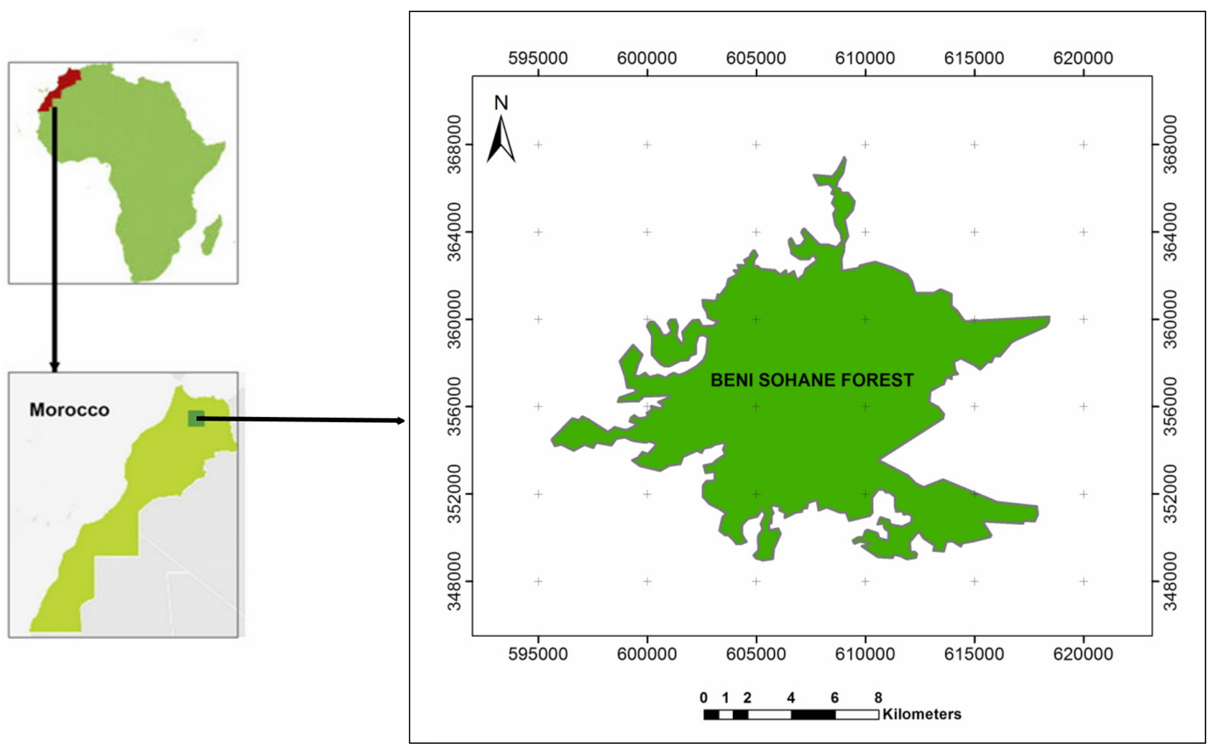
Since the end of the last century, the Beni Sohane forest has undergone severe degradation due to strong anthropogenic pressure. This has led the Water and Forestry Services to reforest the areas degraded with *Pinus halepensis* Mill. from the 1970s. This is the most widely used species in the Mediterranean region given its ability to adapt to different climates and soils, its yield, and its economic importance (Fernández-Ondoño *et al.,* 2010). Indeed, in the semi-arid areas of the Mediterranean basin, restoration activities during the 20th century were mainly based on extensive plantations of *P. halepensis*, which currently cover thousands of hectares (Maestre and Cortina, 2004; Bello-Rodríguez *et al.,* 2020).

