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Bio indicators of land quality in the tropics: an attempt to integrate soil and vegetation approaches

MASSE Dominique (1), **CHOTTE Jean-Luc** (1) **and PONTANIER Roger** (2)

(1) UR Ibis R083, Centre IRD BP 1386 Dakar, Sénégal
(2) US Jachère S017, Centre IRD BP 1386 Dakar, Sénégal

Abstract

Knowledge of the condition and the management of environmental resources has become an increasing matter of concern because of the pressure put on soil, water and plant by expanding populations. It is of crucial importance to predict any variation of these conditions to prevent irreversible changes. Therefore, the establishment of indicators to provide warning of early perturbations has received a lot of attention.

When investigating an ecosystem and prior to any search for indicators one should ask the question "What function is of interest in the investigation ?". In agroecosystem, the most notable functions are those involved in N and C cycling. Therefore indicators of agroecosystem trends should tackle above (i.e. vegetation, crops, etc) and below (root, soil biota) ground part of these cycles.

In 1994, two multidisciplinary projects on fallow in West and Central Africa supported by the European Union have been launched by research organisations of the north and the south.

Our results revealed the impact of the quality of organic input on soil biota. As a matter of fact, the shift in soil vegetation (crops, herbaceous or woody vegetation) modifies the abundance and the composition of the soil biota. Among them termites and plant parasitic nematodes have proved to be very sensitive to changes in the quality of organic residues. These indices were more sensitive to changes in vegetation than soil organic matter content mainly due to the predominance of coarse textured soils in the studied area.

Keywords: bio-indicators, vegetation, soil, fallows, West and Central Africa

Introduction

Knowledge of the condition and the management of environmental resources has become an increasing matter of concern; because of the pressure put on soil, water and plant by expanding populations. It is of crucial importance to predict any variation of these conditions to prevent irreversible changes. Therefore, the establishment of indicators to provide warning of early perturbations has received a lot of attention.

Nevertheless, the definition and content of the indicators have been numerous and not always clear or in agreement. As far back as 1982, Bick reported that the bio-indicators were in the broader biological sense the organisms used for the detection and quantification of factors or sets of environmental constraints. Whatever the definition the search for land use indicators rely on two different procedures:

- one based on a process like procedure, where the indicators are proposed because they are key factors of specific mechanisms (i.e; acidification, dénitrification, desertification, etc),
- one based on a correlative approach where the indicators are revealed by the confrontation of numerous determinations of multiple land use situations (Maire and Pomel, 1994).

When investigating an ecosystem and prior to any search for indicators one should ask the question "What function is of interest in the investigation ?". In agroecosystem, the most notable functions are those involved in N and C cycling. Therefore indicators of agroecosystem trends should tackle above and below ground part of these cycles.

In 1994, two multidisciplinary projects on fallows management in West and Central Africa supported by the European Union have been launched by research organisations of the north and the south. In the framework of these projects, the identification of bio-indicators of land quality with respect to agricultural production sensus lato (crop and livestock production has been addressed.

This presentation will give a first set of results concerning plant indicators and bio-chemical soil indicators on two sites. This describe the regeneration process during a fallow period (Manlay *et al.,* 2002a ; Lavelle *et al.,* 2000; Cadet *et al.,* 2000). The second set reflects the effect of type of vegetation (leguminous trees, perennials or annuals herbaceous) after four years of fallowing (UE, 1998; Ndour *et al.,* 2001; Masse *et al.,* submitted). Soil analyses concerned soil organic matter, above and below ground production, microbial activity, mesofaunal and macrofaunal diversity.

Materials and Methods

The studies were conducted in two different zones of Senegal characterised by a climate with two contrasted seasons (a dry season of 8 months and a wet season of 4 months) and agricultural practices dominated by cropping systems with different management of fallows. In these zones natural vegetation is dominated by Combretaceae in the woody layer and Andropogoneae in the herbaceous layer. These species are characteristic of the sudano-sahelian and sudanian vegetation.

