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Soil Nitrogen Mineralization under a *Eucalyptus* Plantation and a Natural *Acacia* Forest in Senegal

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ABSTRACT

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In-vitro and in-situ N mineralization were studied in a natural *Acacia seyal* stand and in a *Eucalyptus camaldulensis* plantation in Senegal.

Mineralizable N, measured by 20 days in-vitro incubations, averaged 40-50 ppm in *Acacia* soil and 11-14 ppm in *Eucalyptus* soil, and reached 3.5 and 2.3%, respectively, of total N. The coarse light fractions (>0.2 mm) of *Eucalyptus* soil organic matter did not produce any mineral N; about 80% of the mineral N was supplied by the organo-mineral fraction, as against 30-50% in *Acacia* soil.

In-situ mineralization was related to precipitation, and ranged from 18 to 40 ppm over 4 weeks during the rainy season in the *Acacia* stand where 7-10% of total N was mineralized each year. Under *Eucalyptus*, N mineralization reached only 10 ppm over 3 weeks in the beginning of the rainy season and then decreased sharply. It was assumed that this decrease was related to a depressive effect of herbaceous root growth, the possible processes of which are discussed.

INTRODUCTION

Most tropical soils have a low nitrogen content. A lot of research has been done and is still being carried out to understand N cycling in agricultural soils (Berg et al., 1980). Few data are, however, available for the native vegetation of the semi-arid zone (Jung, 1969; Wetselaar, 1980; Pereira, 1982).

The cycling of N in forest plantations arouses particular interest because these are generally established on poor soils, and fertilizer input has not come into general use (Nwoboshi, 1980; Zech and Weinstable, 1983).

In Senegal, *Eucalyptus* plantation programmes started several years ago. A former study (Bernhard-Reversat, 1987) pointed out the overall decrease in N level in the soil-plant system following soil perturbation and organic matter disappearance, and the establishment of a fast-growing species with low N content. The low level of N cycling suggested the possible occurrence of de-

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creased N mineralization in soil. *Eucalyptus* and other related species were also reported to interfere with soil microbial processes (Pochon et al., 1959; Boquel and Suavin, 1972).

In order to compare mineral N production and N cycling of native stands and *Eucalyptus* plantations, N mineralization measurements were carried out in situ during the rainy season, and potential N mineralization was studied in the laboratory.

SITE DESCRIPTION AND METHODS

Site

The site of Keur Maktar has been previously described (Bernhard-Reversat, 1986). On a long-term basis (more than 30 years) the climate is representative of the Soudano-Sahelian zone: mean annual rainfall is 800 mm and the rainy season, 4–5 months long, is from June to October. However, during the study period 1981–1983, annual rainfall averaged 460 mm and the length of the rainy season was reduced to about 3 months, so that the climate characteristics were those of the Sahelian zone.

The soil was a weathered ferruginous tropical soil, according to the French classification (Jamet and Rieffel, 1976), with a sandy texture.

Natural vegetation is wooded savanna with localized increased tree density resulting in a forest environment. In such densely wooded areas the tree layer is mainly *Acacia seyal*; the undergrowth consists of a monospecific stratum of a herbaceous compositae, *Blainvillea gayana*. The *Acacia* forest plot studied was set in this type of vegetation.

The plantation of *Eucalyptus camaldulensis* studied was planted in 1973–1974 on a nearby site where the forest was clear-felled. Trees were planted 3.5 m apart. The herbaceous undergrowth, mainly graminae, was dominated by *Andropogon gayanus*. Annual standing herbaceous crop was related to annual precipitation, being greatest during years of higher rainfall.

The two stands were both on a gentle slope, the forest site near the top and the plantation downward. Some differences in soil characteristics, such as clay content which varies from 2% in the plantation to 7% in the forest, might be related to topography.

Soil characterization

Mean organic C and total N content of soil was measured on ten replications sampled with an auger to 60 cm depth, and divided into 0–10 cm, 10–20 cm, 20–40 cm and 40–60-cm layers.

Carbon and N content were also determined on soil samples used for in-situ N mineralization studies.