P. halepensis represents an exotic species to our natural ecosystem. Plantations of exotic tree species have the potential to alter biogeochemical cycles in ecosystems due to changes in tree species composition (Freier *et al.,* 2010). The impact of pine afforestation on soil fertility should be nuanced, as it largely depends on the soil type, plantation age (Davis, 1998), and land use. The long-term impact of conifers often results in nutrient loss, soil acidification, decreased biological activity, and surface organic matter accumulation Berg and McClaugherty, 2003). On the other hand, under semi-arid climatic conditions, *P. halepensis* afforestation of abandoned fields has resulted in improvements in most soil quality indicators, reaching levels comparable to those observed under semi-natural forest vegetation after 40 years (Zethof *et al.,* 2019). Also, planting *P. sylvestris* var. *mongolica* Litv. in semi-arid degraded areas in China has improved soil quality and increased carbon sequestration potential (Li *et al.,* 2012). However, even with a 40-year-old plantation, the improvement of most of the physical and chemical properties of the soil rarely reaches the value indicated by natural shrubs (Maestre and Cortina, 2004). In the non-forested areas of southeastern Spain, pine plantations have increased soil fertility, albeit to a lesser degree than the nearby native oak forests (Fernández-Ondoño *et al.,* 2010).

The reforestation of *P. halepensis* in the Beni Sohane forest started more than 45 years ago, and it has negatively affected the biodiversity of our study area (Benarchid *et al.,* 2018). The *P. halepensis* is considered an invasive species in many natural and artificial areas (Bello-Rodríguez *et al.,* 2020). It's becoming more important to assess the effects of reforestation species on soils, as well as their interactions with other species (Yeste *et al.,* 2021). This prompted us to study the impact of 45-year-old *P halepensis plantations* on soil fertility. To achieve this goal, we conducted physico-chemical analyses of soil samples collected under the canopy of pine trees and control samples collected from sparse woods of native forest species.

Materials and Methods

The Beni Sohane forest is located in the northern middle Atlas. It is bounded by geographical 584 Km and 620 Km coordinates in the west and 334 Km and 370 Km in the north (Figure 1). The altitude varies between 800 and 1200 m. The average annual rainfall is 550 mm. The average temperature of the hottest month reaches 35.46°C and in the coldest month, the average temperature decreases to 2.45 °C. The main types of soils are poorly evolved, raw mineral, calcimagnetic, isohumic, and fersiallitic (S.E.I, 2014). The first reforestation began in the



1970s of the last century.

Soil samples were collected from the reforested plots. Each sample consisted of twelve samples taken at different locations and random intervals. Samples were taken with an auger under the foliage of *P. halepensis* trees at 2 depths 0-10 cm and 10-30 cm. Control samples were taken from the native forest adjacent to these sampling locations while ensuring that the same environmental conditions (exposure, topography, altitude, substrate, and soil type) were preserved. Knowing that the pine trees were planted in clearings and sparse woods of native forest species. For each modality, 24 samples were collected with 6 replicates.

The analyses focused on pH, organic carbon, macroelements, and micronutrients. The pH-water was measured using a pH-meter in a soil suspension and distilled water in a soil/water ratio (1/25). Electrical conductivity was measured on a 1/5 aqueous extract at 25 °C. Organic carbon was determined by sulfochromic oxidation of carbon in a mixture of potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid H_2SO_4 at a temperature of 135°C (Walkey and Black, 1934). Total nitrogen was calculated by distillation after mineralization according to the Kjeldahl method (Black *et al.,* 1965). Olsen's phosphorus (P_2O_5) was determined by spectrometry of soluble phosphorus in a sodium hydrogen carbonate solution (Olsen, 1954). Exchangeable cations K^+, Mg^{++}, and Ca^{++} were extracted with ammonium acetate (1 mol/l) at pH 7 and determined by plasma spectrometry (Schollenberger and Simon, 1945). Micronutrients copper (Cu), manganese (Mn), iron (Fe), and zinc (Z) were determined using atomic absorption spectrophotometry, After their extraction at 20°C in a mixed solution of ammonium acetate and EDTA (salt of ethylene diaminotetraacetic acid) at pH 7.3. Boron was determined by plasma spectrometry after extraction with hot water in a calcium chloride solution (0.01 mol/l) (Berger, 1949).

