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Soil macrofauna in relation to soil and leaf litter properties in tree plantations

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ABSTRACT: Soil communities exert strong influences on the processing of organic matter and nutrients. Plantations of trees, especially of nitrogen fixing ones, may affect the soil macrofauna through litter quality and quantity. This study was conducted in a randomized block design with three blocks consisting of *Populus euphratica*, *Eucalyptus camaldulensis*, *Eucalyptus microtheca*, *Acacia farnesiana*, *Acacia salicina*, *Acacia saligna*, *Acacia stenophylla* and *Dalbergia sissoo* monoculture plantations that were established in 1992. Soils and soil macrofauna were sampled in November 2006. Leaf litterfall was collected from November 2006 to November 2007 at bi-weekly intervals. Macroinvertebrate abundance and biomass were consistently higher in *A. salicina* plantations than in the others, whereas they were lowest in *E. camaldulensis*. Tree species and nitrogen fixing trees significantly influenced the soil macrofauna richness. The results suggest that the earthworm distribution is regulated by leaf litter quality (Ca, C and N) whereas the macrofauna richness is regulated by leaf litter mass, soil organic carbon and leaf litter Mg. Totally, it was revealed that the tree species clearly affected macrofauna whereas nitrogen fixation did not.

Keywords: plantation; tree influence on soil; soil macrofauna; leaf litter properties; nitrogen-fixing tree

Soil communities exert strong influences on the processing of organic matter and nutrients (Binkley 1996). Soil faunal activity could improve soil physiochemical properties (Barrios 2007). The studies in the tropics have demonstrated the important role of soil fauna in the regulation of plant litter decomposition (Warren, Zou 2002) and nutrient release (Pellen, Garay 1999). Litter feeding organisms accelerate N mineralization in temperate, deciduous woodlands (Anderson et al. 1985). Earthworms constitute the largest part of invertebrate biomass in most soils (Sinha et al. 2003; Tondoh et al. 2007). The activity of these organisms influences soil processes that control the availability of plant nutrients such as nitrogen (Zou, Bashkin 1998) and also affect organic matter dynamics (Reich et al. 2005; Barrios 2007). Furthermore, soil and litter arthropods can be useful bioindicators of the effects of land management on nutrient dynamics and site productivity (Bird et al. 2004).

At the local level, soil properties (Mathieu et al. 2004) and litter quality and quantity (Zou 1993; Zou, Bashkin 1998; Warren, Zou 2002; Aubert et al. 2003; Negrete-Yankelevich et al. 2008) are the most important factors that regulate macroinvertebrate communities (Tsukamoto, Sabang 2005). Warren and Zou (2002) concluded that soil macroinvertebrates were associated with litter quality more than with litter quantity in Puerto Rico. Tree species rich in calcium were associated with increased native earthworm abundance and diversity, as well as with increased soil pH, exchangeable calcium, percent base saturation and forest floor turnover rate (Reich et al. 2005).

Biologically, higher plants affect the life of almost all the organisms (Antunes et al. 2008). The stud-

ies from temperate systems, besides the evidence available from the tropics, indicate that the litter quality and quantity of plantation species may affect soil macrofauna populations (Warren, Zou 2002). The information like this is rare in drylands. Hence, in order to manage dryland tree plantations in a sustainable manner, the knowledge of the characteristics of soil macrofauna established under drastically changed environments is of particular importance (Tsukamoto, Sabang 2005).

Nitrogen fixing tree species increase soil nitrogen and carbon and accelerate the nutrient cycle rate (Binkley, Giardina 1998; Garcia-Montel, Binkley 1998) and probably reduce other nutrients (Binkley, Giardina 1998). It was demonstrated that differences in species properties such as N content of litterfall were moderate and they were the largest when nitrogen fixing species were included in the comparison (Binkley, Giardina 1998). Consequently, it seems that nitrogen fixing trees could have a different influence on soil macrofauna in comparison with non-nitrogen fixing trees. Zou (1993) and Warren and Zou (2002) showed that nitrogen fixing trees heavily influence soil macrofauna in comparison with non-nitrogen fixing trees.

Two basic questions were asked by Binkley (1996): To what extent do the soil communities differ under different tree species? How does the composition of the soil community relate to overall soil biogeochemistry? Moreover, our understanding of the generality of effects of nitrogen fixing trees in comparison with non-nitrogen fixing trees on soil macrofauna remains incomplete. In line with these questions the aims of this experiment were to assess the soil macrofauna under different tree species and especially to compare it under nitrogen fixing trees and non-nitrogen fixing trees. Furthermore, to investigate the soil macrofauna relations with soil and leaf litter properties. A common garden experiment with eight tree plantations in southwestern Iran that included three nitrogen fixing trees and five non-nitrogen fixing trees was a good opportunity to test these hypotheses.