Mineralizable N

Mineralizable N was measured on the 0–10-cm and 10–20-cm layers of the ten replications sampled for soil characterisation, at the end of the dry season 1980, and on 0–10-cm soil samples collected at 4-week intervals with two replications during the rainy season 1980. In 1982 and 1983, mineralizable N was measured on samples collected for in-situ mineralization studies.

Soil samples were air-dried. Mineralizable N was measured after 20 days in-vitro incubations at 32°C, on 70 g of soil in 250-ml conic flasks where soil humidity was kept to 7% by adding distilled water twice a week.

Mineralizable N was also measured in soil organic matter granulometric fractions. Surface soil (0–1 cm) including litter was separated in five fractions, and top-soil (0–10 cm) in three fractions excluding litter. The following sizes were obtained:

0–1-cm layer		*0–10 cm layer*
>4 mm 0.5–4 mm 0.2–0.5 mm 0.05–0.2 mm	light fractions	0.2–2 mm 0.05–0.2 mm
<0.05 mm	organo-mineral	<0.05 mm

Fractions were done according to Feller (1979). The separation of the litter at 2 or 4 mm was made by dry-sieving. Separations at 0.5, 0.2 and 0.05 mm were made by sieving in water; after each sieving a gentle stirring in water allowed organic matter to separate from mineral soil by flotation. After the last sieving at 0.05 mm the organo-mineral fraction was separated from water by centrifugation. Each fraction was incubated separately, as described previously (Bernhard-Reversat, 1981).

In-situ N mineralization

In-situ mineralization was measured in the 0–10-cm layer of soil, in 56-mm diameter PVC tubes with a 250-μm mesh sieve bottom excluding root growth, and covered to prevent leaching. Lateral holes in the tubes under the cap allowed air circulation. In 1981 four replicates from two composite soil samples (four initial samples for each) were set in each stand. In 1982, eight replicates from one composite sample (ten initial samples) were shown to give more reliable results. The tubes were filled to 10 cm with fresh soil after taking out all visible roots, and were set vertically in the 0–10-cm layer of soil, for a 4-week incubation period. Because of high rainfall variability, soil humidity was also highly variable, and a major shortcoming of this method was the possible difference of humidity inside versus outside the tubes.

In 1983 a weeding experiment was carried out in the *Eucalyptus* plantation. Three plots, 7×10 m each, were manually weeded as needed to prevent herbaceous growth. In each plot, N mineralization was measured on two replications from one composite sample (three initial samples) and compared to three places where grass was allowed to grow naturally.

Chemical determination

Organic C was analysed in a Carmhograph Wosthoff dry combustion analyzer, and total N after Kjeldal digestion in an autoanalyser with indophenol blue (Berthelot), according to the methods used in the ORSTOM analysis laboratory (Paycheng, 1980).

Nitrate N was analysed according to Bremner (1965) and determined colorimetrically with phenol-disulfonic acid after extraction in 2.5 g l^{-1} $CuSO_4$/ 0.6 g l^{-1} $AgSO_4$ solution.

Ammoniacal N was extracted in NaCl solution (10% at pH 2.5) and determined as for total N.

RESULTS

Soil characterisation

The largest differences in organic C and total N appeared in the topsoil, and below 40 cm (Table 1). The C:N ratio ranged from 14 to 15 in the whole profile of the two stands.

Mineralizable nitrogen

A first estimate of the amount of mineralizable N was obtained from ten samples collected in the dry season (Table 2). Results showed a higher mineralization rate in the *Acacia* forest soil. In both stands, mineralization occurred mainly in the 0–10-cm layer and was lower in the 10–20-cm layer. The correlation coefficient between total N and mineralizable N was significant for the forest stand but not for the plantation (Table 2). Average mineralization rates for the 0–10-cm samples collected during the rainy season were similar to those of the dry season, expressed as percent total N.

