

## Spatial variability of soil properties under *Pinus canariensis* canopy in two contrasting soil textures

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**Abstract** Knowledge of the spatial pattern and scale of plant resources is important to aid in understanding the causes of this spatial pattern and their consequences on process at the population, community, and ecosystem levels. We tested whether the effect of individual plants on the soil properties beneath their canopies might be mediated by soil texture, since this soil property has great influence on the soil organic matter protection, the soil cation exchange capacity, and the nutrients diffusion rate. We hypothesize that variables directly related to organic matter (microbial biomass-N [MB-N] or dissolved organic-N [DON]), as well as soil nutrients interacting with soil secondary minerals (PO<sub>4</sub>-P and NH<sub>4</sub>-N), should more closely follow the plant canopy projection in sandy soils than loamy ones. We also expected a higher spatial range and dependence of NO<sub>3</sub>-N in sandy soils, although the spatial distribution should not necessarily be affected by the plant position. To test these hypotheses, we used square plots (8 m×8 m or

6 m×6 m) placed around isolated mature individuals of *Pinus canariensis* in both loamy and sandy soils in *P. canariensis* forests, with replicates in summer and winter. Spatial pattern and scale of MB-N, DON, and inorganic-N and -P were analyzed with geostatistical methods. In the summer sampling, all soil variables had lower spatial ranges in the loamy soil than the sandy soil. However, no clear trend was observed in the winter. The spatial dependence of NO<sub>3</sub>-N from the two sampling dates was higher for the sandy soil than the loamy soil. Kriged maps in the sandy soil revealed that the spatial distributions of the summer soil moisture, MB-N, DON, and PO<sub>4</sub>-P were all dependent on pine location. Our results suggested that the presence of *P. canariensis* individuals may be an important source of spatial heterogeneity in these forests. Soil texture may determine the magnitude of the pine canopy's effect on the spatial distribution of chemical and biological soil properties when water content is scant, but it may have negligible effects under conditions of higher water availability.

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### Introduction

The physical, chemical and biological properties of soils are highly variable over time and space

(Robertson and Gross 1994; Ryel et al. 1996). Spatial heterogeneity may occur simultaneously at different scales, ranging from landscape to individual plant level (Robertson 1988; Ryel and Caldwell 1998). The spatial pattern and scale are also variable in time, even within a single growing season (Cain et al. 1999). Consequently, plants should acquire soil resources that vary in time and space, but that also show temporal changes in their spatial pattern and scale (Ryel et al. 1996).

Knowledge of the spatial pattern and scale of plant resources is important to avoid the negative influence of spatial autocorrelation in field experiments design, as well as to aid in understanding the causes of this spatial pattern and their consequences on process at the population, community, and ecosystem levels (Robertson et al. 1993; Robertson and Gross 1994). Several authors have tried to understand the factors and processes determining the spatial patterns of soil resources (Robertson et al. 1997; Guo et al. 2002). For example, Robertson et al. (1997) suggested that geomorphic influences may determine differences in microtopography and erosion on a scale of tens of meters, while vegetation cover or rhizosphere influences may determine the existence of structures at smaller spatial scales. The influence of plant cover on the spatial pattern of soil resources has been described by several authors (e.g., Schlesinger et al. 1996; Gallardo 2003). Individual plants alter the physical, chemical and biological properties of the soil beneath their canopies, particularly by concentrating biomass and organic matter (Jackson and Caldwell 1993; Gallardo et al. 2000). Where local plant-soil interaction has a greater effect on soil than other factors (as topography or soil texture), we may find a mosaic pattern in soil properties formed by the influence circles of single plants (Zinke 1962; Saetre 1999). Soil nutrient patches in turn influence the individual functioning of plants (Antonovics et al. 1987; Gallardo et al. 2006; Quilchano et al. 2008), and ultimately the structure and function of plant communities and ecosystems (Tilman 1988; Schlesinger et al. 1990; Robertson and Gross 1994). Thus, the spatial relationship between plant and soil is clearly bidirectional (Ettema and Wardle 2002; Covelo et al. 2008; Zhou et al. 2008).

Previous works have found that changes in microbial structure, biomass and activity may be explained by differences in soil texture (Robertson et

al. 1997; Schutter et al. 2001). Soil texture greatly influences soil conditions like organic matter and water retention capacity (Fisher and Binkley 2000). Thus, the higher diffusion rate of sandy soils causes the cycling of soil organic matter and water fluxes to be faster than in loamy or clay soils. Furthermore, sandy soils are also characterized by low cation exchange capacity (CEC), which is essentially limited by the soil organic matter content. However, CEC in loamy and clay soils is based on both the soil organic matter content and on secondary minerals such as clays (Schlesinger 1997). Therefore, soil texture may play an important role in developing the spatial patterns of microbial processes, ultimately influencing nutrient availability for plant growth and the spatial structure of plant communities (Kwon et al. 2007). Soil texture is also more stable than other biotic and abiotic soil factors, which makes it a potentially useful metric for predicting soil spatial heterogeneity (Dupuis and Whalen 2007). However, we are not aware of any work evaluating the effects of soil texture on the spatial pattern and scale of soil variables.