MATERIAL AND METHODS

Study site

The research was carried out in the Dez river floodplain in southwestern Iran (32°24'N, 48°25'E, Fig. 1). Experimental plots were located at an altitude of 143 m above sea level and at the level of the river. Annual rainfall average is about 325.8 mm (131.5–486.4 mm), with about 8-month dry season from April to November. Flood commonly occurs once a year in the area of the plantation and it occurred during May 2006. Average monthly temperatures range from 11.6°C to 35.9°C. The soil type of study site according to US Soil Taxonomy Classification is Entisols (Soil Survey Staff 2006).

Fig 1. The map of the study area and experimental plot layout. Plot treatment codes: (A) *Populus euphratica*, (B) *Eucalyptus camaldulensis*, (C) *E. microtheca*, (D) *Acacia farnesiana*, (E) *A. salicina*, (F) *A. saligna*, (G) *A. stenophylla*, (H) *A. victoriae*, (I) *Dalbergia sissoo*, (J) *Leucaena leucocephala*

The monoculture plantations were established in a randomized complete block design in a deforested land with three blocks along the river in 1992 (Fig. 1). Tree spacing within plantations was 3 m × 3 m on 27 m × 30 m plots. The experiment included ten species at the beginning that were replicated in each block. The species were *Populus euphratica*, *Eucalyptus camaldulensis*, *E. microtheca*, *Acacia farnesiana*, *A. salicina*, *A. saligna*, *A. stenophylla*, *A. victoriae*, *Dalbergia sissoo*, and *Leucaena leucocephala*. The first three species are non-nitrogen fixing trees and the others are nitro-

Table 1. Survival, height and diameter of tree species in the plantations. The values are means

Plantations	Diameter (cm)	Height (m)	Survival (%)
P. euphratica	12	11.35	57.77
E. camaldulensis	28	18.45	92.22
E. microtheca	24	12.96	89.25
A. farnesiana	6	6.65	89.99
A. saligna	11	7.95	47.96
A. stenophylla	12	9.35	77.40
A. salicina	16	13.80	86.29
D. sissoo	24	13.70	76.66

gen fixing trees. In 2006, *L. leucocephala* and *A. victoriae* had not enough surviving trees and the study was carried out with the remaining species. The mean survival, height and diameter of the eight planted species are shown in Table 1.

Soil macrofauna

Soil macrofauna was collected by hand sorting using a randomly located 0.25 m^2 sampling frame, and two subsamples were taken per plot (one composite sample per plot × 3 blocks × 8 tree species = 24 samples). All macroinvertebrate organisms (macroscopic organisms) in litter and mineral soil were collected to a depth of 25 cm. Soil was excavated as quickly as possible and placed on a big dish. The numbers of organisms were counted and the fresh weight biomass for each individual was determined on the day of collection by rinsing the organism, drying on absorbent paper, and weighing (Warren, Zou 2002). The organisms were identified to the order and class level. Macrofauna was sampled in November 2006.

Soil

Soils were sampled to a depth of 25 cm on each plot in November 2006 using a 7.6 cm diameter core sampler after removing the litter layer. Composite samples including five subsamples (one at the centre and four in the corners) on each plot were collected (one composite sample on each plot × 3 blocks × 8 tree species = 24 samples). All soil samples were air-dried and sieved through 2-mm mesh screens. The pH of the mineral soil was determined in a soil:water suspension (1:1 w/v) using a glass electrode. Soil organic matter was determined by means of wet oxidation (Walkley and Black method). Total N was determined by the Kjeldahl method. Available P was determined with a spectrophotometer using the Olsen method. Available K, Ca and Mg were determined with an atomic absorption spectrophotometer (Burt 2004).

Leaf litterfall

Leaf litterfall was collected from the beginning of November 2006 and extended to November 2007 at bi-weekly intervals. Two leaf litter traps, each of 0.25 m^2, were randomly arranged on each plot. Each trap consisted of 2-mm mesh nylon netting (on a wooden frame) suspended from a wire hoop and held 20 cm above the ground. Composite samples for each plot, comprising leaf litter collected over one year, were used for nutrient analyses (one composite sample on each plot × 3 blocks × 8 tree species = 24 samples). Leaf litter was dried at 65°C and ground prior to the analysis of nutrients. Carbon was assumed to be 45% of the ash-free dry mass. Nitrogen was analyzed using the Kjeldahl method, P using a spectrophotometer (by the Olsen method), and K, Ca and Mg were determined using an atomic absorption spectrophotometer after ashing (6 h at 450°C) and dissolving in HCl (Ribeiro et al. 2002).