The statistical treatment of the data consisted in first comparing the fertility of the soil samples of the reforested plots, and those of the control plots without taking into account the soil depth, which will be represented in the rest of the article by the depth 0 - 30 cm. Second, the analyses were carried out by comparing the effect of *P. halepensis* reforestation at soil depths 0 - 10 cm and 10 - 30 cm. Shapiro-Wilk and Levene tests were applied to verify the normality and homoscedasticity of the variables. A logarithmic transformation was needed to satisfy these conditions for total nitrogen (total N), organic carbon/total nitrogen ratio (C:N), manganese (Mn), iron (Fe), zinc (Z), and boron (B) (Ingrand, 2017). For variables that met the criteria of normality and homoscedasticity, the Student test was used to compare means. While for Olsen phosphorus (P) and pH that did not meet these criteria even after transformation, they were subjected to the non-parametric Mann Withney U test. The statistical treatments were carried out using IBM SPSS Statistics 22 software.

Results and Discussion

The analysis of 24 soil samples from Beni Sohane Forest showed that the soil texture was clayey to silty-clayey with an average clay content of 46%. The conductivity was very low, with an average of 0.16 mS/cm. As for the variables studied, they are summarized in Table 1.

Effect on the pH

The pH values of all samples were alkaline, ranging from 8.1 to 8.9. The average pH value of the pine plantation was almost the same as the pH value of the control sample, being 8.70 and 8.56 respectively. Statistical tests of student (t) and Mann Whitney (U) revealed no significant difference between the samples of the reforested plots, and those of the control samples at all depths of 0-10 cm, 10-30 cm, and 0-30 cm (Tables 2 and 3). Correspondingly, the 5-year-old plantation of *P. radiata* on New Zealand pastures did not affect soil pH (Chirino *et al.,* 2010). In contrast, a meta-analysis of 61 studies on the effect of *P. halepensis* afforestation showed moderate acidification of 0.3 (Berthrong *et al.,* 2009). Other studies in New Zealand have found that planting a variety of pine trees can cause soil acidification. The average pH decreased by 0.2 to 0.5 units in 17 to 30-year-old *P. radiata* plantations (Giddens *et al.,* 1997), reduced by 0.1 to 1 unit in the mature coniferous forest (Belton *et al.,* 1996). In 46-year-old conifer plantations in central Ontario, a reduction of 1.28 units was achieved (Brand *et al.,* 1986). A positive relationship was discovered between the age of *Pinus spp.* Stands, and the degree of soil pH decrease (Davis and Lang, 1991). It should be noted that the acidifying effect of conifer plantations was obtained usually on acid soils with a pH of about 5.

Conifers can have an acidifying effect due to the strong organic acids produced by their litter and ectomycorrhizae. The loss of exchangeable cations (especially calcium), the intake of organic acids, and the increase in soil respiration may lead to a drop in pH (Parfitt *et al.*, 1997). The extent to which conifers alter soil conditions depends on the initial buffering capacity of the soil (Duffy, 2014). The decrease in pH is more pronounced when conifers are planted on soils with low buffering capacity and low organic matter content (Davis, 1998). In our study area, the absence of acidifying effect of the soil following reforestation with *P. halepensis* could be explained on the one hand, by the buffering capacity of soils that were basic and relatively rich in organic matter with respective averages of 8.63 and 3.87%. The lack of acidification can also be explained by the relatively high average calcium and magnesium content are 8059 mg/kg and 129 mg/kg, respectively.