In this paper, we focus on the spatial pattern of organic-N fractions (microbial biomass-N [MB-N] and dissolved organic-N [DON]) and inorganic-N and -P ( $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$  and  $\text{PO}_4\text{-P}$ ) in the soils of *Pinus canariensis* forests in the Canary Islands (Spain). We are mainly interested in nitrogen because *P. canariensis* forests are usually N-limited (Tausz et al. 2004; Durán et al. 2008). DON was included because the recognized importance of organic N uptake by plants is increasing, especially in N-poor systems, where plants and microorganisms may compete for these organic forms of N (Jones and Willet 2006, Rodríguez et al. 2007). To our knowledge, there is no information on the spatial pattern of soil DON in forest ecosystems (Rodríguez et al. 2008). Our primary goal was to study the effect of *P. canariensis* canopies on the spatial pattern and scale of N and P soil fractions in two contrasting soil textures. We hypothesize that the location of the pine canopy inside the plot will influence the spatial structure of the studied soil variables, but that this effect would depend on soil texture and the biogeochemical properties of soil variables. Thus, variables that are directly related to organic matter, such as MB-N or DON, should more closely follow the plant canopy projection in sandy soils than in loamy ones, showing higher organic nitrogen levels beneath than

outside the plant canopy. In addition, soil nutrients interacting with soil secondary minerals, such as  $\text{PO}_4\text{-P}$  and  $\text{NH}_4\text{-N}$ , should be also more heavily influenced by plant location in sandy soils than in loamy ones, showing also highest nutrient levels under the plant canopy. Moreover, because of the high mobility of  $\text{NO}_3\text{-N}$ , we should expect a higher diffusion rate of this nutrient in sandy soils, leading to a higher spatial range and dependence. However, because the nitrification is a process performed mostly by chemoautotroph microorganisms, the spatial distribution should not necessarily be affected by the plant position.

## Methods

### Area of study

The study was carried out in La Palma Island (Canary Islands, Spain,  $28^\circ 41' \text{ N}$ ,  $17^\circ 45' \text{ W}$ ) in two *Pinus canariensis* stands with the same climate and vegetation characteristics but different soil textures (Table 1). Mean annual precipitation and temperature were 600 mm and  $16^\circ\text{C}$ , respectively (Climent et al. 2004). In this plant community, it is easy to find *P. canariensis* forests with similar physical characteristics but differing soil textures, because of different soil ages formed from volcanic eruptions during different times of the island's geologic history. Thus, in young volcanic soils at La Palma Island, mechanical weathering dominates over chemical weathering, producing a coarse-textured soil as compared with older soils. Loamy soil (Leptic Umbrisol) was derived from the weathering of volcanic basaltic rock (400000–800000 years old). These soils are characterized by a relative high water-holding capacity, which alleviates water deficit during the dry season. Sandy soil (Regosol) is a young soil (< 20000 years old) derived from the weathering of basaltic rocks and

characterized by an incipient A horizon and low water-holding capacity (FAO 1996). *Pinus canariensis* Chr. Sm. ex DC is an endemic pine of the Canary Islands. Today, *P. canariensis* is the most extensive forest community on this island, with the best-developed pine forests and the oldest trees (Génova et al. 1999). These forests are mainly composed of mature pine individuals, covering almost 80% of the soil surface. Under the pine canopy, the understory is sparse and is composed of *Adenocarpus viscosus* (Wild.) Webb & Berthel, *Erica arborea* L. and *Cistus symphytifolius* Lam.

### Experimental design

Two soil samplings were carried out: the first one in late winter (March 2005), with the highest water availability, and the other one in the mid-summer (August 2005), with lowest water availability (Table 2). For both soil sampling dates, we selected one isolated mature individual of *P. canariensis* each for the loamy and sandy soils. A squared plot was placed around each pine individual. Pine selection was randomly performed in the winter; then, for the summer soil sampling, we selected different isolated individuals to avoid previously disturbed soils, but we chose them as close as possible to the winter-sampled individuals. All selected individuals had similar canopy sizes (3–4 m) and heights (ca. 20 m). The sampled plots were homogeneous in terms of slope (< 5%) and soil rock cover. Plot dimensions depended on the size of the individual plant inside the plot and were chosen to maximize the spatial detection of soil properties around individual plants. Thus, winter-sampled plots were smaller (6 m × 6 m) than summer-sampled plots (8 m × 8 m). Soil samples were collected from the top 10 cm of the soil profile at 100 cm intervals with a metallic cylinder of 5 cm diameter × 15 cm high. Within each plot, soils were sampled on a smaller scale by randomly selecting four 1 × 1 m squares,