Mineralizable N in the different granulometric fractions is given in Tables 3 and 4. Mineralization rate was higher in surface soil (0–1 cm), where organic matter is less humified and N and C are more available, than in the 0–10-cm

TABLE 1

Mean organic C and total N content, as calculated from ten samples (M=mean, Sm=standard error of the mean)

Soil layer (cm)		C (‰)		N (‰)	
		Eucalyptus plantation	*Acacia* forest	*Eucalyptus* plantation	*Acacia* forest
0–10	M	7.7	15.8	0.53	1.13
	Sm	0.7	1.9	0.06	0.13
10–20	M	3.3	5.3	0.22	0.37
	Sm	0.3	0.8	0.02	0.05
20–40	M	2.2	3.8	0.15	0.25
	Sm	0.2	0.4	0.01	0.03
40–60	M	1.6	3.2	0.11	0.22
	Sm	0.1	0.5	0.01	0.03

TABLE 2

Mean N mineralization during 20 days in-vitro incubation (standard error of the mean in brackets) and correlation coefficient with total N (r)

Soil layer (cm)	*Eucalyptus* plantation			*Acacia* forest		
	μg per g soil	% total N	r	μg per g soil	% total N	r
Dry season sampling						
0–10	11.2***	2.3*	0.38	30.9	3.4	0.88***
	(1.5)	(0.3)		(7.6)	(0.5)	
10–20	0.9***	0.4**	0.10	4.1	1.1	0.62**
	(0.4)	(0.2)		(1.0)	(0.2)	
Rainy Season sampling						
0–10	13.7***	2.2***	0.26	48.3	3.5	0.57
	(1.3)	(0.1)		(4.8)	(0.1)	

Significance of difference from *Acacia* forest stand and of correlation coefficient: * 10% ; ** 5%; *** <1%.

layer. Mineralization rate increased with decreasing fraction size in the plantation soil, and to a lesser extent in the *Acacia* forest soil (Fig. 1). Under *Eucalyptus* no mineralization occurred in the coarse fraction; consequently, most of the mineral N was supplied by the organo-mineral fraction, while under *Acacia*, light fractions supplied more than 50% of mineral N.

TABLE 3

Mineralizable N in granulometric fractions of the 0–10 cm layer of soil: % of total N of the fraction (mean of two replicates)

	Fraction (mm)		
	0.2–2	0.05–0.2	<0.05
Eucalyptus plantation	0.2	2.6	5.8
Acacia forest	3.0	3.3	5.3

TABLE 4

Mineralizable N in granulometric fraction of surface soil (0–1 cm) (mean of two replicates) in *Eucalyptus* plantation and *Acacia* forest

		Fraction (mm)				
		>4	0.5–4	0.2–0.5	0.05–02	<0.05
% total N	Plantation	0	0	0	6.3	11.5
	Forest	0	0.3	10.2	9.2	12.7
% total N mineralization	Plantation	0	0	0	14	86
	Forest	0	3	43	21	33

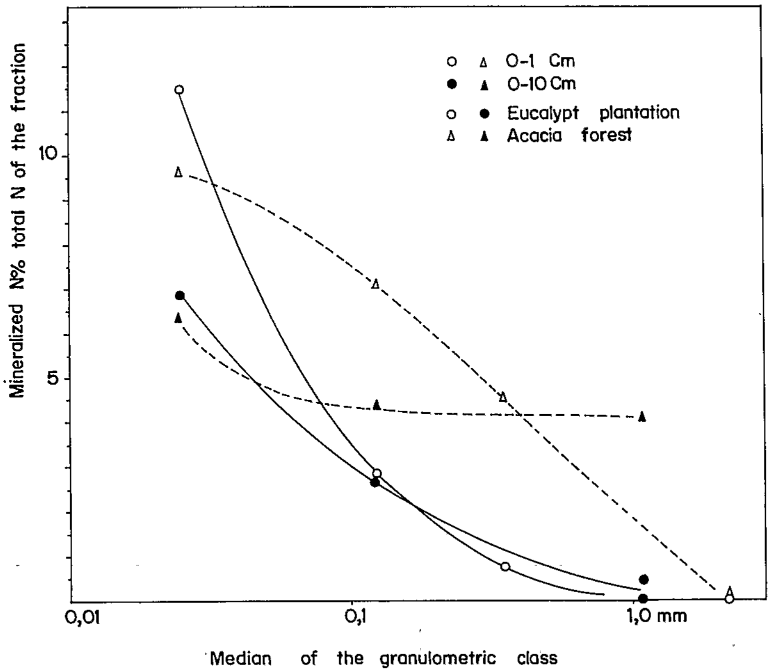

Fig. 1. N mineralization in granulometric fractions of soil organic matter.

