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# NITROGEN CYCLING IN A SOIL TREE SYSTEM IN A SAHELIAN SAVANA. EXAMPLE OF ACACIA SENEGAL


F. Bernhardt-Reversat

F. BERNHARD-REVERSAT and H. POUPON
ORSTOM, BP 1386, Dakar, Sénégal


## I. Introduction

The need for tree conservation in the Sahel, and the role of trees in the sahelian ecosystem equilibrium has been emphasized during the last years. One aspect of the role of trees is their impact on soil nutrients and on nutrient cycling (CHARREAU et al, 1970, JUNG, 1969).

In the present work we try to study the nitrogen cycle in a soil-tree system in a sahelian savanna of north Senegal. *Acacia Senegal* was chosen because it is present in a great part of the Sahelian zone and is well represented in the study area. Beside it has some economic importance as a gum tree, and it is used for reaforestation.

The study area was described by BILLE et al (1972). The mean annual precipitation is 300 mm per year falling during a three months wet season. The relief is a succession of dunes and depressions. The trees are scattered on the dunes and slopes, and their density is higher in the depressions. The herbaceous stratum is scarce and irregular in the open, but is dense and higher under the trees. The population of *Acacia Senegal* was studied for several years in a protected quadrat (POUPON, 1977).

The N cycle study was undertaken recently in the same quadrat. Twelve trees were studied for total N, mineral N, and mineralization in soil. Sampling was done on several trees to obtain mean values of N content of leaves and wood, and for herbaceous biomass and N content. Biomass of trees was estimated with established relationships between tree girth and biomass.

## II. Accumulation of nitrogen in the vegetation

### 1. Accumulation of nitrogen in the tree (table 1)

The biomass of 21 trees was measured by H. POUPON and relationships were established between tree girth and the different parts of tree biomass : twigs, branches, trunk, roots and leaves. The equations were in the form of log y = a log x + b where y is the biomass, and x the girth of the tree.

These equations were used to calculate the biomass of the tree studied for soil N. Samples of wood and leaves were analysed for N content. (N content of root is assumed to be the same than that of wood). Branches and trunk had the same N content of about 0,43 % (standard error of 0,09 for 13 samples). N content of twigs was 0,62 %, N content of leaves was 3,0 % (standard error of 0,29 for 12 samples).

## 2 - Accumulation of nitrogen in the herbaceous standing crop

The biomass of ~~herbes~~ herbs under the trees was measured in 1976 and 1977 at the end of the wet season, in october, and N content was determinated. Because of the low precipitation in 1977 (120 mm) the biomass of herbs was weak, but the N content was higher. Neverthelss the accumulation of N was lower than in 1976.

The following values, of 1976, are assumed to represent a "mean" year. The biomass of aerial parts under Acacia was 0,42 $kg/m^2$ (standard error of 0,1 for 8 samples) with a mean N content of 1,07 % (stadderd error 0,3). The biomass of roots was 0,26 $kg/m^2$ (standard error of 0,05) with a N content of 1,66 % determinated on a composite sample.

The total N immobilised is 8,7 $g/m^2$ under the trees in the open it was 4,7 $g/m^2$

In 1977, with low rainfall, the aerial biomass of herbs under Acacia was only 0,23 $kg/m^2$ with 1,33 % N. The root biomass was not measured, but we can estimate the total accumulation of N about 6 $g/m^2$.

## III. Return of nitrogen to the soil (table 2)

Nitrogen is returned to the soil by tree litter, leaching of leaves and branches by throughfall, herbaceous litter, roots.

Acacia leaves are turning yellow before they fall. Yellow leaves taken off from the tree or freshly fallen on the soil have been analysed. They showed a N content of 2 %, that is two third of green leaves content. One third of leaf nitrogen is withdrawn to the tree before leaf fall. The N content of yellow leaves was used with the leaf biomass to calculate the annual return to the soil by litter. Annual return by tree roots was not measured.