Statistical analyses

Several diversity descriptors were calculated from the number and abundance of orders and classes of soil macrofauna in each tree plantation, namely richness (Margalef and Menhinick), diversity (Shannon H) and evenness (Sheldon) indices. These indices were calculated in PAST version 1.39. General linear model analyses of variance (ANOVA) were used to compare abundance and biomass of organisms, soil and leaf litter properties and diversity indices between tree plantations. Duncan's

Table 2. Soil macrofauna abundance in the plantations of the tree species (the values are mean (S.E.))

Plantations	Soil macrofauna						
	Chilopoda	Formicidae	Isopoda	Araneae	Coleoptera	Collembola	Gastropoda
P. euphratica	0 (0.0)	1.33 (1.33)	5.33 (2.30)	5.33 (2.66)	5.33 (12.22)	5.33 (3.52)	4 (1.33)
E. camaldulensis	0 (0.0)	0 (0.0)	4 (2.30)	1.33 (1.33)	2.66 (1.33)	6.66 (3.53)	4 (0.0)
E. microtheca	1.33 (1.33)	6.66 (4.80)	14.66 (1.33)	5.33 (1.33)	14.66 (8.11)	13.33 (7.42)	8 (6.11)
A. farnesiana	0 (0.0)	0 (0.0)	5.33 (3.52)	0 (0.0)	2.66 (2.66)	1.33 (1.33)	6.66 (2.66)
A. saligna	1.33 (1.33)	1.33 (1.33)	17.33 (4.80)	1.33 (1.33)	8 (8)	4 (4)	8.13 (2.67)
A. stenophylla	0 (0.0)	1.33 (1.33)	17.33 (3.53)	0 (0.0)	41.33 (18.66)	10.66 (2.66)	0 (0.0)
A. salicina	1.33 (1.33)	0 (0.0)	21.33 (17.49)	1.33 (1.33)	20 (12.86)	2.66 (2.66)	0 (0.0)
D. sissoo	0 (0.0)	0 (0.0)	16 (3.52)	0 (0.0)	10.66 (5.81)	2.66 (2.66)	4 (4)

Table 3. Abundance and biomass of soil macrofauna in the plantations of the tree species (the values are mean (S.E.)[a, c])

	ANOVA[b]	Non-NFT	NFT	ANOVA[b]	*D. sissoo*	*A. salicina*	*A. stenophylla*	*A. saligna*	*A. farnesiana*	*E. microtheca*	*E. camaldulensis*	*P. euphratica*
Abundance (individuals·m^{-2})												
Earthworms	ns	40.4 (10.10)	77.3 (15.40)	**	104.0^{ab} (29.48)	161.3^{a} (15.02)	54.7^{bc} (24.91)	28.0^{c} (11.55)	38.7^{c} (18.52)	57.3^{bc} (19.64)	14.7^{c} (14.66)	49.3^{bc} (10.41)
Arthropods	ns	34.2 (9.78)	37.9 (8.14)	ns	29.3 (13.13)	46.7 (29.78)	70.7 (11.39)	33.3 (9.61)	9.3 (2.66)	56.0 (18.90)	14.7 (5.81)	32.0 (18.04)
Total	ns	79.80 (15.23)	118.9 (19.33)	**	137.3^{ab} (41.33)	208.0^{a} (44.60)	125.3^{ab} (33.38)	69.5^{bc} (24.26)	54.7^{bc} (13.92)	121.3^{abc} (23.24)	33.3^{c} (9.61)	85.3^{bc} (13.90)
Biomass (g·m^{-2})												
Earthworms	ns	8.0 (2.22)	11.7 (2.28)	**	13.7^{b} (3.27)	25.1^{a} (3.40)	7.1^{bc} (2.78)	5.1^{bc} (2.13)	7.3^{bc} (3.85)	10.4^{bc} (4.39)	1.3^{c} (1.33)	12.4^{b} (1.89)
Arthropods	ns	1.44 (0.48)	1.89 (0.78)	ns	1.1 (0.31)	2.2 (1.50)	1.1 (0.24)	4.6 (3.66)	0.5 (0.37)	1.8 (1.01)	1.6 (1.18)	0.9 (0.34)
Total	ns	10.1 (2.43)	14.3 (2.35)	*	15.3^{b} (3.83)	27.3^{a} (2.06)	8.1^{b} (3.01)	11.6^{b} (5.88)	9.3^{b} (3.39)	13.0^{b} (5.02)	3.6^{b} (2.97)	13.8^{b} (2.11)

[a]different letters following values within a row indicate the differences based on Duncan, [b]ANOVA – analysis of variance results were used for comparison of eight trees and the two groups, respectively, ns – treatment effect not significant, $^{*}P < 0.05$, $^{**}P < 0.01$, [c]NFT – nitrogen fixing tree (the five last trees), Non-NFT – non-nitrogen fixing tree (the first three trees)

procedure was used to separate the means of dependent variables which were significantly affected by treatments. The Pearson correlations were used for finding the relationships of soil macrofauna abundance, biomass and diversity descriptors with soil and leaf litter properties. Normality and homogeneity of variance of the data were checked for all analyses. All statistical analyses were done using SAS 9 software.