Effect on organic carbon content and total nitrogen

Soil analysis showed that the average content of organic C and total N in the reforestation plot samples were lower than those recorded in the control samples of the native forest by -33% and -36% respectively. Similar findings were obtained from pine plantations, where organic C was reduced by -25% (Chirino *et al.*, 2010) and -21% (Duffy, 2014). And

Table 1. Main results of Physicochemical soil analyses

	Reforested plots			Control plots (Native forest)			Comparison in %(*)		
Soil depth	0-10 cm	10-30 cm cm	Weighted average	0-10 cm	10-30 cm	Weighted average	0-10 cm	10-30 cm	0-30 cm
pH	8.65 (0.07)	8.75 (0.05)	8.71	8.47 (0.09)	8.65 (0.06)	8.59	-	-	-
Organic. C %	2.18 (0.45)	1.17 (0.34)	1.51	3.54 (0.65)	1.59 (0.34)	2.24	-38	-26	-33
Total N%	0.21 (0.04)	0.11 (0.03)	0.14	0.34 (0.06)	0.15 (0.03)	0.22	-38	-27	-33
C:N%	10.58 (0.09)	10.30 (0.22)	10.39	10.47 (0.05)	10.37 (0.11)	10.40	1	-1	-0.1
P (mg/kg)	2.91 (1.02)	2.18 (0.36)	2.43	5.24 (1.36)	4.15 (0.97)	4.51	-44	-47	-46
K (mg/kg)	193.67 (42.98)	131.83 (36.56)	152.44	251.77 (37.61)	133.22 (21.00)	172.73	-23	-1	-12
Mg (mg/kg)	141.00 (26.32)	102.60 (15.00)	115.40	160.50 (16.53)	111.60 (7.80)	127.90	-12	-8	-10
Ca (mg/kg)	7838.28 (453.76)	7913.90 (418.75)	7888.69	8123.93 (527.19)	8360.25 (991.64)	8280.21	-3	-5	-5
Cu (mg/kg)	0.79 (0.17)	0.80 (0.20)	0.80	1.14 (0.43)	0.99 (0.19)	1.04	-31	-19	-23
Mn (mg/kg)	17.77 (3.30)	16.53 (4.24)	16.94	24.37 (6.06)	19.31 (3.29)	18.80	-27	-14	-10
Fe (mg/kg)	12.29 (3.22)	9,10 (1.88)	10,20	20.27 (6.63)	9.67 (1.24)	13.20	-39	-6	-12
Z (mg/kg)	0.62 (0.17)	0.31 (0.13)	0.41	1.26 (0.39)	0.37 (0.05)	0.67	-51	-16	-39
B (mg/kg)	0.48 (0.09)	4.26 (0.05)	0.33	0.82 (0.13)	0.37 (0.05)	0.52	-41	-30	-37
Average nutrient content (Organic C, N total , P, K, Mg, Ca, Cu, Fe, Z and B								-32	-14
-25									

In brackets (): Standard error with 6 reetitions for each modality.

(*) The comparison between the nutrient content of the reforested plots and the control plots is expressed in percentage, and the calculation formula is as follows:

$$\text{Comparison in } \% \frac{Xr - Xc}{Xc}$$

Xr : Average nutrient content of reforested plots.

Xc : Average nutrient content of native forest controls.

total nitrogen content was also reduced by -50% (Fernández-Ondoño *et al.,* 2010), -30% (Duffy, 2014) and -20% (Berthrong *et al.,* 2009). In contrast, Ruiz-Navarro *et al.* (2009) showed that pine plantation had no significant impact on soil organic C. Indeed, a meta-analysis of 74 publications conducted by Guo and Gifford (2002) found that the afforestation of pastures by deciduous tree species does not affect the carbon storage of the soil, but when pine trees are planted, these carbon storages are reduced. This is because deciduous trees can store more organic C in the soil than coniferous trees (Laganière *et al.,* 2010).

The C:N ratios of the reforested plots and native forest plots were almost the same, 10.39 and 10.40, respectively, indicating high microbial activity and strong organic matter mineralization. Likewise, Davis (1995) found that the planting of *P. radiata* had no effect on this ratio, but it had a high value of 15, indicating an acid pH of close to 5 and low microbial activity in the study region (Bardgett and Leemans, 1995). While, compared with abandoned farmland, the C:N ratio has significantly increased after 22 years of planting *P. halepensis* (Segura *et al.,* 2020). Furthermore, Berthrong *et al.* (2009) showed an increase in the C:N ratio of 11.6% in pine afforestation compared to unplanted land.

