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Full Length Research Paper

Dynamics of culturable soil microbial communities during decomposition of some agroforestry species in a semi arid and arid tropical agroecozones of West Africa

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Field litterbag studies were conducted during the dry season between years 2000 and 2001 in typical semi-arid and arid agroecozones of West Africa to measure the dynamics of culturable bacterial and fungal communities in the topsoils. Five different agroforestry leaf litters namely *Dactyladenia*, *Pterocarpus*, *Alchonea*, *Senna*, and *Gliricidia* species were decomposed, and their effects on soil microflora were studied. Bacterial densities in all the studied plots of the two agroecozones varied from the order of 10^8 to 10^{10} cfu/g, while fungal densities ranged in the order of 10^3 and 10^4 cfu/g. Ecological zones impacted significantly ($P < 0.05$) on bacterial proliferation, but not on fungal growth. Sampling period significantly ($P < 0.05$) affected microbial density and the semi-arid agroecozone was more supportive of microbial proliferation than the arid zone. A total of nine predominant fungal species belonging to the genera *Aspergillus*, *Scopulariopsis*, *Alternaria*, *Penicillium*, *Micromonospora*, *Trichophyton* and *Neurospora* were observed in both the semi-arid and arid agroecozones, although their distributions under both agroecozones did not follow any definite pattern.

Key words: Microflora types, agroforestry topsoil, culturable microbes, bacteria, fungi, soil enrichment.

INTRODUCTION

Soil microorganisms constitute the basic consumer trophic level of the decomposer subsystem (Wardle et al., 1997). As such, they control the breakdown of organic matter and hence the release of nutrients and their availability to other organisms thus contributing to maintaining long-term agricultural sustainability through net productivity of the agroecosystem (Jenkinson, 1988; Robertson et al., 1994).

West Africa covers a wide range of agroecological zones (agroeco-zones), which are classified by the length of growing period (LGP) (Tian et al., 2007). The LGP is determined by rainfall amount, rainfall pattern and potential evaporation. Although solar radiation was not a criterion for dividing West African agroeco-zones, it is the main cause for the variation in evaporation as temperature regimes in West Africa are uniform with little seasonal variation (Jagtap, 1995). Other workers have reported that since different agroeco-zones have different climatic conditions, the decomposition rate of plant residues varies with agroeco-zones (Vanlauwe et al., 1997; Couteaux et al., 2002). The natural decomposition rate of plant residues is well known to decrease with the decrease in moisture availability largely determined by rainfall amount and solar radiation, thus there is a decreasing gradient of decomposition rates from the humid to arid West Africa (Tian et al., 2007).

In West Africa, plant residues are often applied as mulch in crop cultivation, leading to an increase in soil

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moisture levels of such soils (Lal, 1978; Tian et al., 1993b). Such increases in soil moisture can accelerate the plant residue decomposition. However, the degree of increase in decomposition due to mulching effect would be different in different agroeco-zones of West Africa, and as well on different plant residues. The mulching effect-induced decomposition is expected to be greater in the dry than the wet agroeco-zones as the moisture availability is more limited in the dry compared to wet agroeco-zones (Tian et al., 2007), and this is expected to variously affect the microbial community structure.

The increasing interest in using plant residues as main nutrient source in low-input agriculture in the tropics has led to greater consideration for decomposition studies aimed at better residue management. During decomposition of litter, nutrients are either released (mineralized) or immobilized as a result of soil microflora and microfauna activities, depending on the chemical composition of the residue; C/N ratio, lignin and polyphenol concentrations thus contributing to nutrient and carbon cycling (Gallardo et al., 1997; Hoorens et al., 2003).

In our previous studies (Okoh et al., 1999a) we observed significant differences in the dynamics of populations of springtails, culturable bacteria and fungi in the topsoils of several plots of different agroforestry species. It was noted that plantation type significantly influenced species diversity of culturable microbial communities (Okoh et al., 1999b; Okoh et al., 2000). Tian et al. (1995) further developed an equation for calculating plant residue quality index (PRQI) in forest-savannah transition zones of tropics based on the C/N ratio, lignin and polyphenol concentration of the plant residues. But in determining this index, the important ingredients of the microbial community structure especially under other ecological conditions were not considered. In this paper, we report the dynamics of culturable bacterial and fungal communities in the topsoils during decomposition of five plant residues used as mulch materials in typical semi-arid and arid agroecozones of West Africa.