RESULTS

The main soil macrofauna in all the plantations was earthworm (Oligochaeta). Arthropods were also common. Formicidae, Coleoptera, Collembola, Araneae, Chilopoda, Isopoda. and Gastropoda were found (Table 2).

For the statistical analysis, the first six taxa were grouped as "arthropods" and all of them plus earthworm as "total" due to their relatively low abundance and biomass. The average of soil macroinvertebrate abundances and biomass (total in Table 3) were consistently higher in *A. salicina* plantations than in the other tree plantations, while they were lowest in *E. camaldulensis* plantations (Table 3). The abundance and biomass of arthropods did not show any significant differences ($P < 0.05$), although great differences appeared among the plantations. The earthworm abundance and biomass showed significant differences between different tree species ($P = 0.002$ and $P = 0.003$, respectively) (Table 3). It should be considered that the earthworm abundance and biomass under *E. camaldulensis* was the lowest.

The comparison of soil macrofauna abundance and biomass between the two groups of tree plantations, nitrogen fixing trees and non-nitrogen fixing trees, showed higher mean values in the nitrogen fixing tree plantations, but did not show any significant differences. For example the earthworm abundance averaged 77.3 and 40.4 individuals·m^{-2} under nitrogen fixing trees and non-nitrogen fixing trees, respectively. This might be a result of considerable soil macrofauna variance (Table 3).

Shannon H, Margalef and Sheldon indices did not significantly differ among the tree plantations. The Menhinick richness index was significantly ($P = 0.047$) higher in *E. camaldulensis* and *E. microtheca* plantations than in *A. salicina*. Nitrogen fixing tree plantations had significantly higher richness (Menhinick and Margalef) than non-nitrogen fixing trees. Diversity and evenness were not significantly different between nitrogen fixing trees and non-nitrogen fixing tree plantations (Table 4).

Fourteen years after the plantations were established, all the studied soil properties significantly differed ($P = 0.01$) among the plantations, except the soil pH. Under non-nitrogen fixing trees soil organic carbon, C/N ratio, available K and Ca were higher than under nitrogen fixing trees (Table 5),

Table 4. Soil macrofauna diversity, richness and evenness in the plantations of the tree species (the values are mean (S.E.)[a, c])

	ANOVA[b]	Non-NFT	NFT	ANOVA[b]	*D. sissoo*	*A. salicina*	*A. stenophylla*	*A. saligna*	*A. farnesiana*	*E. microtheca*	*E. camaldulensis*	*P. euphratica*
Shannon H	ns	1.17 (0.13)	0.89 (0.11)	ns	0.70 (0.27)	0.57 (0.24)	1.18 (0.11)	1.18 (0.30)	0.80 (0.21)	1.43 (0.14)	1.05 (0.26)	1.04 (0.26)
Menhinick	**	1.2 (0.09)	0.79 (0.08)	*	0.59^{bc} (0.12)	0.53^{c} (0.10)	0.84^{abc} (0.18)	1.05^{abc} (0.21)	0.95^{abc} (0.14)	1.15^{ab} (0.05)	1.38^{a} (0.28)	1.08^{abc} (0.04)
Margalef	**	1.4 (0.12)	0.87 (0.1)	ns	0.67 (0.19)	0.59 (0.15)	1.02 (0.19)	1.15 (0.36)	0.93 (0.15)	1.56 (0.17)	1.40 (0.32)	1.31 (0.12)
Evenness e^H/S (Sheldon)	ns	0.70 (0.07)	0.70 (0.03)	ns	0.64 (0.04)	0.56 (0.05)	0.76 (0.03)	0.83 (0.04)	0.71 (0.14)	0.70 (0.12)	0.81 (0.12)	0.59 (0.10)

[a]different letters following values within a row indicate the differences based on Duncan, [b]ANOVA – analysis of variance results were used for comparison of eight trees and the two groups, respectively, ns – treatment effect not significant, *$P < 0.05$, **$P < 0.01$, [c]NFT – nitrogen fixing tree (the five last trees), Non-NFT – non-nitrogen fixing tree (the first three trees)

Table 5. Soil properties in the plantations of the tree species (the values are mean (S.E.)[a, c])