Troughfall was studies during two years to estimate the amount of nitrogen leached from the tree crown. The N content of rain under the tree and in the open was determinated. During the wet season of 1976, for 630 mm of rain, 2,2 g of N/m$^2$ was brought to the soil, from which 1,8 g/m$^2$ was washed on the tree crown, and 0,4 g/m$^2$ was supposed to be brought from the atmosphere. Stem flow was measured during some times but the amount of N returned to the soil by this way was small.

In the studied area all the herbaceous species are annual, so it can be assumed that all the nitrogen accumulated in the herbaceous standing crop is returned to the soil each year. The mean values of herbaceous biomass and N accumulation were not used for the little trees where ~~it is~~ they are probably lower (no measurements were made under them).

## IV. NITROGEN ACCUMULATION IN SOIL (table 3)

Total nitrogen in soil was first studied by establishing the profile distribution of N content under the tree. This was done under several trees and the general trend observed was that of the example given at the figure 1. It shows that except for the soil around the trunk, nitrogen is evenly distributed under the tree crown, and that only the surface layer of soil has a higher N content than in the open.

N content of the 0-10 cm layer was determinated every month in a composite sample for each tree studied. The annual means are given in table 3.

A positive correlation ($r = 0,71$) is observed with the tree girth which indicates that accumulation of nitrogen in the soil increases during the life of the tree.

## V. NITROGEN MINERALIZATION IN SOIL (table 4)

The profile of potential mineralization, measured by three weeks incubations of humidified soils, is shown by the example given in figure 2. It can be observed that mineralisation occurs principally in the first 10 cm of soil and that deeper soil has a significative production of mineral N only near the trunk.

Mineralisation in situ was measured in the surface soil under the crown, taking samples at various distances from the trunk (the depth of sampling was 0-7 cm the first year and 0-10 cm the second year). Measurements were done every four weeks from june to october, and the results are shown in table 4.

During the wet season mineral N was produced mainly in the form of $NO_3$-N. The two years of measurement had different rainfall (330 mm in 1976, 120 mm in 1977). Nevertheless the amount of mineral N produced is the same, as there was enough rainfall to achieve the mineralization of the mineralisable N present in the soil.

The results of the table 4 show a great variability, and the relation between N mineralized and the age of the tree (tree girth) is weak. The mean value is 3,7 g N/m$^2$ (30 g/tree) for Acacia on the dune, and 8,2 g/m$^2$ (142 g/tree) for trees at the foot of the slopes.

Some measurements were done during the dry season and showed a very low production of $NH_4$-N which is probably due to chemico-physical factors (DOMMERGUES et al. 1971). The amount of $NH_4$-N produced ranges from 0,5 to 1 g/m$^2$ for the whole dry season. Some occasional showers occur during the dry month which may bring about a production of mineral N, if the soil is moistened thus in 1976, there was a mineralization of 5 g N/m$^2$ for the whole dry season with two showers.

V. Possible inputs and outputs

Inputs and outputs have not been measured but some observations were made on this subject.

Inputs are mainly due to rainfall and to fixation of atmospheric nitrogen by microorganisms. Nitrogen concentration in rain was low and its contribution to inputs was about 0,4 g N/m$^2$/year, as previously noted.

Symbiotic fixation could occur in a leguminous tree as *Acacia senegal*. Seedlings grown in the laboratory as well as seedlings found in the field showed numerous nodules. However the search for nodules on adult tree roots was negative, except in one tree for ten trees sampled. It is possible that symbiotic fixation occurs during the first years of the tree life, but rarely in adult trees. In the laboratory it was observed that nodulation was inhibited when seedlings were grown in soil taken off under an old Acacia, but not in soil taken off in the open. In the latest soil, addition of nitrate inhibited nodulation. The active nitrate production in soil under the tree during the wet season could be partly responsible for the absence of nodules in adult trees, but very few is known on this subject.

The dryness is perhaps another factor. A good nodulation was reported by ORCHARD et al. (1956) in *Acacia mollissima* forests in a wetter zone, and they observed that nodulation decreased with increasing soil N. MOORE et al. (1967) found a poor nodulation in an *Acacia harpophylla* forest during a dry year, but they observed a substantial nodulation in wetter years.