**Table 1** Location and soil physical and chemical characteristics of the two studied *P. canariensis* stands

	Location	Altitude (m)	Sand (%)	Silt (%)	Clay (%)	pH soil	Total C (%)
Loamy soil	$28^\circ 47' 5'' \text{ N}$ $17^\circ 55' 52'' \text{ W}$	1215	50	30	20	6.7	2.34
Sandy soil	$28^\circ 37' 34'' \text{ N}$ $17^\circ 50' 37'' \text{ W}$	1206	90	10	0	6.6	2.31

**Table 2** Mean and standard error for all soil properties measured in two differently textured soils

Variable	Sampling	Loamy soil	N	Sandy soil	N
Soil moisture	Winter	24.41±0.42	85	4.45±0.43	83
	Summer	6.24±0.13	117	0.36±0.03	116
MB-N	Winter	56.91±2.51	85	11.22±0.94	81
	Summer	12.08±0.69	112	10.32±1.14	116
DON	Winter	5.34±0.30	82	2.07±0.23	75
	Summer	12.12±0.29	115	1.83±0.24	104
NH <sub>4</sub> -N	Winter	18.88±1.64	87	11.82±0.81	84
	Summer	3.60±0.19	118	7.32±0.45	113
NO <sub>3</sub> -N	Winter	4.21±0.34	79	3.43±0.19	81
	Summer	1.33±0.05	113	2.43±0.11	116
PO <sub>4</sub> -P	Winter	4.79±0.20	81	13.42±1.11	85
	Summer	3.39±0.16	111	6.09±0.74	121

All variables are expressed as mg kg<sup>-1</sup> soil, except soil moisture (expressed as %).

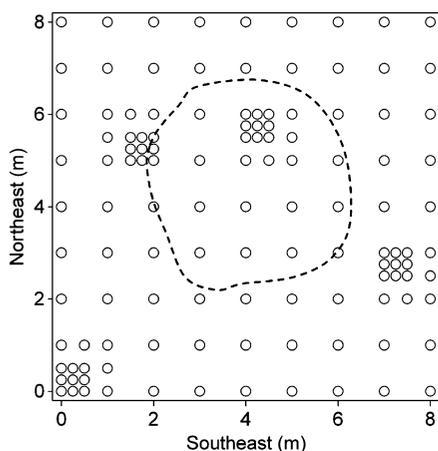
collecting samples at 50 and 25 cm intervals (Fig. 1). The total number of soil samples was 89 from the winter plots and 121 from the summer plots. Samples were immediately placed in an ice-filled cooler and transported to the lab.

#### Laboratory analysis

Soil samples were sieved (< 2 mm mesh size), and sub-samples were oven-dried at 80°C for 48 h to calculate soil moisture. MB-N was analyzed by the fumigation-extraction method of Brookes et al.

(1985). Soil sub-samples (5-g of fresh soil) were fumigated with chloroform for 5 days. Non-fumigated sub-samples served as the controls. Fumigated and non-fumigated soil sub-samples were extracted with 50 ml of 0.5 M K<sub>2</sub>SO<sub>4</sub>. Total N in these extracts was estimated via a persulfate oxidation technique wherein total-N was oxidized to NO<sub>3</sub>-N (D'Elia et al. 1977). The NO<sub>3</sub>-N concentration in these digests was estimated by colorimetry (indophenol blue method) in a microplate reader (Sims et al. 1995). This method has proven to be a rapid and efficient way to measure total N in K<sub>2</sub>SO<sub>4</sub> extracts (Cabrera and Beare 1993; Hossain et al. 1993). MB-N was calculated as the difference between total-N concentration in the fumigated and the non-fumigated soil sub-samples divided by the fraction of microbial-N extracted after CHCl<sub>3</sub> fumigation (K<sub>n</sub>=0.54, Joergensen and Mueller 1996). Soil DON was estimated by subtracting mineral-N from total-N in the non-fumigated soil sub-sample extracts (Cabrera and Beare 1993; Doyle et al. 2004).

Mineral-N was extracted in 5-g of fresh soil sub-samples with 50 ml of 2M KCL by shaking them for 1 h at 200 rpm in an orbital shaker, and then the suspension was filtered through a 0.45 μm Millipore filter. These extracts were used to determine the amount of NH<sub>4</sub>-N and NO<sub>3</sub>-N by colorimetry, as described above. Extractable-P was estimated following the method of Nelson and Sommers (1996). Fresh soil sub-samples (2-g) were shaken with 40 ml of 0.5 M NaHCO<sub>3</sub> in an orbital shaker for 1 h at



**Fig. 1** Summer sampling design around a *P. canariensis* individual growing on sandy soil. Each circle shows a sampling point, and the dotted line represents the tree canopy projection

200 rpm, then filtered through a 0.45  $\mu\text{m}$  Millipore filter and analyzed for  $\text{PO}_4\text{-P}$  using a nutrient auto-analyzer (Bran + Luebbe - AA3). Organic and inorganic nutrient pools were expressed in milligrams per kilogram of dry soil.