	ANOVA[b]	Non-NFT	NFT	ANOVA[b]	*D. sissoo*	*A. salicina*	*A. stenophylla*	*A. saligna*	*A. farnesiana*	*E. microtheca*	*E. camaldulensis*	*P. euphratica*
Soil pH	ns	7.92 (0.03)	8.00 (0.05)	ns	7.97 (0.03)	7.99 (0.02)	7.87 (0.03)	8.21 (0.15)	7.96 (0.01)	7.94 (0.06)	7.85 (0.01)	7.97 (0.01)
Organic carbon (%)	*	2.5 (0.2)	2.0 (0.1)	**	1.5^{d} (0.2)	2.5^{ab} (0.1)	1.9^{d} (0.1)	1.5^{d} (0.2)	2.4^{bc} (0.1)	2.0^{cd} (0.2)	2.5^{ab} (0.1)	3.0^{a} (0.2)
Total nitrogen (%)	ns	0.081 (0.004)	0.085 (0.006)	**	0.057^{c} (0.004)	0.108^{a} (0.005)	0.080^{bc} (0.010)	0.073^{bc} (0.011)	0.106^{a} (0.007)	0.067^{bc} (0.007)	0.085^{ab} (0.005)	0.091^{ab} (0.008)
C/N ratio	**	31 (1)	24 (1)	**	27^{bc} (1)	23^{c} (0)	24^{c} (3)	21^{c} (1)	23^{c} (1)	30^{ab} (3)	30^{ab} (2)	32^{a} (1)
P (mg·kg^{-1})	ns	3.9 (0.9)	3.6 (0.5)	**	5.8^{ab} (0.4)	1.8^{c} (0.2)	2.7^{c} (0.6)	2.3^{c} (0.5)	5.2^{ab} (1.5)	3.8^{bc} (1.4)	6.5^{a} (0.9)	1.5^{c} (0.2)
K (mg·kg^{-1})	**	159 (20)	105 (6)	**	78^{d} (9)	128^{bc} (5)	123^{bc} (7)	106^{cd} (6)	91^{d} (6)	230^{a} (15)	149^{b} (15)	99^{cd} (6)
Ca (mg·kg^{-1})	**	1,475 (92)	934 (74)	**	832^{d} (33)	$1,059^{c}$ (23)	$1,373^{b}$ (77)	567^{e} (20)	840^{d} (46)	$1,259^{b}$ (45)	$1,828^{a}$ (12)	$1,337^{b}$ (67)
Mg (mg·kg^{-1})	ns	556 (60)	544 (85)	**	253^{de} (48)	$1,044^{a}$ (39)	720^{b} (8)	177^{e} (19)	524^{c} (14)	340^{d} (7)	712^{b} (74)	616^{bc} (11)

[a]different letters following values within a row indicate the differences based on Duncan, [b]ANOVA – analysis of variance results were used for comparison of eight trees and the two groups, respectively, ns – treatment effect not significant, *$P < 0.05$, **$P < 0.01$, [c]NFT – nitrogen fixing tree (the five last trees), Non-NFT – non-nitrogen fixing tree (the first three trees)

whereas soil pH, total N, P and Mg were not significantly different between the two groups (Table 5).

All the studied leaf litter properties and leaf litter mass were significantly different ($P = 0.01$) among tree plantations. The comparison of leaf litter mass and properties of nitrogen fixing trees with non-nitrogen fixing trees showed that the nitrogen fixing trees had significantly lower mass, carbon, C/N ratio and potassium and higher total nitrogen. Other properties (P, Ca and Mg) were not significantly different (Table 6).

The abundance of earthworms and total soil macrofauna were correlated only significantly ($P < 0.05$) with leaf litter ash (ash has a negative correlation with carbon) and calcium. Earthworm and total soil macrofauna biomass were also significantly correlated ($P < 0.05$) with these properties. Soil macrofauna evenness and diversity indices were not significantly correlated with soil and litter properties while among richness indices the Menhinick index was positively correlated with leaf litter mass (Fig. 2).

DISCUSSION

Looking at the results of earthworm abundance showed that its variations led to differences in total soil macrofauna as it is the main soil macrofauna. Warren and Zou (2002) did not find any differences in earthworm populations under different planted species whereas Wardle and Lavelle (1997) reported an effect of individual tree species on earthworm distribution in a French Guianan forest. Hence, the food preference of earthworms may be an important regulatory factor. The occurrence of the large number and biomass of soil macrofauna (especially earthworms) on *A. salicina* plots may be due to higher litter palatability. The number and biomass of earthworms and total soil macrofauna increased with leaf litter calcium and decreased with leaf litter carbon in the plantations. Therefore, as *A. salicina* had the highest leaf litter calcium and the lowest carbon, it had the highest earthworm abundance and biomass. The results

Table 6. Leaf litter mass and characteristics of different species in the plantations (the values are mean (S.E.) [a, c])