Sonkorong (SO) (13°46'N-15°31'W): mean annual rainfall of 603 mm, dominated by intensive agricultural practices where only few fallows of short duration are left, soils are described as sandy, ferruginous and classified as Oxisol (FAO, 1998),

Sare Yorobana (SY) (12°49'N-14°53'W): mean annual rainfall of 1109 mm, three main land use systems centered around the village and distributed along a smooth toposequence can be distinguished. The up-slope plateau is still covered with wide areas covered by secondary savanna and old fallow (Manlay *et al.,* 2002a). The soils are described as sandy, ferruginous and classified as ferric Lixisols (FAO, 1998).

At SO, experimental plots were designed to test the efficiency of different fallow practices, meant to substitute long lasting fallow, in the improvement of soil properties. *Andropogon gayanus* and *Acacia holosericea* were installed on continuously cropped fields. At SY a time saving synchronic method was adopted. Neighboring fallow plots of different ages (1 year- to 30 year-old plots) were considered as representative of the same plot along the succession assuming they had the same pedological features.

Soil analyses concerned soil organic matter, above and below vegetation production, meso and microfauna and microbial activities.

Results and Discussion

Bioindicators of fallow duration

After crop abandonment woody and root components increased at the expense of the herbaceous layer, while litter showed no clear pattern of evolution (Figure 1a). For the local fallows disturbed mostly by fire, the present study demonstrates the existence of an ecological threshold around 10 years after crop abandonment. After that period no variation in aboveground woody biomass was measured. A similar value had already been recorded under similar ecozones. However it might strongly vary, depending on climate and cropping history. Low woody biomass at equilibrium and net productivity of fallows of Sare Yorobana are likely to express soil constraints rather than climate conditions. Shallow (30-40 cm deep) clay accumulation in plateau and glacis soils generates seasonal hydromorphy and a physical barrier. These physical constraints and nutrient-limited availability could seriously restrict root and plant development. These results stressed out the predominant role played by the tree layer in the control of the whole ecosystem plant dynamics (Manlay *et al.,* 2002a).

In Sare Yorobana, soil organic matter (SOM) content increased strongly during the first two years of natural fallow and remained constant thereafter (Manlay *et al.,* 2002b) (Figure 1b). This exponential model of C accumulation is to some extent consistent with that proposed by Nye and Greenland (1960). However, the gain in C content is far less important than that recorded for clay soils. Several factors may explain the weak response of local soils to fallow management. For plateau soils of High Casamance, sand-loamy texture does not allow for efficient SOM protection against microbial oxidation, leaching and erosion losses (Feller and Beare, 1997). Seasonal rainfall, and soil moisture and temperature patterns unfavourable to humification might also be advocated to explain limited SOM storage. Harvest of deadwood by people, as well as CO_2 emission induced by fire might also be put forward, although the effect of fire on SOM content of young fallows has recently been questioned (Masse *et al.,* 1997). The investigation of the forms of SOM accumulation indicated that more than half of C increase recorded for the 0-20 cm layer occurred in the (50-2,000) µm size fraction, this fraction being known to have a fast turnover and to play biological functions such as C and nutrient sources.

Total macrofauna density increased within the first years of fallow and decreased after 15 years (Figure 1c). The increase was mainly due to termites. However, the structure of these populations and the abundance of the different component varied with the fallow duration. The specific richness was very low at the onset of the fallow and increased sharply within the very first years of fallow as a result of the capacity of the remainder populations to colonise their new environment. A decrease in the specific richness was recorded in fallow older than 15 years indicative of interactions between the different component of the soil biota. The shape of this curve features a classical evolution of soil biota submitted to exogenous perturbations, equilibrium between each of its component being deeply affected soon after the perturbation.