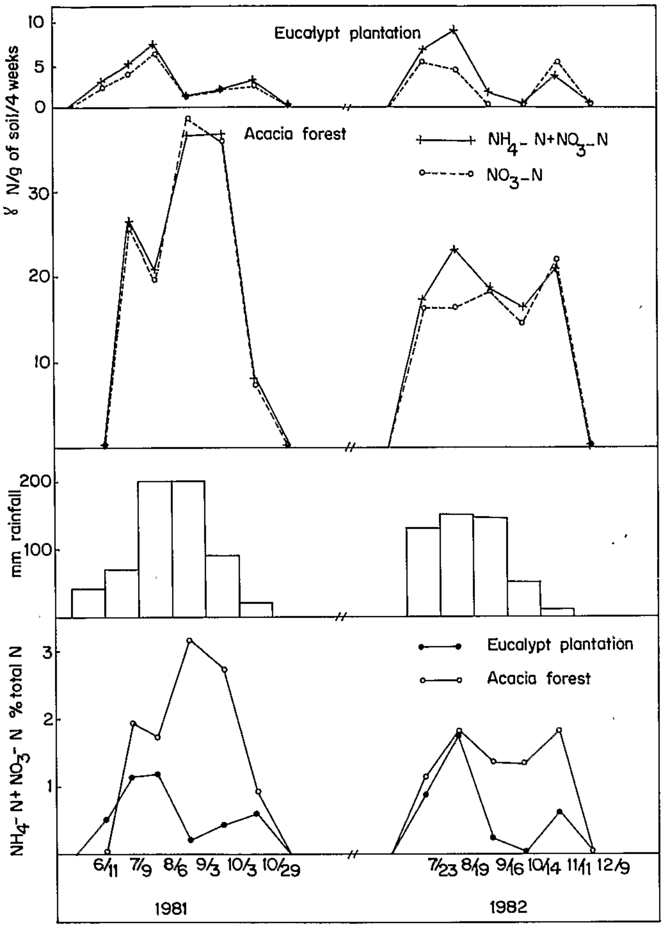

Fig. 2. In-situ N mineralization during two rainy seasons, in μg per g of soil (above) and in % of total N (below).

In-situ N mineralization

Comparison between forest and plantation

The results of measurements carried out during two rainy seasons are shown in Fig. 2 and Table 5.

Under native vegetation, N mineralization occurred at a high level for the whole rainy season during which the soil was wet. Under *Eucalyptus*, N mineralization was high at the beginning of the rainy season and then decreased sharply in August and September; a weak increase occurred at the end of the wet season before the soil dried.

It was observed that the drastic decrease in mineral-N production in early August fitted with the period of strong herbaceous growth, and that recovering

TABLE 5

In-situ mineralized N during the rainy season

	Eucalyptus plantation		*Acacia* forest	
	1981	1982	1981	1982
μg N per g of soil per year	21	22	126	94
% total N per year	4.1	3.5	10.7	7.4

TABLE 6

Comparison of in-vitro and in-situ incubation of 1982 *Eucalyptus* soil samples (μg N per g of soil)

		Date of sampling			
		23 July	19 August	16 September	14 October
In situ	(4 weeks)	2.2	0	0.5	5.4
In vitro	(3 weeks)	12.1	20.9	20.8	16.6