	ANOVA[b]	Non-NFT	NFT	ANOVA[b]	*D. sissoo*	*A. salicina*	*A. stenophylla*	*A. saligna*	*A. farnesiana*	*E. microtheca*	*E. camaldulensis*	*P. euphratica*
Mass ($t \cdot ha^{-1} \cdot year^{-1}$)	*	12.2 (1.3)	7.6 (1.1)	**	8.6^{bc} (2.7)	6.4^{c} (1.6)	6.4^{c} (0.7)	13.1^{ab} (2.3)	3.4^{c} (0.4)	13.0^{ab} (1.6)	15.2^{a} (2.3)	8.5^{bc} (1.3)
Carbon (%)	**	40.6 (0.4)	38.6 (0.4)	**	38.6^{d} (0.1)	35.8^{e} (0.6)	39.6^{bc} (0.3)	38.7^{cd} (0.3)	40.3^{b} (0.5)	41.2^{a} (0.3)	41.4^{a} (0.3)	39.2^{cd} (0.3)
Total nitrogen (%)	**	0.959 (0.051)	1.563 (0.136)	**	1.588^{b} (0.046)	1.550^{b} (0.066)	1.083^{c} (0.005)	1.113^{c} (0.000)	2.483^{a} (0.084)	1.087^{c} (0.044)	0.856^{d} (0.106)	0.934^{cd} (0.063)
C/N ratio	**	43 (0)	27 (0)	**	24^{c} (1)	23^{cd} (1)	37^{b} (1)	35^{b} (0)	16^{d} (1)	38^{b} (2)	50^{a} (5)	42^{ab} (3)
P ($mg \cdot g^{-1}$)	ns	3.6 (0.1)	3.4 (0.2)	**	3.7^{b} (0.1)	3.6^{bc} (0.1)	2.7^{d} (0.1)	2.6^{d} (0.0)	4.2^{a} (0.3)	3.9^{ab} (0.1)	3.2^{c} (0.0)	3.6^{bc} (0.1)
K ($mg \cdot g^{-1}$)	**	7 (1)	4 (1)	**	3^{de} (0)	7^{ab} (1)	4^{cde} (0.9)	1^{e} (0)	5^{bcd} (1)	6^{abc} (1)	7^{ab} (1)	8^{a} (2)
Ca ($mg \cdot g^{-1}$)	ns	53 (7)	59 (10)	**	96^{a} (2)	102^{a} (9)	50^{c} (7)	37^{c} (5)	11^{d} (2)	46^{c} (5)	36^{c} (10)	76^{b} (4)
Mg ($mg \cdot g^{-1}$)	ns	4 (0)	4 (1)	**	6^{a} (1)	3^{c} (0)	4^{b} (0)	5^{ab} (0)	2^{c} (0)	3^{c} (0)	3^{c} (1)	5^{b} (0)

[a]different letters following values within a row indicate the differences based on Duncan, [b]ANOVA – analysis of variance results were used for comparison of eight trees and the two groups, respectively, ns – treatment effect not significant, $^{*}P < 0.05$, $^{**}P < 0.01$, [c]NFT – nitrogen fixing tree (the five last trees), Non-NFT – non-nitrogen fixing tree (the first three trees)

of Reich et al. (2005) as well as ours showed the positive association of earthworm abundance with litter calcium. Zou and Bashkin (1998) found the high density of earthworms under *Eucalyptus* and concluded that it might be a result of insensitivity of earthworms to phenolics, or to phenolic adsorption by clay, or to the highest nutrient content of soil. While Mboukou-Kimbatsa et al. (2007) found no relationship between earthworm density and either litter phenolics or top soil phenolics. If we accept that the earthworm sensitivity to plant phenolics was the reason of the lowest earthworm abundance on *E. camaldulensis* plots, this question comes to mind: why was not the earthworm abundance in *E. microtheca* in the group with lowest abundance (c group based on Duncan, Table 3), whereas the earthworm abundances in *A. farnesiana* and *A. saligna* were in it? The answer could be found in other soil and leaf litter properties.