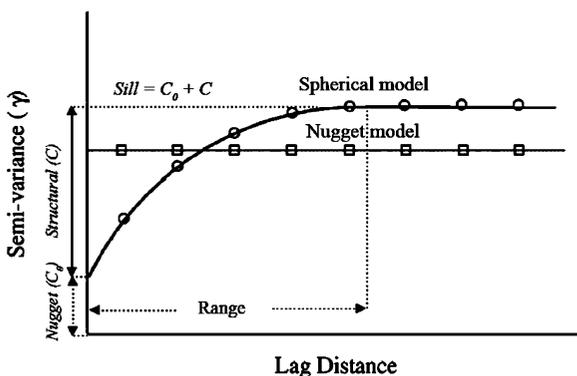
### Statistical analysis

We used geostatistical analysis to estimate the spatial pattern and scale of the studied soil variables (Robertson 1987; Rossi et al. 1992). Prior to geostatistical analysis, all soil properties were transformed to normal distributions according to the formula proposed by Box and Cox (1964):

$$Y' = \log(Y), \text{ if } \lambda = 0; \quad Y' = (Y^\lambda - 1)/\lambda, \text{ otherwise}$$

where  $\lambda$  is the transformation parameter.

We used semivariograms to show the average variance found in comparisons between samples taken at increasing distances from one another, i.e., the lag interval. To facilitate comparisons, all semivariograms were fitted to a spherical model (Fig. 2); the use of other models did not significantly improve the fit. To estimate the magnitude of spatial dependence, we calculated the percentage of total variance (sill;  $C_0 + C$ ) explained by the structural variance ( $C$ , variance explained by spatial autocorrelation). When no spatial dependence between samples is detected for the observed scale ( $[C/(C_0 + C)] = 0$ ), the variogram turns



**Fig. 2** Schematic diagram of a semivariogram showing the proportion of variance (semivariance) found at increasing distances of paired samples (lag distances). The nugget model is expected when soil properties are randomly distributed. The spherical model is expected when soil properties show spatial autocorrelation over a range and independence beyond that distance

flat, and it is known as the nugget model. Variance that occurs on a smaller scale than the field sampling is found at 0 lag distance and is known as nugget variance ( $C_0$ ). A high nugget variance also may indicate sampling or analytical errors (Isaaks and Srivastava 1989). Spatial range indicates the geographic scale of this dependence, i.e., the distance beyond which samples are spatially independent. The model fitted to the semivariogram allows for interpolation (“kriging”), which provides optimal and unbiased estimates of non-sampled points. The interpolation of points using semivariograms (kriging) requires the assumption of stationarity, which held true for all our variables (Legendre and Fortin 1989).

All geostatistical analyses were performed with R 2.7.2 for Linux (R Development Core Team 2008), using the geoR and gstat modules (Pebesma and Wesseling 1998; Ribeiro and Diggle 2001).

### Results

Mean and standard errors for soil variables can be found in Table 2. In sandy soils, most empirical semivariograms were successfully fitted to a spherical model (excepting winter DON), indicating spatial dependence within these soils ( $p < 0.05$ , Table 3). However, in loamy soils, detection of spatial structure failed for a third of the soil variables studied in the winter sampling and for a half of those studied in the summer.

For both the winter and summer sampling, spatial dependence ranged lower for the loamy soil (36–56% and 31–62%, respectively) than for the sandy soil (25–81% and 43–100%, respectively); spatial dependence of  $\text{NO}_3\text{-N}$  was higher for both sampling dates in the sandy soil than the loamy soil (Table 3).

The scale at which soil variables showed spatial dependence (spatial range) varied between 0.71 and 4.23 m (Table 3, Figs. 3 and 4). All soil variables measured in the summer sampling had lower spatial ranges in the loamy soil than in the sandy soil (Table 3, Figs. 4 and 5). However, no clear trend was observed in the winter sampling (Table 3, Fig. 3).

Kriged maps for the sandy soil showed that only the spatial distribution of the summer soil moisture, MB-N, DON, and  $\text{PO}_4\text{-P}$  were dependent on pine location, with spatial ranges matching the pine canopy diameter (Fig. 5).