Effect on macronutrient content and micronutrient

The introduction of *P. halepensis* in the Beni Sohane forest resulted in the reduction of all other nutrients, especially Olsen P and B, whose content was significantly lower than that of the native forest. The reduction in nutrient levels ranged on average from -46% for Olsen P to -5% for Ca (Table 1). However, the Student (t) test showed that only for B, there was a significant difference between the samples of the reforested plots and the samples of the control samples at p-value of 5% (Table 2). As for the Olsen P, which did not meet the conditions of normality and homoscedasticity even after transformation, the non-parametric Mann Whitney U test at the 5% level showed that their concentrations recorded in the reforested plots were significantly lower than those of the native forest controls (Table 3).

Many studies have shown that pine tree plantations lead to reduced soil nutrient content. Compared with native forests, reforestation of pine trees (*P. strobus*, *P. resinosa* and *P. echinata*) resulted in lower Mn (-37%), B (-24%), and Zn (-13%) contents compared to those of native forests (Duffy, 2014). The K and Ca contents in a pine forest were also significantly lower than the K and Ca contents in native forests (Fernández-Ondoño *et al.,* 2010), and that total P, Ca, and Mg concentrations in grasslands in New Zealand decreased after planting *P. radiata* (Chirino *et al.,* 2010).

However, conifer plantations had a positive effect on soil Olsen P levels when planted on grasslands in

Table 2. Student's t-test for soil characteristic variables with a significance level of 5%

Variables	Depth (0-10cm) n=12		Depth (10-20 cm) n=12		Depth (0-30 cm) n=24	
	t	Sign (5%)	t	Sign (5%)	t	Sign (5%)
pH [(a)]	1,611	0,138	1,327	0,214	-	-
Organic C	-1,716	0,117	-0,863	0,408	-1,610	0,122
Total N	-1,739	0,113	-0,866	0,407	-1,699	0,103
C:N	1,017	0,333	-0,278	0,787	0,039	0,969
P [(a)]	-1,462	0,175	1,720	0,116	-	-
K	-1,017	0,333	-0,033	0,974	-0,755	0,458
Mg	-0,627	0,544	-0,532	0,606	-0,738	0,468
Ca	-408	0,692	-0,415	0,687	-0,596	0,557
Cu	-0,495	0,631	-0,715	0,491	-1,067	0,297
Mn	-0,956	0,362	-0,518	0,616	-1,094	0,286
Fe	-1,068	0,311	-0,534	0,605	1,556	0,132
Z	-1,500	0,165	-0,483	0,681	-1,696	0,104
B [(*)]	-2,230	0,050	-1,619	0,137	-2,160	0,042

(a) : At the depth of (10-30 cm), pH and phosphorus did not meet the criteria of normality and homoscedasticity even after transformation.

(*) : Significant difference between the boron content of reforested plots and those of the native forest for depths 0-30 and 0-10 cm at the significance level p = 0.05%.

New Zealand. In the plantations of 5 coniferous, these levels were 2 to 4 times that of the adjacent grassland, indicating an overall improvement in soil fertility for associated or later vegetation (Belton *et al.,* 1996). Higher Olsen's P content has been recorded in older coniferous forests, especially (Davis and Lang, 1991). Even though pine plantations have increased soil fertility as compared to non-forested areas, they have not been able to match the fertility of nearby native *Quercus ilex* forests. (Fernández-Ondoño *et al.,* 2010). It seems that afforestation of grasslands with conifers improves the mineralization of the organic matter and the availability of P in the topsoil, making it possible to meet the high demand for P from trees, thanks to greater phosphatase activity of tree roots associated with ectomycorrhizae and favorable soil moisture and temperature conditions (Chen *et al.*, 2008). Li *et al.* (2019) have shown that compared with deciduous tree species, coniferous trees have a higher demand for P.