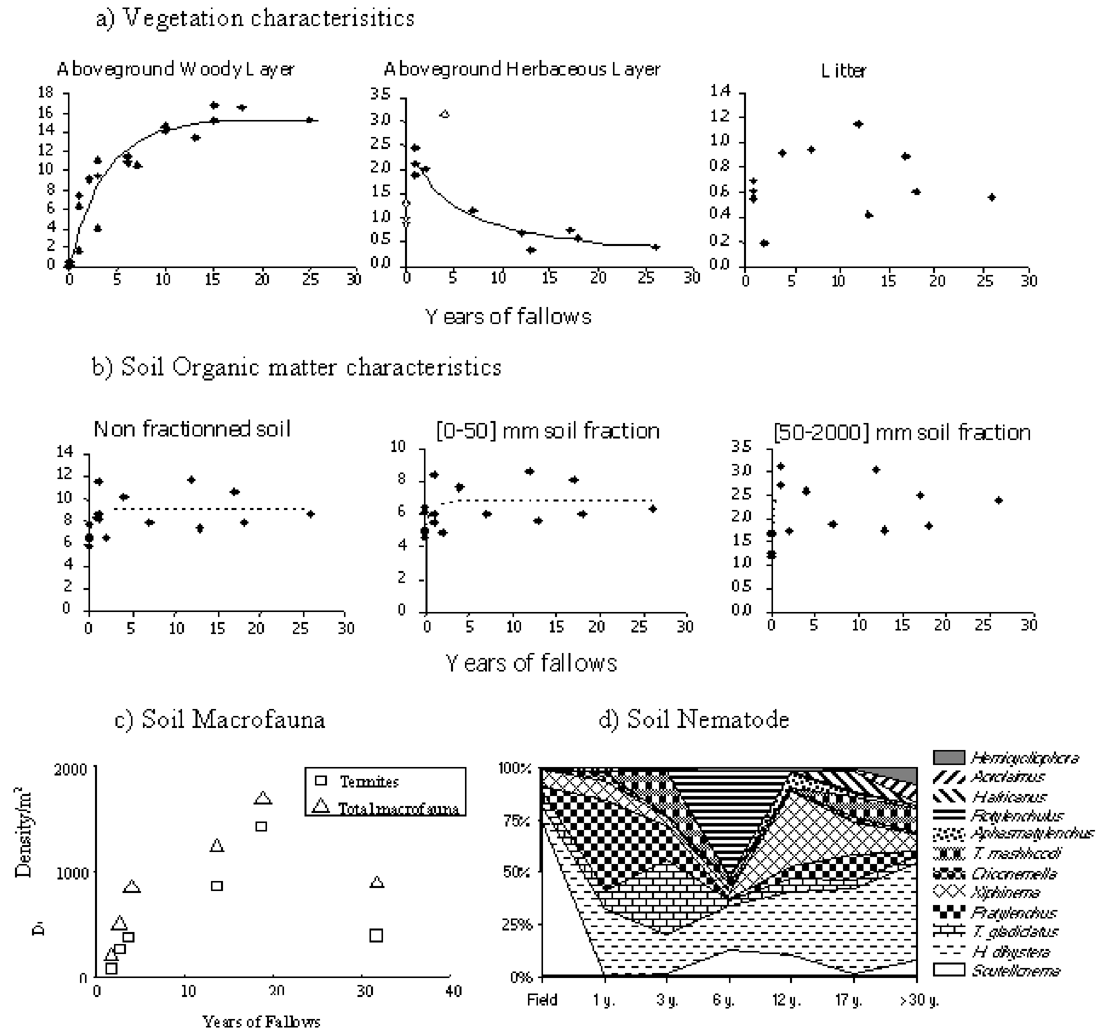

Figure 1 Vegetation, soil organic matter, macrofauna and nematods characteristics in a set of differents age of fallowing in Sare Yorobana, High Casamance, Senegal.

Alike for macrofauna, any variation in plant parasitic nematodes abundance was recorded in ageing fallow compared to cropped fields (Cadet *et al.,* 2000). Nevertheless, the community structure revealed important modifications. In fallow older than 7 years, *Scutellonema cavenessi* and *Tylenchorhynchus gladiolatus*, dominant species in continuously cropped situations and known to be responsible for severe damages on food crops, disappeared at the expense of species of less pathogenic impact such as *Criconemella* sp., *Tylenchorhynchus* sp., *Longidorus* sp., *Aphasmatylenchus* sp. et *Pratylenchus* sp. *Helicotylenchus dihystera* and *H. africanus* dominated the plant parasitic populations in 20-year-old fallows and a secondary forest (Pate, 1997). *Helicotylenchus dihystera* is suspected to play a key role in the regulation of the pathogenicity of the whole nematode community (Villenave and Cadet, 1998).