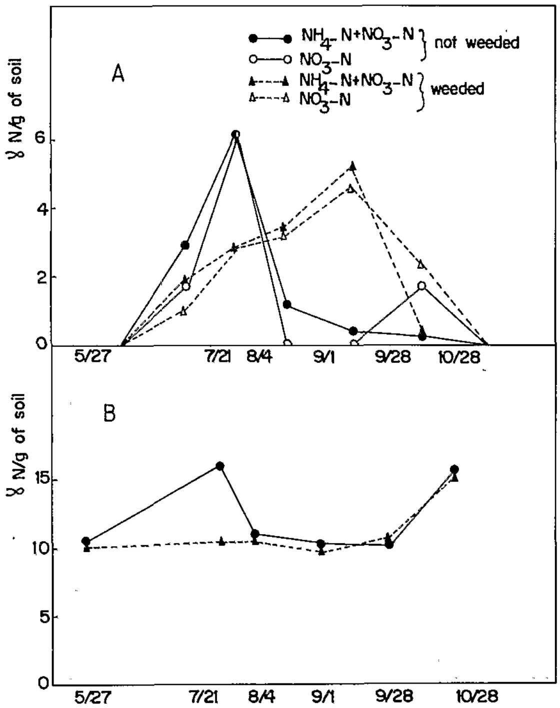

Fig. 3. N mineralization under *Eucalyptus* with and without grass cover, A: in-situ 4-week incubations, B: in-vitro 3-week incubations.

mineralization occurred when the grass cover was dry or cut down. These facts suggested the hypothesis of depressing effect of herbaceous growth on N mineralization rate. In 1980, low rainfall resulted in low herbaceous growth (0.2 t ha^{-1} versus 2.3 and 3.2 t ha^{-1} in 1981 and 1982 respectively) and preliminary N mineralization measurement, with reduced sampling, showed a higher rate than the following years (about 6.8% of total N) under *Eucalyptus*.

However, when 1982 initial soil samples used for in-situ measurements were air-dried and incubated in vitro after further rehumidification, they exhibited high mineral-N production (Table 6).

Field experiment on grass effect

This experiment was conducted in 1983 but unfortunately rainfall was very low this year, resulting in a low level of mineralization. Nevertheless, a difference between treatments was clearly shown (Fig. 3A). In the control plots, no N mineralization occurred in August and September, while in the weeded plots maximum mineralization occurred during this period, pointing out the role of grass cover in suppressing mineralization. When initial soil samples from the weeded and control plots were air-dried and incubated in vitro they both showed a high mineral-N production (Fig. 3B).

DISCUSSION

As reported for other tropical soils (Bernhard-Reversat, 1974, 1981b; De Rham, 1973 in Africa; Pereira, 1982 in South America; Wetselaar, 1980 in Australia) most of the mineral N produced was nitrate N. However, the experimental device prevents root absorbtion, which might compete with nitrifiers for ammonium in natural conditions, and decrease nitrate production.

In-situ N mineralization under the native *Acacia* forest was about 7–11% of soil total N per year. In Ivory Coast rain forest, 8–12% of total N was mineralized (depending on the site; Bernhard-Reversat, 1974); in a Sahelian savanna of north Senegal 8–12% was mineralized under the trees or in the open in places where enough soil humidity was available, while this rate decreased on the top of dunes (Bernhard-Reversat, 1981b). It seems that in these natural environments the part of total N wich was mineralized each year was of the same order of magnitude, whatever the climate and the length of the wet season, although total soil N is related to climate.

Under *Eucalyptus* plantation, mineral-N production was lowered. At least three processes were involved: the low soil total N content; the resistance of organic N to mineralization; and the depressive effect of herbaceous growth.

Low total N content under *Eucalyptus* was related to low organic matter content and resulted from soil disturbance when the plantation was established, and from the low N content of *Eucalyptus* litter.

Eucalyptus leaves and litter are known to contain specific organic substances which display allelopathic properties (Del Moral and Muller, 1969), but there is little evidence from the literature for an antibiotic effect on soil microorganisms. Pochon et al. (1959) reported only a slight antibiotic effect. Under natural *Eucalyptus* forests in Australia, mineralization was higher than in adjacent pine plantations, as reported by Jones and Richard (1977) and Hopmans et al. (1980). Rather than an antibiotic effect of *Eucalyptus*, Pochon et al. (1959) pointed out the lack of balance between micro-organisms related to microclimate change and increased insolation under this species in Mediterranean climate. In Senegal, obvious microclimate changes occurred when *Eucalyptus* plantations were established on *Acacia* forest sites, but their influence on microbial activity was not investigated.