METHODOLOGY

Study site

The study was conducted in the dry season between 2000 and 2001 at two sites in Nigeria located in Kano and Zinder representing major West Africa agroecozones. Kano (12°3'N, 8°32'E) is in the region of Sudan Savanna agroeco-zone (semi-arid climate, LGP = 90 – 150) with a mean annual temperature of 26.7°C, rainfall (monomodal) of 686 mm and sunshine hours of 2,941. Zinder (13°58'N, 8°53'E) is located in the Sahel agroeco-zone (arid climate, LGP<90) with a mean annual temperature of 28.7°C, rainfall (monomodal) of 402 mm and sunshine hours of 3,345. Detailed descriptions of these sites are articulated in our recent report (Tian et al., 2007).

Agroforestry species

The plant residues used in this study were species native to sub-Saharan Africa and includes *Dactyladenia*, *Pterocarpus*, *Alchonea,* *Senna*, and *Gliricidia* species, as well as a litterbag (empty) control.

Activities

A maize plot (10 × 10 m) was selected in each of the locations of this study. Litterbags (24 × 26 cm and 5 mm mesh-size) containing 42 g per bag of oven dried weight material of each plant residue were laid on each maize plot in triplicate for a period of 14 weeks. Topsoil (7.5 cm depth) samples underneath the litterbags were collected in sterile sterilin tubes and transported to the laboratory on ice pack for culturable bacteria and fungi determination as described in our previous report (Okoh et al., 1999a). Culturable aerobic heterotrophic bacteria and fungi colony forming units determined using standard pour plate technique (Seeley and VanDenmark, 1981). 1 g of the soil sample was transferred into a McCartney bottle containing 9 ml of sterile normal saline solution which was regarded as the stock suspension, from which serial dilutions were prepared using sterile peptone water. 1 ml of each dilution was plated in triplicate. Nutrient agar (Difco) known to support the growth of most aerobic and heterotrophic bacteria (Davies et al., 1980) was used for the bacterial count. Meanwhile, potato dextrose agar (Difco) containing 64 µg/l penicillin G was used for fungal estimation. Plates with microbial colonies of between 30 and 300 were selected for enumeration and the numbers of colonies were multiplied by the dilution factors (DHSC, 1969). Fungal types whose colony forming units (cfu) from the 10^{-2} dilutions were equal to or greater than 10 cfu were regarded as predominant and were selected for identification as described by Talbot (1978).

Statistical analyses

The statistical analysis was done using the SAS version 9 Software. All tests were carried out at a 5% level of significance. To test for condition, plot and week effects on the microbial density, a three way analysis of variance (ANOVA) was used. In the event of a significant effect having been detected, the Tukey's multiple comparisons procedure which gives the minimum significant difference was used to separate the levels of the significant effect. Any differences exceeding the minimum significant difference were considered to have a statistical significant difference.

RESULTS AND DISCUSSION

The culturable bacterial communities in the topsoil of all the treatment plots in the semi-arid agroecozone generally increased in density in the 8^{th} and 14^{th} weeks after an earlier lull in the 4^{th} week. Initial bacterial densities in the plots ranged between 7.1×10^8 and 1.1×10^9 cfu/g, and increased to between 1.6×10^{10} and 3.7×10^{10} cfu/g in the studied 14^{th} weeks period as the observed plant residue decomposition progressed (Figure 1). Peak fungal density was observed in the *Senna* applied plot to reach 5.7×10^4 cfu/g during the 4^{th} week, and fungal densities were lowest in all plots during the 14^{th} week (Figure 2). In the arid agroecozone, initial bacterial density ranged between 1.5×10^8 (*Gliricidia* applied plot) and 6.5×10^8 (*Alchornea* applied plot) cfu/g, and reached maximum levels in the *Pterocarpus* applied plot (8.24×10^8 cfu/g) in the 8^{th} week (Figure 3). Initial fungal density in the arid zone varied from 1.0×10^3 (*Dactyladenia* applied plot) to 1.46×10^4 (*Alchornea* applied plot) cfu/g.