**Table 3** Variogram model parameters for all soil properties measured in the sandy and loamy soil plots

Variable	Soil	Sill ( $C_0+C$ )	Nugget ( $C_0$ )	Range (m)	$C/(C_0+C)$ (%)	$r^2$
<i>Winter sampling</i>						
Soil moisture	Loamy	Nugget model ( $[C/(C_0+C)]=0$ )				
	Sandy	1.46	1.08	2.93	25	0.76
MB-N	Loamy	109.64	68.95	3.37	37	0.65
	Sandy	7.2	4.29	1.09	40	0.70
DON	Loamy	Nugget model ( $[C/(C_0+C)]=0$ )				
	Sandy	Nugget model ( $[C/(C_0+C)]=0$ )				
NH <sub>4</sub> -N	Loamy	5.10	2.26	1.52	56	0.72
	Sandy	4.06	1.86	2.39	54	0.80
NO <sub>3</sub> -N	Loamy	2.1	1.35	3.08	36	0.98
	Sandy	0.37	0.07	0.94	81	0.69
PO <sub>4</sub> -P	Loamy	0.24	0.12	3.70	50	0.93
	Sandy	0.87	0.30	1.68	66	0.82
<i>Summer sampling</i>						
Soil moisture	Loamy	30.33	19.42	1.76	36	0.64
	Sandy	0.42	0.24	4.23	43	0.95
MB-N	Loamy	Nugget model ( $[C/(C_0+C)]=0$ )				
	Sandy	8.10	3.75	3.86	54	0.92
DON	Loamy	0.13	0.05	0.71	62	0.72
	Sandy	7.25	3.90	4.15	46	0.84
NH <sub>4</sub> -N	Loamy	Nugget model ( $[C/(C_0+C)]=0$ )				
	Sandy	2.78	1.59	1.05	43	0.64
NO <sub>3</sub> -N	Loamy	0.27	0.18	1.08	31	0.60
	Sandy	0.55	0.22	2.85	60	0.83
PO <sub>4</sub> -P	Loamy	Nugget model ( $[C/(C_0+C)]=0$ )				
	Sandy	0.30	0.00	4.20	100	0.92

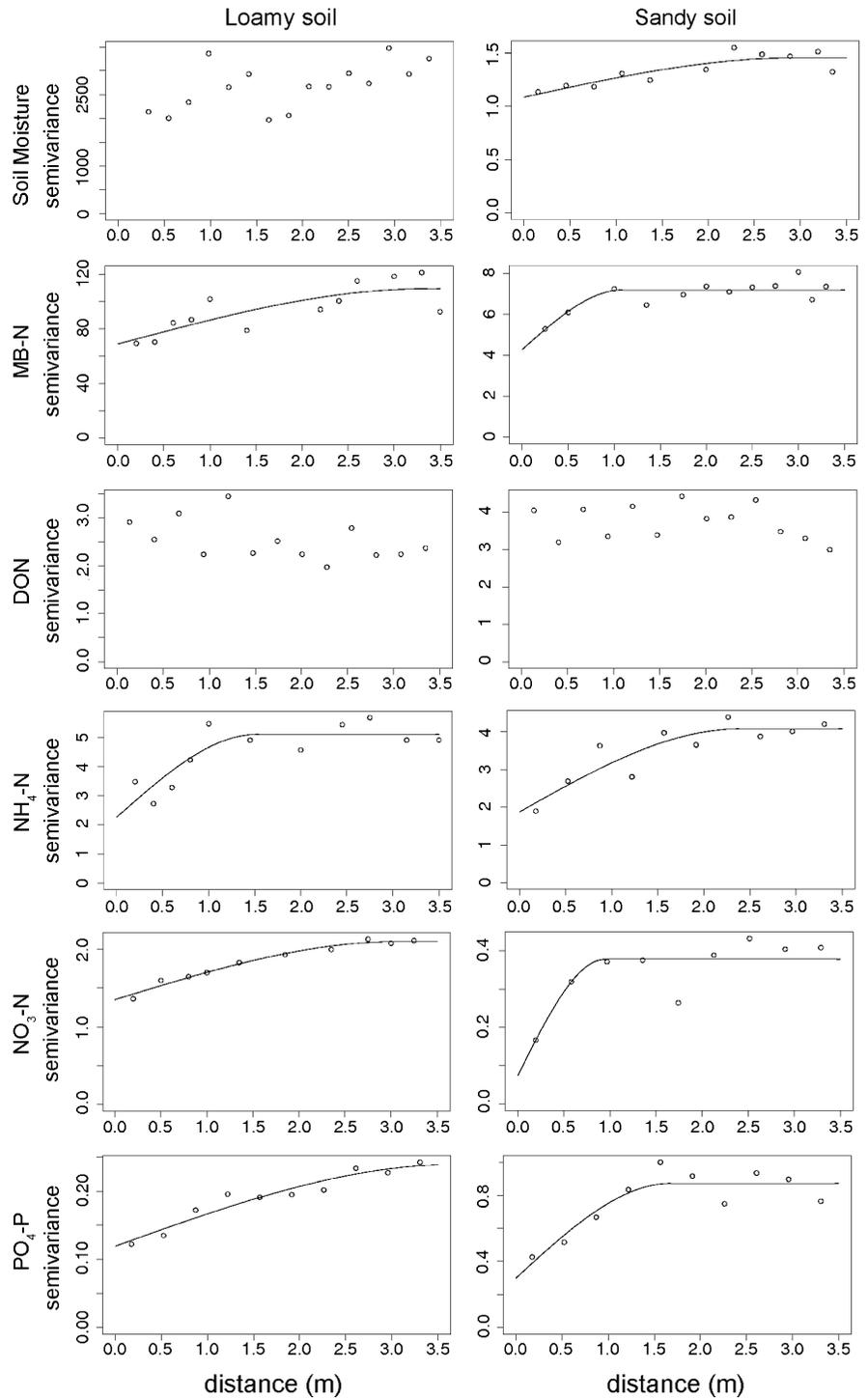
All variables are expressed as mg kg<sup>-1</sup> soil, except soil moisture (%).