Non-symbiotic fixation in soil was not investigated.

Outputs by denitrification seems to be possible, at least in the lower part of slope and in depressions where the soil can be temporarily water-logged. Losses of mineral nitrogen was observed once during the wet season of 1976, after a heavy rainfall (BERNHARD-REVERSAT, 1977).

Losses of nitrogen out of the ecosystem must not be important as water flow in the soil does not go deeper than 3 m, which is the depth of tree roots, according to A. CORNET who studies the water balance in this ecosystem. Nevertheless it can happens that $NO_3$ or soluble organic nitrogen is leached beneath the bulk of the herbaceous roots after a heavy rainfall, particularly during a year as 1977 where the herbaceous standing crop was low and the amount of mineral N in it was smaller than the amount produced by mineralization. This could be the explanation for the $NO_3$ distribution observed in a profile established after the 1977 wet season under Acacia, and shown at figure 3.

## VI. Conclusions

Taking the mean for adult *Acacia* situated in the lower part of slopes, the annual flow of nitrogen was about 12 $g/m^2$, which is a relatively high value, comparable to some forest ecosystems. It can be supposed that an *Acacia* forest issued from plantation should have an active N cycle. An important part of nitrogen flow passes through the herbaceous stratum, and is then available to cattle.

Compared to the nitrogen cycle out side the cover of trees, nitrogen flow is 2,5 to 3 times greater under the tree, as shown in table 5. The turn-over of soil N is 10 %/year in the open, and 14 % under the tree. The higher N accumulation in herbs under the tree is not only due to a higher biomass, but also to a higher N content.

If the year 1976, with mean rainfall, is compared to a year with low precipitations as 1977, it appears that only N flow from vegetation to soil is lowered :

| | 1976 | 1977 |
|---|---|---|
| return by tree leaves | 0,8 | 0,8 |
| return by throughfall | 1,8 | 0,6 |
| return by herbaceous litter | 8,7 | 6,0 |
| total | 11,3 | 6,3 |

The production of mineral N in soil was about the same for the two years, as the soil was humid for a sufficent number of days to achieve the mineralization of the mineralizable N. Only if this number is not reached should the mineral N production be decreased. However a succession of several dry years with low herbaceous growth should result in a decrease of mineralizable N.

In conclusion, rainfall is the main environmental factor influencing the nitrogen ~~factor~~ cycle in the system studied :

- by limiting vegetation growth and then nitrogen utilization and return,
- by controlling mineral N production in the soil, more or less strongly according to the amount of precipitation,
- eventually by causing denitrification or leaching of mineral N in the soil.

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## Table 1

### Accumulation of N in the trees

| tree n° | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| girth cm | | 26 | 27 | 35 | 35 | 38 | 39 | 40 | 47 | 48 | 49 | 49 | 57 |
| situation(1) | | D | D | D | LS | LS | LS | LS | D | LS | LS | LS | LS |
| Twigs | biomass kg | 4,0 | 4,4 | 9,0 | 9,0 | 11,3 | 12,2 | 13,1 | 20,3 | 21,5 | 22,8 | 22,8 | 34,6 |
| | N g | 25 | 27 | 56 | 56 | 70 | 76 | 81 | 126 | 133 | 141 | 141 | 214 |
| wood (trunk + branches + roots) | biomass kg | 21 | 23 | 38 | 38 | 45 | 47 | 50 | 70 | 73 | 76 | 76 | 106 |
| | N g | 102 | 109 | 181 | 181 | 215 | 227 | 233 | 335 | 351 | 366 | 366 | 511 |
| leaves | biomass kg | 0,25 | 0,26 | 0,39 | 0,39 | 0,44 | 0,46 | 0,48 | 0,61 | 0,63 | 0,65 | 0,65 | 0,83 |
| | N g | 8 | 8 | 12 | 12 | 13 | 14 | 15 | 18 | 19 | 20 | 20 | 25 |
| total N | g/tree | 130 | 140 | 250 | 250 | 300 | 320 | 330 | 480 | 500 | 530 | 530 | 750 |
| | g/m² | 23 | 31 | 44 | 10 | 9 | 31 | 32 | 38 | 49 | 32 | 40 | 23 |