The low nutrient levels found in the reforested plots compared to the native forest in our study area could be explained by *P. halepen*sis trees' high demand for these elements to ensure their rapid growth. In mature stands, *P. halepensis* trees developed a taller canopy that supplanted all native tree species (*Quercus rotundifolia*, *Juniperus phoenicea*, *Juniperus oxycedrus*, *Tetraclinis articulata*, *Pistacia lentiscus*, and *Phyllyrea augustifolia*). Barbero and Quézel (1989) describe *P. halepensis* as an expansionist model characterized by high reproduction, early fruiting, and high biomass production. The ability of pines and other conifers to access nutrients in soil organic matter is due to their association with ectomycorrhizal fungi, which generate extracellular enzymes that enable trees to access nutrients not accessible to non-ectomycorrhizal plants (Marschner and Dell, 1994). Therefore, compared to native forests, the most significant changes in soil characteristics recorded in exotic plantations (such as *Pinus* and *Eucalyptus*) may be due to the higher growth rates of these species (Berthrong *et al.,* 2009).

Effect of the soil depth

The decrease of soil fertility was more pronounced in the 0-10 cm topsoil layer, with mean levels of all nutrients being lower on average (-32%) than those in the native forest and only (-18%) for the 10-30 cm depth (Table 1). For the top layer of 0-10 cm, the content of organic C was reduced (-38%), the content of macronutrients (total N, P, K, Mg and, Ca) was reduced (-27%), and the content of micronutrients (Cu, Mn, Fe, Z and B) was reduced (-38%). While for the soil layer of 10-30 cm, organic carbon decreased (-26%), macronutrients decreased (-19%), and micronutrients decreased (-17%). However, the Student's t-test with a significance level of 5% showed that at the depth of 0-10 cm, only the B content in reforested plots was significantly lower than those of the native forest controls. While there was no significant difference between the samples from the reforested plots and those from the control plots for all other variables at the two depths 0 - 10 cm and 10 - 30 cm (Table 2). Montero and Delitti **(2017)** found that soil carbon storage in the 0-5 cm top layer of pine afforestation was higher than that of natural forests, while soil carbon storage below 10 cm was lower. The rise in soil nutrient levels following the planting of *P. sylvestris var. mongolica Litv.* was greater in the first 5 cm than in the depth 5-15 cm (Li *et al.,* 2012). However, the assimilable nutrient contents of pine woods in southeastern Spain were significantly lower than those of native forests at all depths (0-5 cm, 5-10 cm, and >10 cm) (Fernández-Ondoño *et al.,*2010). On the other hand, the Olsen P level in the soil increased by 42% to 62% at a depth of 0-5 cm and increased by 62% to 100% at a depth of 5-10 cm (Chirino *et al.,* 2010). Also, compared to the control site, the concentration of available P in forest land tends to increase rapidly with the increase of depth, while total P concentration decreases with the increase of depth (Deng *et al.,* 2017).

Table 3. Mann Whitney U nonparametric test of pH and phosphorus at depth 0-30 cm

Designation	U	Sign 5%
pH	44,000	0.094
P_2O_5 (*)	35,000	0.031*

(*) Significant difference between the Olsen phosphorus content of reforested plots and those of native forest at the significance level p = 0.05%.

Conclusion

The reforestation of P. halepensis in the Beni Sohane forest has negatively affected soil fertility, especially for Olsen P and B, which had significantly lower average levels than in the native forest. In the topsoil layer of 0-10 cm, the negative impact of reforestation is the most obvious. At this depth, the average nutrient level was -39% lower than that of the native forest, while at a depth of 10-30 cm it was only -18%. The pH value was not affected by this reforestation. It seems that the use of *P. halepensis* in native forest reforestation should be challenged. Any reforestation of mountain habitats requires a detailed understanding of its impact on soil nutrient flux and balance. Consequently, it would be more fitting to prioritize native forest species over expansionist exotic species.

Conflict of Interest

The authors declared that the present study was performed in absence of any conflict of interest.

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