## Discussion

The pine canopy had a clear effect on the spatial pattern of some measured soil variables. However, this effect was seen only in the sandy soil, and never in the loamy soil. In the summer sampling, variables directly related to soil organic matter content, such as soil moisture, MB-N, and DON, showed the highest spatial dependence from plant canopy in the sandy soil, as suggested by our hypothesis. A higher organic matter buildup from litterfall along with higher soil moisture beneath the pine canopy may explain the higher MB-N and DON content (Jones et al. 2005). The lack of spatial correlation between the pine canopy projection and these soil variables measured in the loamy soil may be related to the ability of clay to stabilize soil organic matter through mineral-organic matter binding and through the physical protection provided by the micropores in clay

aggregates (Wattel-Koekkoek et al. 2001). Consequently, the turnover of soil organic matter should be lower in the loamy soils than in sandy ones; the spatial distribution of this organic matter should therefore be less dependent of recently added organic matter coming from the plant canopy. A high extractable-P accumulation under the pine canopy was also observed in sandy soil from the summer sampling. The fact that there are fewer secondary minerals like clays in these soils would render the spatial distribution of PO<sub>4</sub>-P concentration more dependent of the organic-P accumulated under the pine canopy (Smeck 1985). In contrast, the lack of any NH<sub>4</sub>-N spatial pattern related to plant canopy location in this sandy soil may be explained by the N limitation of primary production in these forests (Tausz et al. 2004), which may depress the soil available N across the plot. Thus, the active uptake of N by plants and soil microorganisms during the

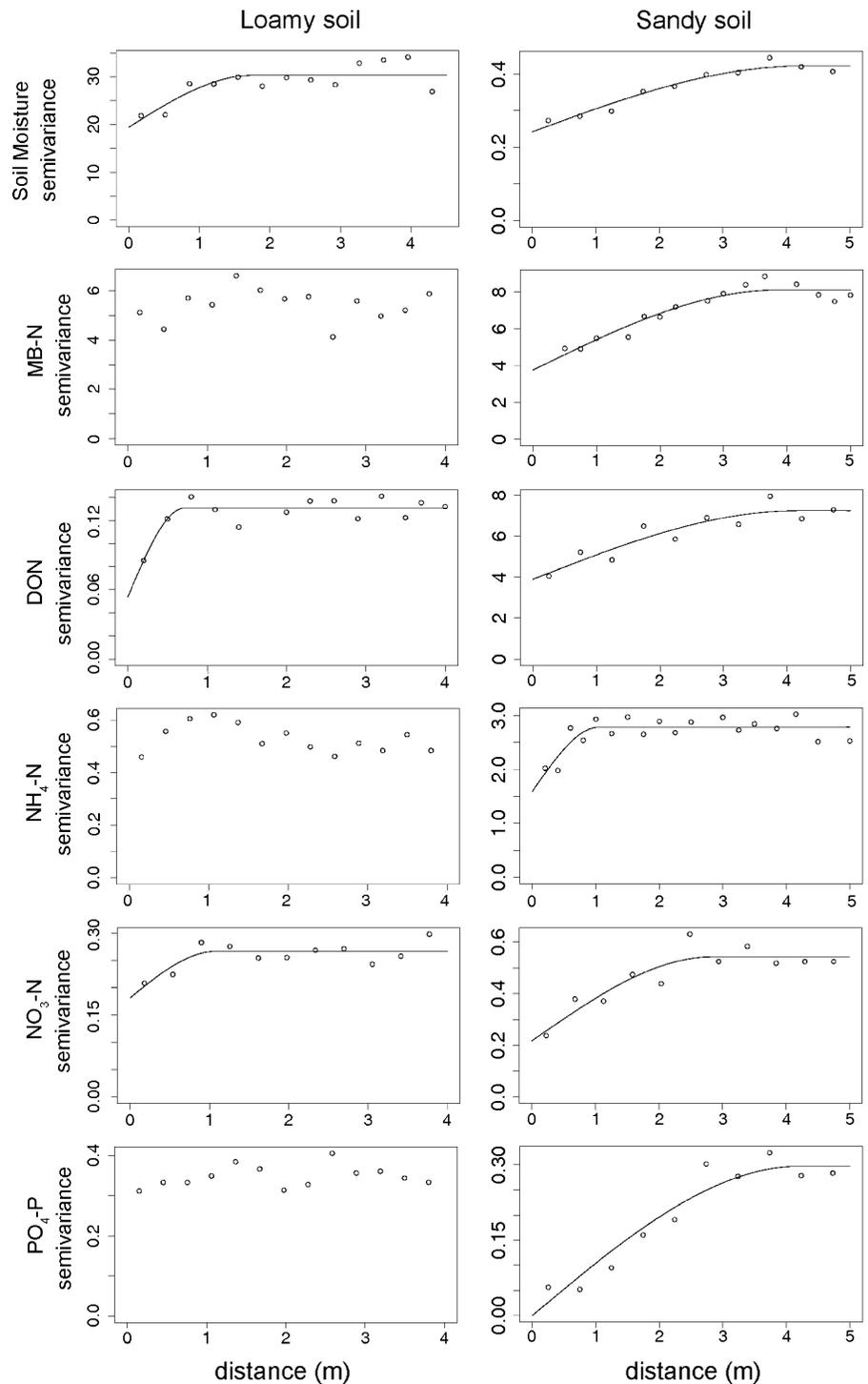
**Fig. 3** Semivariograms for all soil properties measured in the loamy and sandy soil of the winter sampling. Soil moisture was expressed as a percentage. All other variables were expressed as  $\text{mg kg}^{-1}$  soil