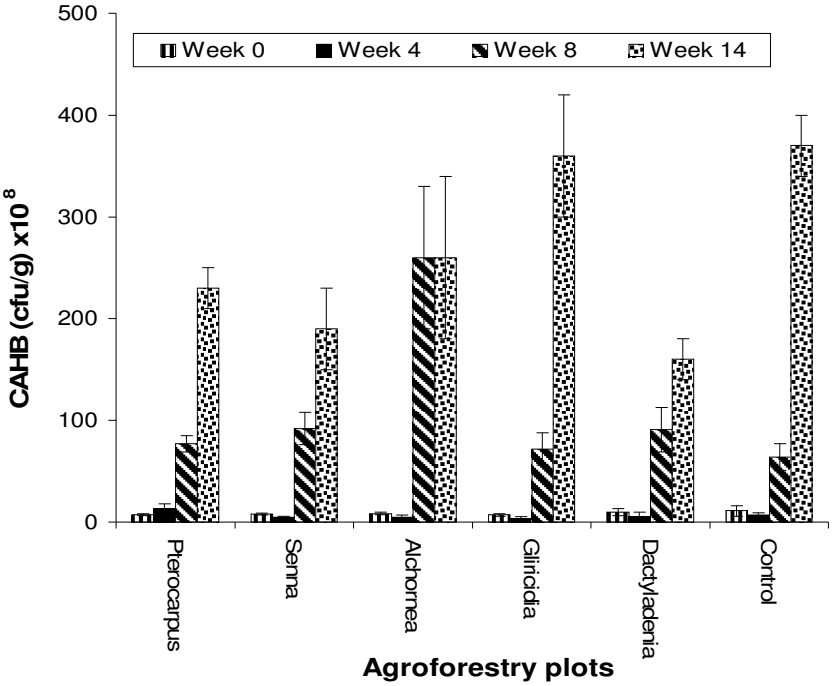

Figure 1. Response of the soil culturable aerobic heterotrophic bacterial (CAHB) communities during decomposition of leaf litters of different agroforestry species in a typical semi-arid region of Nigeria.

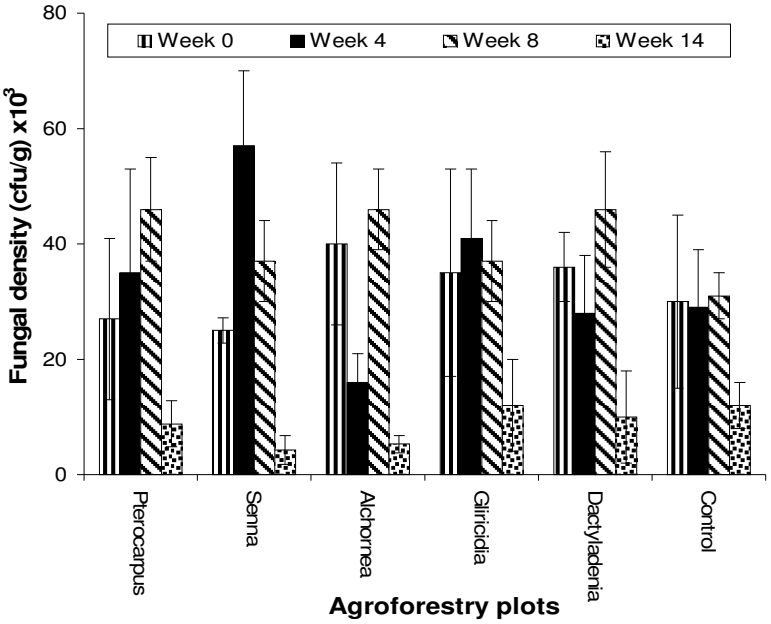

Figure 2. Response of the soil fungal communities during decomposition of leaf litters of different agroforestry species in a typical semi-arid region of Nigeria.

Fungal density reached peak level of 9.23×10^4 cfu/g in the plot that had *Alchornea* plant tissue material in the 4th (Figure 4). A total of nine predominant fungal species were observed in the semi-arid agroecozone (Table 1), while eight species were observed in the arid zone (Table 2). The fungal isolates belonged to the genera *Aspergillus*, *Scopulariopsis*, *Alternaria*, *Penicillium*, *Micromonospora*, *Trichophyton* and *Neurospora*.