Bioindicators of short improved fallow

The resprouting of the natural vegetation installed after a long period of cropping was almost nil after 4 years, wood biomass of this situation (nvf) being very little (Figure 2). By contrast, the plantation of *Acacia holosericea* (acf) allowed a similar wood production as that recorded from old fallow at Saré Yorobana. Similarly, the aboveground biomass of the plots with *Andropogon gayanus* (anf) was higher than that of the natural vegetation fallow. For the two situations where the natural vegetation had been replaced either by a woody species or an herbaceous species, the production of below ground biomass was higher than that of the plot where the natural vegetation had been left. This was particularly evident for fine roots of the upper soil layer (0-10 cm) (Figure 2). Despite significant impact of fallow management on the vegetal production, any significant effect on soil organic matter was recorded between the different plot either in the upper soil layer (0-10 cm) nor in the deeper one (10-30 cm) (Figure 2) (Masse, 1998). This is consistent with the results obtained at Saré Yorobana as soils of both situations are coarse textured, being therefore little affected by the different management of organic resources. For such soils, simulated variations of C content after Nye and Greenland's model (1960) are very little, mostly undetectable by traditional methods even for situations where large amounts of residues are recycled.

Thought the termites represented the most important group of the total macrofauna whatever the situation, the abundance of the different groups varied significantly. Ants, earthworms and myriapodes were less abundant in the acacia plots than in the natural 4 year-old fallow (Figure 3; Floret, 1998). Moreover, the contribution of the different species of termites to the total population depended on the situation. Wood feeder termites (e.g. *Eremotermes* sp) dominated in the herbaceous fallow, while fungus growing termites peaked in plots planted with acacia (Floret, 1998). Fungus growing termites are known to be ubiquitous capable to survive in a wide variety of environments. The variation in the composition of the termite populations under *Acacia holosericea*, compared to that under natural vegetation or *Andropogon gayanus*, was due the disappearance of termites species rather to the presence of new species (UE, 1998). Contrastingly, any effect of *Acacia holosericea* was noticed on the plant parasitic nematofauna (Figure 3). This woody species seemed to be a favourable host for the most abundant phytoparastic nematodes encountered in this ecological zone. Moreover, *Scutellonema cavenessi* tend to have a better development at its vicinity than at the vicinity of most natural plant.

Total microbial biomass was significantly higher after the 4 year-old acacia fallow than after 4 years of andropogon or natural vegetation (Figure 4). By contrast, carbon potentially mineralised was the highest in the soil under the natural vegetation. For the chitinase activity, *Andropogon gayanus* plot recorded the significantly higher activity in comparison to the two other plots (Figure 4). Chitin is a common structural substance and can be found in the cell wall of fungi. The presence of chitinase activity in the *Andropogon gayanus* improved fallow might be explained by the presence of a high fungal biomass in these fallows (Ndour *et al.,* 2001). Among the different management practices, the introduction of *Acacia holosericea* depleted every enzyme activity. High concentration of phenolic compounds, responsible for growth inhibition of soil micro-organisms might explain this findings (Duponnois *et al.,* 2001). Any relationship between enzymes activities and microbial biomass was recorded. For the ß-glucosidase, this appeared to be anomalous since this activity releases important energy sources for soil micro-organisms, been thought to stimulate their development. However, the assayed enzymes may originate from the activity of organisms other than microbial biomass such as protozoan and invertebrates.