growing season would decrease the spatial dependence from the pine canopy location found in the summer (Schlesinger et al. 1996; Wang et al. 2007). As we expected, soil  $\text{NO}_3\text{-N}$  showed no spatial

structure related to the pine canopy; this may also be related to the active N uptake by plants and microbes, as well as to the lack of any relationship between soil organic matter accumulation and the

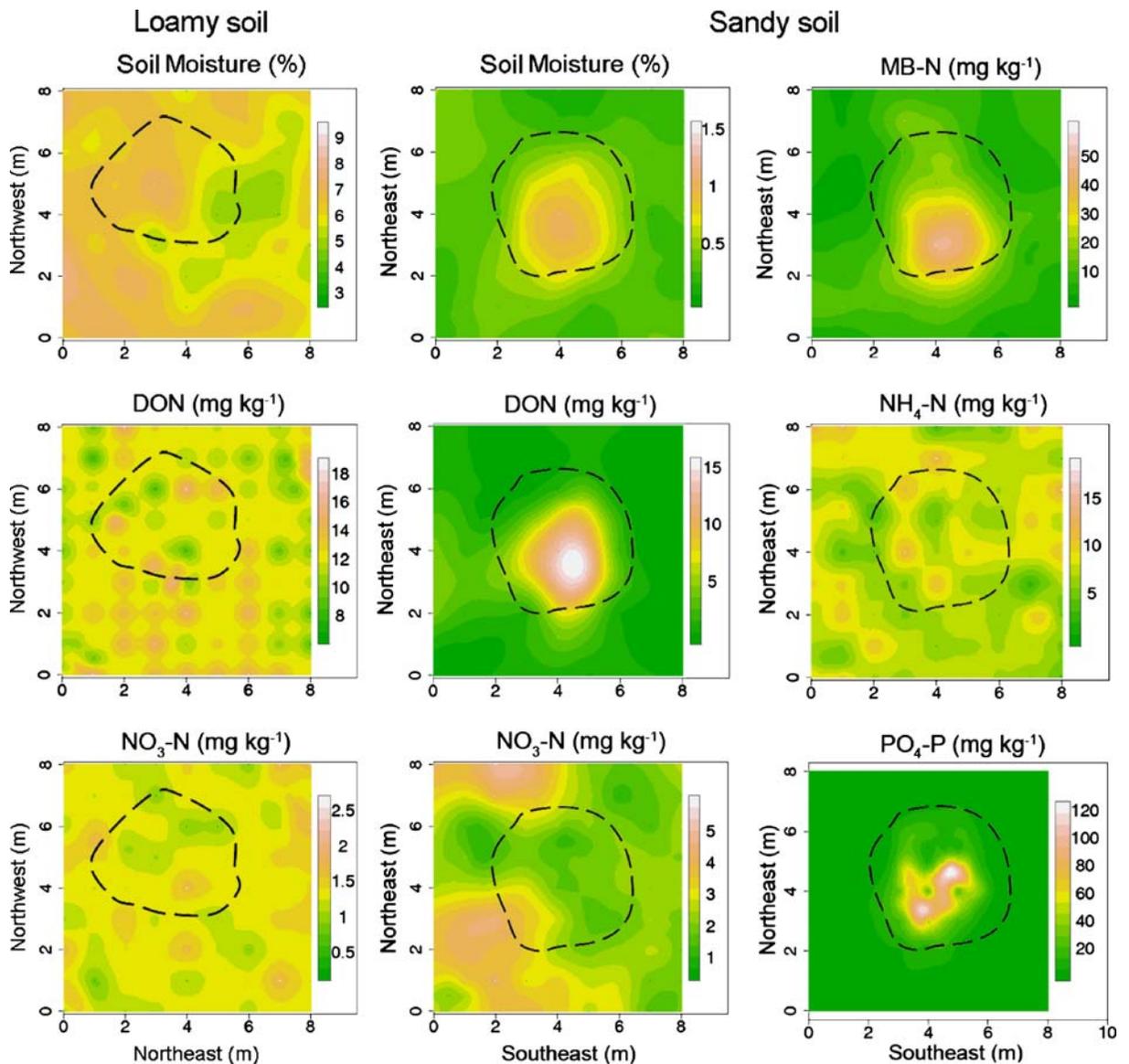
**Fig. 4** Semivariograms for all soil properties measured in the loamy and sandy soil of the summer sampling. Soil moisture was expressed as a percentage. All other variables were expressed as  $\text{mg kg}^{-1}$  soil