The low N degradation rate under *Eucalyptus* was linked to the light organic fractions. As discussed by Oades and Ladd (1977) a surface effect may explain the increasing trend to mineralization with decreasing particule size, but the difference in slopes of the curves (Fig. 1) pointed out the higher resistance of light fractions of *Eucalyptus* soils, while similar mineralization rates were observed in *Eucalyptus* and *Acacia* soils' organo-mineral fractions.

The lack of correlation between organic N and mineralizable N under *Eucalyptus* was striking. It may be related to the concept of the occurrence of two pools of organic N in soil (Stanford and Smith, 1972) confirmed by recent modelization studies (Broadbent, 1986; Deans et al., 1986), and which differ in their mineralization rate. The occurrence, in *Eucalyptus* soil, of residual organic matter from the native *Acacia* forest soil not correlated with the current pool built up from *Eucalyptus* organic material may account for the observed discrepancy. The labile pool, mainly linked to the organo-mineral fraction, may come from soluble substances which are in great amounts in *Eucalyptus* litter, and/or may have a microbial origin, according to Cameron and Posner (1979). More investigations are needed to clarify the origin of mineral N.

Evidence for a depressive effect of herbaceous growth resulted from in-situ investigation, as mineral-N production decreased in the absence of root absorption. The process involved is not well understood. A hypothesis could be the immobilization of mineral N related to a high supply of carbohydrates in accumulated root exudates or in decaying fine rootlets, graminae being known to have a rapid root turn-over. It should be assumed, then, that either the accountable microflora was killed by drying or that the supplied carbohydrates were made unavailable by drying. Another hypothesis is the occurrence of an inhibitor of mineralization in root exudates which was inactivated by drying.

Few data are reported about such a depressing effect. Mills (1953) and Meiklejohn (1955) stated that some cultivated grasses suppress nitrification. Soils under elephant grass, *Paspalum* and *Chloris* showed a very low nitrate content, and nitrification recovered quickly after elephant grass was cleared but more slowly after *Paspalum* and *Cloris*. Wetselaar (1980) stated that the mineralization coefficient in a clay loam was lower after all-grass pasture crop (1.3%) than after other non-graminae crops (5.5–7.0%). De Rham (1971, 1973) studying in-situ N mineralization in various soils of the Ivory Coast found a very low mineral-N production in Andropogonae-dominated savannas; citing Berlier (1956), he suggested an antagonism between savanna graminae and soil nitrifier bacteria in Ivory Coast savannas. Boughey et al. (1964) pointed out such an antagonism associated with *Hyparrhenia* species. However this is probably not as general feature, as a high in-situ mineralization coefficient (8–12%) was found in a Sahelian savanna (Bernhard-Reversat, 1981b). During the present study, in-situ measurements were made in another *Eucalyptus* stand established on a sandy clay loam. In this stand the herbaceous vegetation consisted of numerous species, mainly graminae but not *Andropogon*; sustained N mineralization was observed during the whole rainy season with a herbaceous standing crop of 1.0 t ha^{-1}, and a weak decrease in mineralization occurred with a standing crop of 3.2 t ha^{-1}. The extent of the depressive effect could be related to the dominant herbaceous species, and a particular effect of Andropogonae is suggested from the present study and from the literature.

CONCLUSION

In native vegetation, soil N mineralization rate was high during the short rainy season, allowing a relatively high rate of N cycling in the ecosystem.

The decrease in mineral N production under *Eucalyptus* was related to the low level of N in the soil–plant system but also to a low mineralization rate, which lowered the level of N cycling; this may help to decrease N losses.

The growth of graminae sharply decreased mineral N production for 2 months. When the rainy season was short, only mineral N produced in the early season was available for plants. In the case of mineral-N shortage, competition between trees and grass rather disavantaged the trees, as mineral N was mainly produced in the top layer of soil where graminae roots were concentrated. The weeding of young plantation, which is practiced to reduce water competition, may help to provide more N to the trees.

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