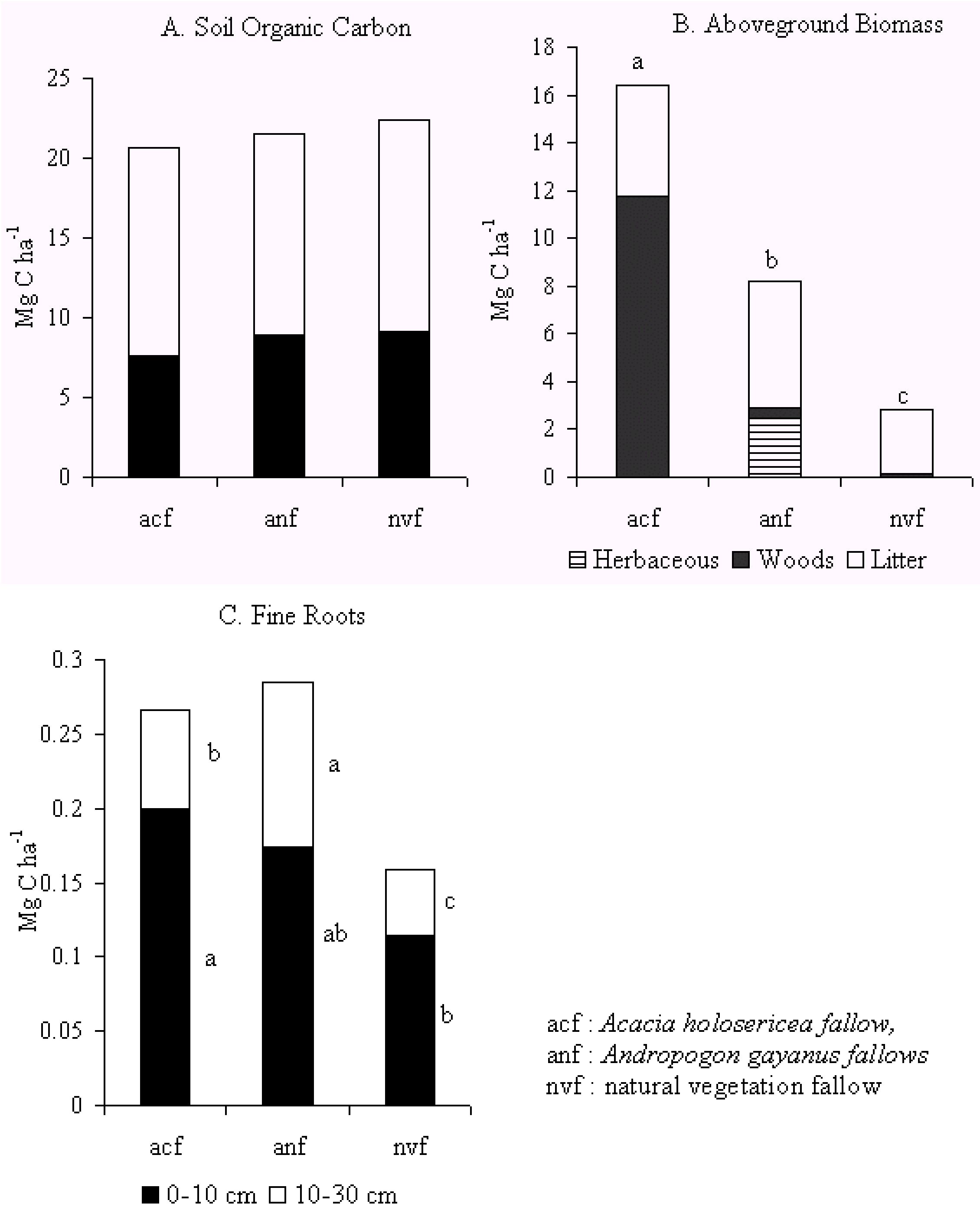

Figure 2 Soils and vegetation characteristics under different type of vegetation in 4 year-old fallows.