Although we did not find any other association with earthworm abundance and biomass besides leaf litter Ca and C, other soil and leaf litter properties might have an influence on them. As demonstrated (Table 5), soil nitrogen did not differ among *E. camaldulensis*, *E. microtheca*, *A. farnesiana*, and *A. saligna*, while leaf litter N (Table 6) was the lowest under *E. camaldulensis*. Hence, leaf litter N could be another factor regulating the earthworm abundance and biomass in these plantations. In order to statistically examine these results partial correlations were used. The partial correlations of earthworm abundance and biomass with leaf litter calcium while using leaf litter nitrogen as control (covariate) showed higher correlations ($R = 0.8863$ and $R = 0.8866$, respectively) and higher probabilities ($P = 0.008$ for both). Therefore leaf litter nitrogen is the third regulating factor of earthworm abundance and biomass in these plantations. In line with our results, Zou (1993) found a positive correlation of litterfall N with earthworm density. While Mboukou-Kimbatsa et al. (2007) stated that nitrogen release was weak during the decom-

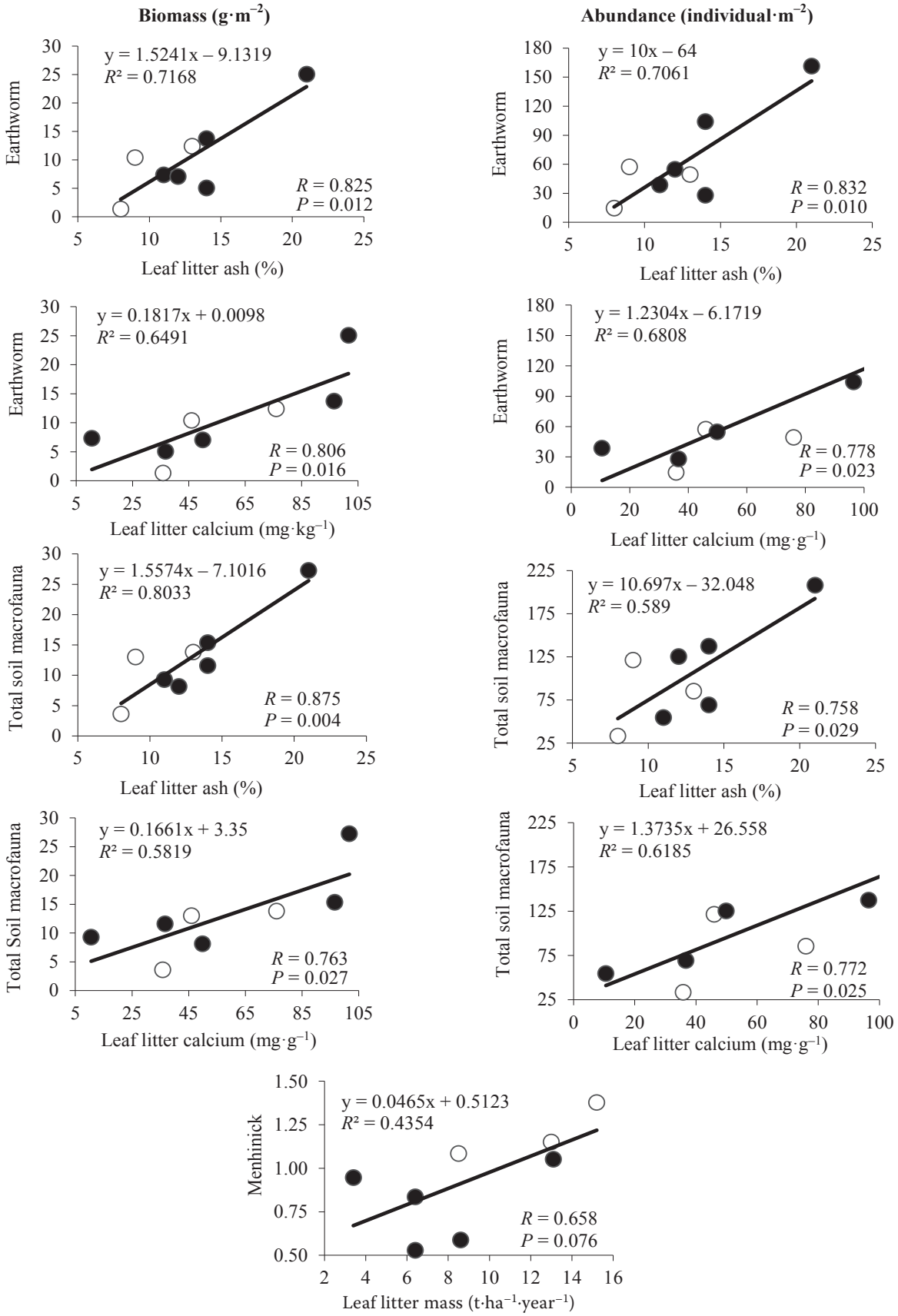

Fig. 2 Correlation of abundance, biomass and richness of soil macrofauna with litter mass, carbon and calcium are shown
● shows nitrogen fixin tree and ○ shows non-nitrogen fixin tree

position of *Eucalyptus* litter and the plantation soil was poor in nitrogen, thus nitrogen limitation might be one factor for the low earthworm density in Congolese *Eucalyptus* plantations.