chemoautotrophic nitrification processes that are likely operating in these forests.

The effects of the pine canopy on the spatial distribution of soil variables were detected only in the

summer soil samples, which had the lowest level of soil moisture. The relatively higher soil water content found in the summer under the pine canopy may be driving the spatial distribution of the other soil



**Fig. 5** Interpolation maps (kriging) for all soil properties with spatial structure measured in the loamy and sandy soil of the summer sampling. The dotted line represents the tree canopy

projection. Winter sampling maps were omitted because no effect of plant canopy on soil variables was observed

variables. Thus, no differences were detected in the winter between samples taken from underneath and outside of pine canopy either with respect to soil moisture or to the other soil variables. As suggested by James et al. (2003), significant effects of plants on soil resources emerge with a high probability when the resource is scarce. This idea is consistent with the notion of resource availability in arid areas and the importance of, in this case, autogenic engineers such

as pine trees. Ryel et al. (1996) also found an increase of the spatial structure of soil water content from spring to summer in a sagebrush-wheatgrass steppe. The increased soil moisture found under the pine canopy in the summer sampling may be an effect of lower soil evaporation, which is caused by the protection of the canopy. However, it may be also indicating hydraulic lift, as was found for other pine species (e.g., Filella and Peñuelas 2003). This process

stimulates microbial activity, and it may also explain the higher MB-N, DON and extractable-P found beneath the pine canopy in the summer samples as compared with the winter ones. The lack of a similar pattern for the  $\text{NH}_4\text{-N}$  could be due to the fast recycling of this resource motivated by an active uptake by plants, as we discussed above.

We expected that differences in diffusion rates between sandy and loamy soils would affect the spatial distribution of soil  $\text{NO}_3\text{-N}$ . A higher diffusion rate should lead to a higher spatial range, i.e., the distance at which soil  $\text{NO}_3\text{-N}$  is autocorrelated. Because the diffusion rate is an explicit spatial phenomenon, we also expected a higher spatial dependence in sandy soils than in loamy ones. However, only in summer were both the spatial range and spatial dependence highest in the sandy soil. In the winter samples, only the spatial dependence was highest in the sandy soil. The decrease in the  $\text{NO}_3\text{-N}$  spatial range in winter may be related to losses of  $\text{NO}_3\text{-N}$  through percolation under high water content, in contrast with the summer soil conditions.

The spatial dependence found in this study was highly variable across soil variables, soil texture, and sampling dates, but with value ranges similar to other work. For example, Jackson and Caldwell (1993), using a similar sampling design, found spatial dependence between 34% and 93% for different soil variables. Spatial dependence was more variable in the sandy soil than in loamy soil, perhaps reflecting that differences in the diffusion ability of nutrient should be more significant in sandy soil. The spatial range found in our study was similar to those found by other authors working at the same spatial scale (Lechowicz and Bell 1991; Gross et al. 1995; Gallardo and Paramá 2007). These authors suggested that this fine-scale heterogeneity was derived from the effects of individual plants on nutrient availability through differences in stemflow, throughflow, litter-fall, or litter decomposition. However, our results only detected the individual effect of trees in one of the temporal replicates and in the sandy soil, indicating that other factors (such as texture, soil moisture, etc.) may be responsible for this fine scale heterogeneity.

Although we believe that soil water content may help explain differences in the spatial patterns between summer and winter soil samples, caution is required because our temporal replicates were done on nearby but different pine individuals. In addition,

handling a high number of soil samples restricted us from collecting samples from more than one individual per soil type. The inconsistencies between replicate plots and the temporal changes observed by other authors in spatial patterns suggest that conclusions based on data from a single plot or at a single sampling date should be interpreted with care (Guo et al. 2002).

Our results suggested that the presence of *Pinus canariensis* individuals may be an important source of spatial heterogeneity in these forests. Soil texture may determine the magnitude of the pine canopy effect on the spatial distribution of chemical and biological soil properties when water content is scant, but it may have negligible effect under conditions of higher water availability. Knowledge of these spatial trends may help us to understand the ecosystem functioning. Therefore, more studies need to be done in different ecosystems to confirm the general validity of results found in this study.

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