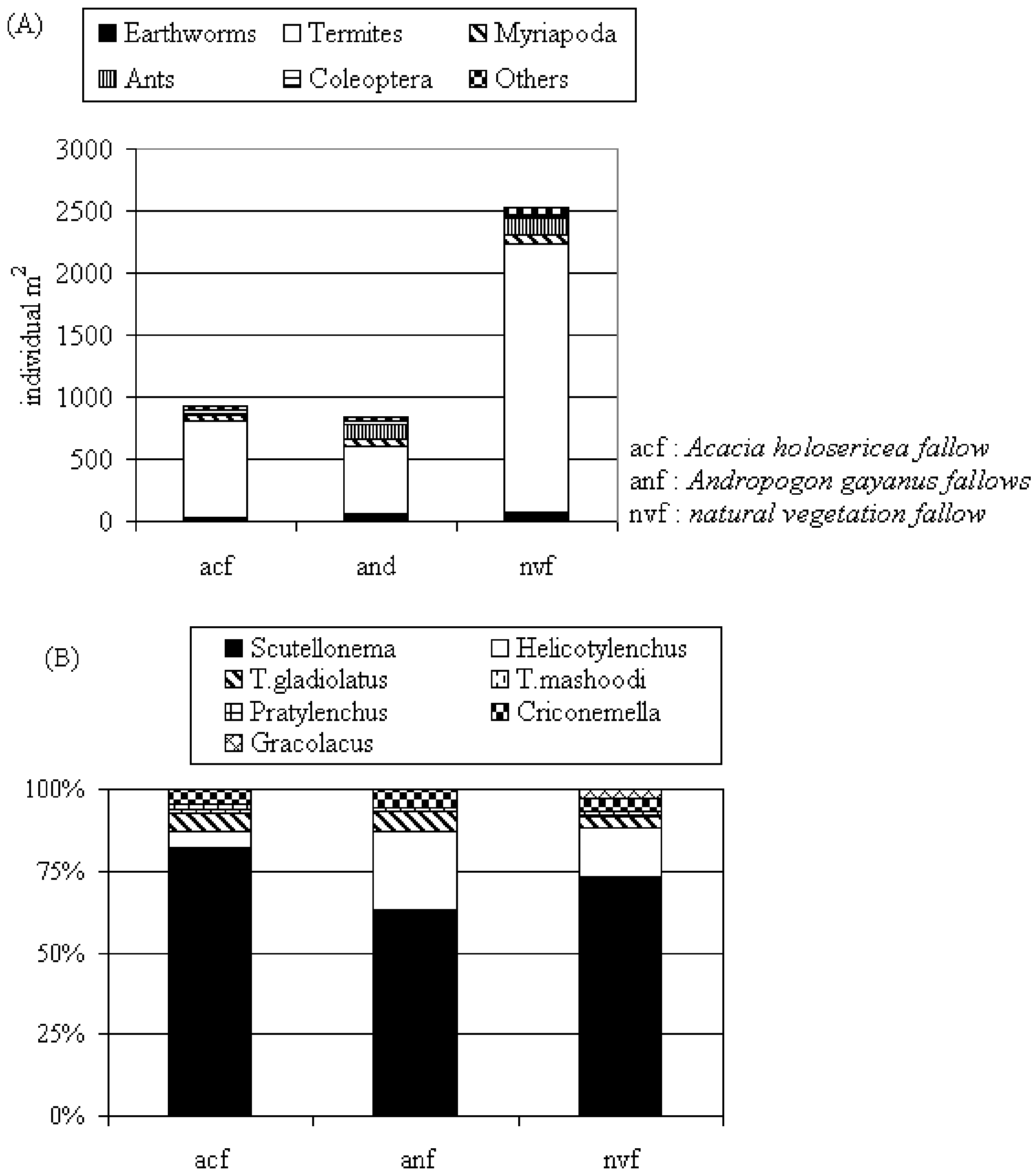

Figure 3 Soil macrofauna (A) and plant parasitic nematodes (B) under different type of vegetation in 4 year-old fallows.

Conclusion

This study carried out in a representative area of semi-arid zones of West African savannas indicated that relevant indices to monitor any changes in response to vegetation modifications in the crop - fallow rotations should necessarily focus on biotic components. For these coarser textured soils, where well accepted indices such as soil organic matter content, could not be proposed since the impact of the management of organic resources is very little. In these areas, the vegetation plays a key role in controlling most of the soil processes. Soil organisms are therefore strongly affected by the development or the introduction of new woody and herbaceous species (Jones *et al.,* 1994). Our results confirm these findings with a strong impact of the quality of organic input. As a matter of fact, the shift in soil vegetation (crops, herbaceous or woody vegetation) modifies the abundance and the composition of the soil biota. Among them termites and plant parasitic nematodes have proved to very sensitive to changes in organic inputs (Manlay *et al.,* 2000). No clear patterns of the impact of the management of fallows on the microbial community could be drawn from these results. Very recent results (data not shown) indicated that there is a need to adjust the recent development of molecular techniques for the definition of microbial indicators of land quality.