Although we did not find any differences in soil macrofauna abundance and biomass of nitrogen fixing tree plantations in comparison with non-nitrogen fixing tree ones, *A. salicina* (as a nitrogen fixing tree species) had the highest soil macrofauna abundance and biomass (especially of earthworms) in comparison with other tree plantations, and *E. camaldulensis* (as a non-nitrogen fixing tree species) plantation had the lowest. The lack of differences between nitrogen fixing and non-nitrogen fixing groups could be explained by the high variation in the soil macrofauna abundance and biomass under the tree plantations of each group that results in the overlapping of some tree species of the two groups. Totally, the results of this section demonstrated the effect of tree species on soil macrofauna and the non-nitrogen fixing effect.

Scientists have long recognized that high levels of earthworm abundance are associated with faster plant litter decomposition in terrestrial ecosystems (Tsukamoto, Sabang 2005). Dechaine et al. (2005) believed that since earthworms compose the highest biomass among the tropical soil macrofauna, their role in plant litter decomposition may determine the structure and function of tropical forest. They also expressed an opinion that by reducing the earthworm number in tropical soils, decomposition rates of plant litter decreased. In addition to direct consumption, earthworms accelerate plant litter decomposition through elevating the soil microbial activity and enhancing the inoculation of soil microbes (Dechaine et al. 2005). Hence, since *A. salicina* had the highest earthworm abundance and biomass, it could be predicted that its litter decomposes faster than the litter of the species with the lowest earthworm abundance. It should be kept in mind that the litter decomposition is controlled by climate and litter quality besides the soil macrofauna (Barajas-Guzman, Avarez-Sanchez 2003). Attention must also be paid to the fact that we carried out the study in one season, while litter decomposition is a slow process that lasts for a long time.

Scientists have related the soil macrofauna richness to various sources and conditions of its environment. Microclimate variation, as a result of different canopy and root structures, can directly control the survival of organisms at all levels of the decomposer food-web (Negrete-Yankelevich et al. 2008). On the other hand, Pospiech and Skalski (2006) noted that higher concentrations of macro-elements (Ca, N and K) in soil, together with the height of herbaceous plants, beneficially affected the community richness. Aubert et al. (2003) pointed out in another research that the difference in soil macrofauna at the stand level in a beech forest depends on litter quality. Additionally, temperature and C/N ratio are abiotic factors with the greatest influence on the variation of taxa abundance and presence/absence among sites (Antunes et al. 2008). Although we did not find a significant correlation of macrofauna richness with soil and leaf litter properties, richness showed its highest correlation ($R = 0.076$) with leaf litter mass. The results of partial correlations of macrofauna richness with leaf litter mass while using soil organic carbon and leaf litter Mg as control (covariate) showed higher correlations ($R = 0.858$ and $R = 0.805$, respectively) and significant higher probabilities ($P = 0.014$ and $P = 0.029$, respectively). Leaf litter mass and soil organic carbon positively and leaf litter Mg negatively affected the soil macrofauna richness. Therefore, we could relate the higher richness of orders and classes of macrofauna in non-nitrogen fixing tree plantations to higher leaf litter mass and soil organic carbon. Higher richness in the *E. camaldulensis* and *E. microtheca* plantations in comparison with *A. salicina* could also be related to leaf litter mass, soil organic carbon and leaf litter Mg. In contrast to our results, Pellen and Garay (1999) found that the richness of big arthropods was higher under *Acacia mangium* in comparison with *E. grandis* in the drier season and related it to more litter under *Acacia*; whereas we found more leaf litter under non-nitrogen fixing trees, especially *E. camaldulensis*. These results implied that nitrogen fixing did not have any effect on soil macrofauna richness and soil macrofauna richness is regulated by leaf litter mass, soil organic carbon and leaf litter Mg. Whereas Reich et al. (2005) reported a lower number of taxa under *Eucalyptus* and related it to high levels of phenolic compounds in its leaves.

The soil and litter properties did not differ to such an extent to make these plantations able to support different evenness and consequently diversity. Antunes et al. (2008) also drew a similar conclusion for the lack of differences in evenness and diversity in different vegetation cover.

The results from our study suggest that the tree species clearly affected the soil macrofauna whereas nitrogen fixation did not. But the effect of nitrogen fixation on macrofauna should not be denied and needs more researches. It also revealed that the

distribution of earthworms is regulated by leaf litter quality (Ca, C and N) whereas the macrofauna richness is regulated by leaf litter mass, soil organic carbon and leaf litter Mg. Since the soil macrofauna is an important factor regulating the litter decomposition, further studies are recommended on the relationship of soil macrofauna abundance and richness with litter decomposition. As our study was conducted in one season, additional researches in different seasons are still necessary to elucidate the influence of seasonal variation on soil macrofauna.

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