(1) D: dune, LS: lower part of slopes

## Table 2

### Annual N return to the soil

| tree n° | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | open LS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N in tree litter g/m² | 0,44 | 0,91 | 1,7 | 1,4 | 0,36 | 0,28 | 0,94 | 0,97 | 1,24 | 0,78 | 0,98 | 0,52 | — |
| total N return g/m² | — | — | — | — | 10,9 | 10,8 | 11,4 | 11,5 | 11,7 | 11,3 | 11,5 | 11,0 | 4,7 |
| total N return g/tree | — | — | — | — | 268 | 339 | 116 | 145 | 119 | 137 | 152 | 354 | — |

## Table 3

### Accumulation of N in soil

| tree n° | 1 | 2 | 3 | 4* | 5 | 6 | 7 | 8 | 9* | 10* | 11* | 12 | open D | open LS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N content ‰ | 0,28 | 0,47 | 0,43 | 0,64 | 0,29 | 0,51 | 0,55 | 0,47 | 0,76 | 0,33 | 0,76 | 0,80 | 0,17 | 0,27 |
| N g/m² | 48 | 80 | 73 | 76 | 49 | 88 | 94 | 80 | 90 | 63 | 90 | 136 | 29 | 46 |
| N g/tree | 542 | 456 | 328 | 433 | 1200 | 2520 | 959 | 1010 | 918 | 1045 | 1188 | 4379 | — | — |

* measured in 1976, others in 1977

Table 4

Mineral N produced in the soil from June to October

| tree n° | 1 | 2 | 3 | 4* | 5 | 6 | 7 | 8 | 9* | 10* | 11* | 12 | open D | open LS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N g/m² | 3,6 | 3.8 | 4.2 | 8.4 | 6.2 | 5.5 | 14.9 | 3.1 | 8.4 | 7.0 | 6.3 | 9.0 | 2.2 | 4.5 |
| N g/tree | 41 | 22 | 19 | 48 | 153 | 183 | 152 | 39 | 139 | 86 | 83 | 290 | — | — |

* measured in 1976, others in 1978

Table 5

Main flows and stocks of N under Acacia and in the open for a year with mean rainfall. (means for the lower part of slopes)

| | | Acacia | open |
|---|---|---|---|
| N immobilization in vegetation | g/m² | 32.6 | 4.7 |
| N return to the soil | g/m²/yr | 11.3 | 4.7 |
| total N in soil | g/m² | 86 | 46 |
| N mineralized | g/m²/yr | 11.5 | 4.9 |

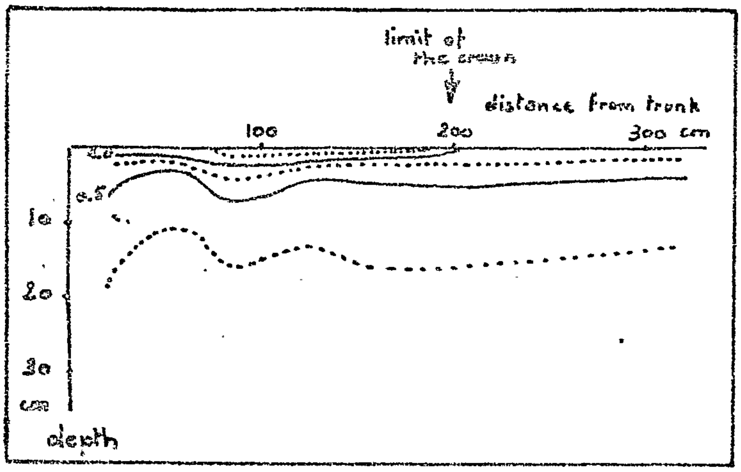


Fig. 1. Curves of equirepartition of total N under an *Acacia* (N ‰)