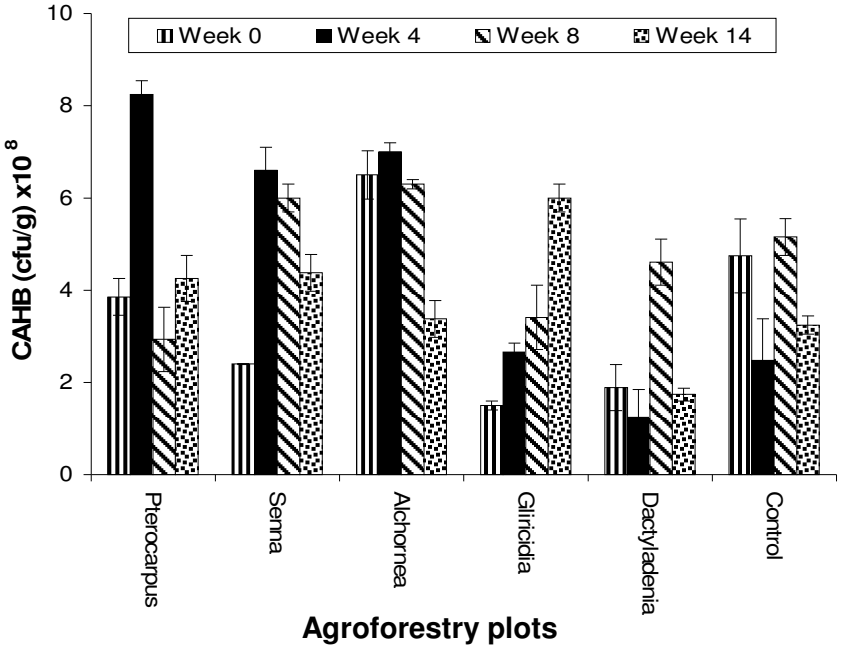

Figure 3. Response of the soil culturable aerobic heterotrophic bacterial (CAHB) communities during decomposition of leaf litters of different agroforestry species in a typical arid region of Nigeria.

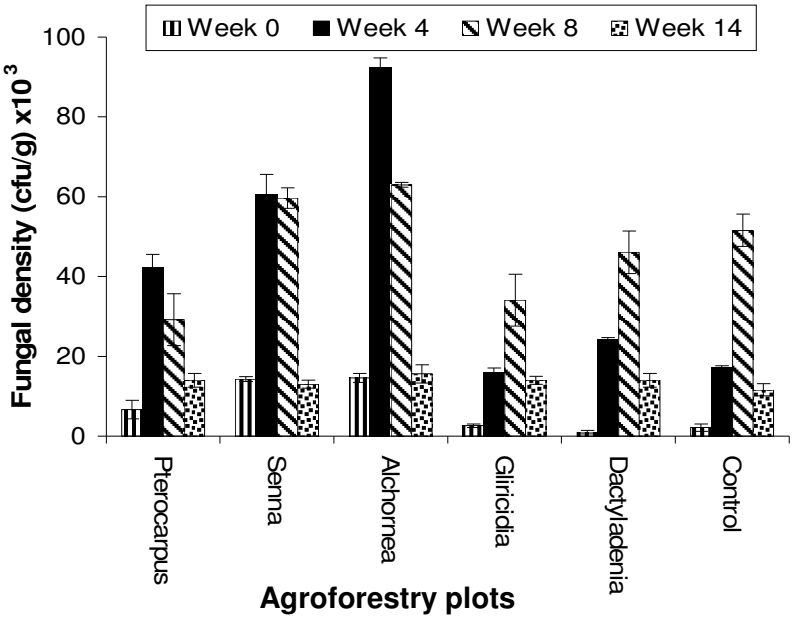

Figure 4. Response of the soil fungal communities during decomposition of leaf litters of different agroforestry species in a typical arid region of Nigeria.

The decomposition of the litters of all the plant residues used in this study resulted in an increase in microbial biomass especially in the early stage of the decomposition in accordance with the system-theoretical hypothesis of Odum (1956, 1969). Similar research outcomes were reported by Dilly and co-workers (2004). The microbial densities observed in both studied agroecozones is quite comparable with the range reported by other workers on similar study (Alexander, 1977). However, the magnitude of the microbial densities

Table 1. Regimes of the predominant fungal isolates observed in the soils at the beginning (Week 0) and termination (Week 14) of the leaf litter decomposition study in the semi-arid region of Nigeria.