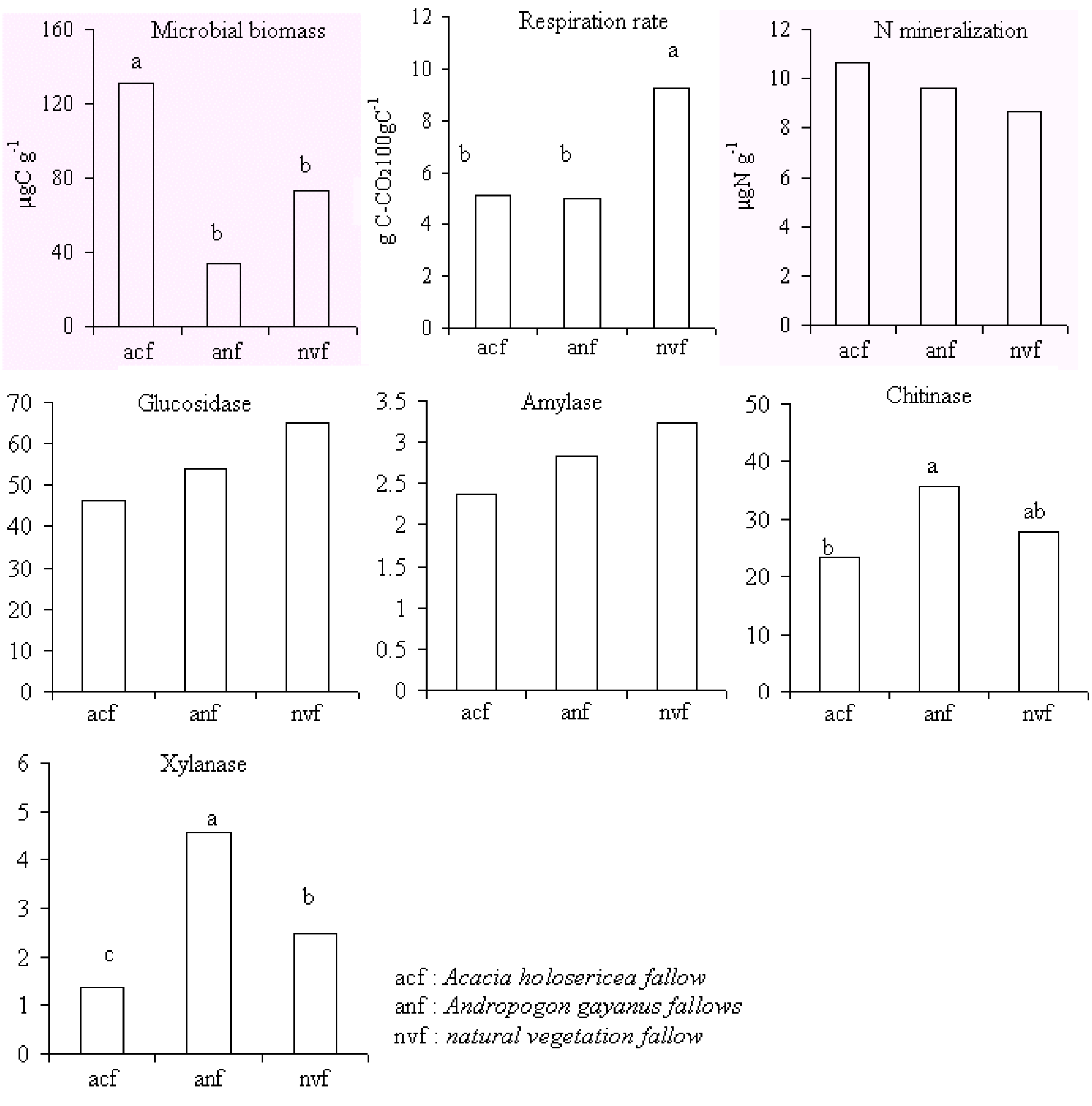

Figure 4 Soil microbial biomass and activities (µg product g^{-1} h^{-1}) under differentthe type of vegetation in 4 year-old fallows.

There is a need for further researches in order to complement these first sets of results. Special attention should put on the interactions between the different components of the soil biota and the impact of these interactions in plant productivity. However our results stressed out the fact that organic resources should not only be thought as a means to monitor soil organic pools but also as a way to manipulate the different component of soil biota.

Aknowledgments

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