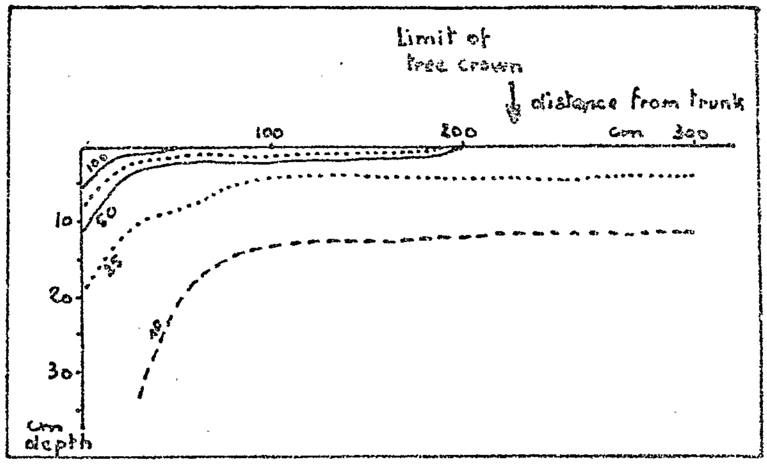


Fig. 2. Curves of equirepartition of mineralizable N under an *Acacia* ($NO_3$-N γ/g of soil/3weeks)

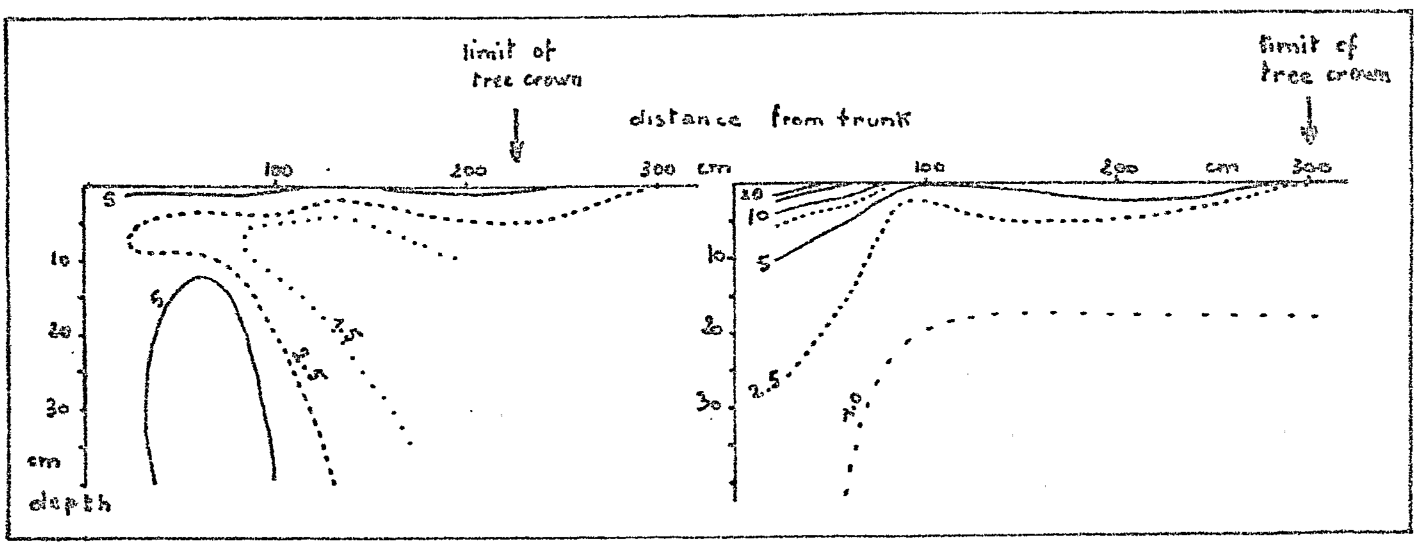


Fig. 3. Curves of equirepartition of $NO_3$-N under two *Acacia* A: after the wet season of 1977, B: after a mean wet season, 1975. ($NO_3$-N γ/g of soil)