Predominant fungal isolates	Agroforestry plots applied with											
	AL		GL		SE		PT		DA		CN	
	0	14	0	14	0	14	0	14	0	14	0	14
Aspergillus niger												
Aspergillus fumigatus	√	√				√		√		√		√
Aspergillus flavus	√	√	√	√				√		√		
Scopulariopsis brevicaulis	√		√									
Alternaria sp.	√		√	√	√	√	√	√	√		√	√
Penicillium camemberti	√	√	√	√			√	√	√	√	√	
Micromonospora sp.										√	√	√
Trichophyton rubrum						√						
Neurospora pseudophilia				√					√		√	√
Total	5	3	4	4	1	3	2	4	3	4	4	4

AL, *Alchornea*; GL, *Gliricidia*; SE, *Senna*; PT, *Pterocarpus*; DA, *Dactyladenia*; CN, Control.

Table 2. Regimes of the predominant fungal isolates observed in the soils at the beginning (Week 0) and termination (Week 14) of the leaf litter decomposition study in the arid region of Nigeria.

Predominant fungal isolates	Agroforestry plots applied with											
	AL		GL		SE		PT		DA		CN	
	0	14	0	14	0	14	0	14	0	14	0	14
Aspergillus niger	√	√	√	√			√				√	√
Aspergillus fumigatus	√	√	√		√					√	√	√
Aspergillus flavus					√	√	√			√	√	√
Scopulariopsis brevicaulis		√										
Alternaria sp.				√				√	√			
Penicillium camemberti				√	√		√	√	√		√	√
Micromonospora sp.					√	√		√			√	
Trichophyton rubrum	√		√			√			√	√		√
Total	3	3	3	3	4	3	3	3	3	3	5	5

AL, *Alchornea*; GL, *Gliricidia*; SE, *Senna*; PT, *Pterocarpus*; DA, *Dactyladenia*; CN, Control.

are lower than we previously reported for an agroforestry arboretum (Okoh et al., 1999a) and a biosphere reserve in a humid ecological setting (Okoh et al., 2000).

Also, whilst the variation in bacterial and fungal densities in the different plots for each agroecozone were not significantly different, the impact of ecological zones were for bacterial proliferation ($P<0.05$), but not for fungal growth. It was noted that sampling period significantly ($P < 0.05$) affected microbial density in the semi-arid agroecozone, which supported more growth as indicated by the microbial proliferation than the arid setting (Table 3). The variations observed under the different treatments could be related to the expected variations in the organic qualities of the different plant residues used. Dilly et al. (2001) and Neely et al. (2001) reported that the change in the quality of the organic matter induces a succession of microbial communities, with some dominating at specific stages in the decomposition process (Rosenbrock, 1995). Wardle et al. (1999) and Robinson et al. (1999) suggested that a decline in bacterial proliferation during the decomposition period could be due to the release of some toxic bactericidal compounds from the plant residues. Such compounds can be furnished into the soil if one of the component litter materials contains high amounts of secondary compounds, such as phenolic compounds, which are known to slow down the decomposition of litter mixtures in several ways by forming resistant complexes with proteins (Hättenschwiler and Vitousek, 2000) thus directly inhibiting microbial growth and activity (Hoorens and Stroetenga, 2003).

However, unlike in the case of bacteria, the soil fungal densities generally increased up to the 8th week period. It

Table 3. Results of statistical analysis.

Bacteria					
Source	**DF**	**Anova SS**	**Mean square**	**F value**	**Pr > F**
Condition	1	102228.7110	102228.7110	20.58	<.0001
Plot	5	7228.5973	1445.7195	0.29	0.9150
Week	3	129681.4543	43227.1514	8.70	0.0002

Tukey's Studentized Range (HSD) Test for density.
Minimum significant difference 41.187.
Means with the same letter are not significantly different.

Tukey grouping	Mean	N	Condition
A	96.49	24	Semi-arid
B	4.19	24	Arid

Fungi					
Source	**DF**	**Anova SS**	**Mean square**	**F value**	**Pr > F**
Condition	1	25.056300	25.056300	0.12	0.7323
plot	5	1262.496667	252.499333	1.20	0.3295
week	3	8524.065900	2841.355300	13.46	<0.0001

Tukey's Studentized Range (HSD) Test for density.
Minimum significant difference 8.4906.
Means with the same letter are not significantly different.

Tukey grouping	Mean	N	Condition
A	28.933	24	Semiarid
A	27.488	24	Arid

will appear that factors other than the plant residues influenced the observed increases in the fungal growth as implied by the similar fungal densities observed in all the plots in the 14th week. Also, a total of nine predominant fungal species belonging to seven genera were observed in both the semi-arid and arid agroecozones. Although the occurrence of the fungi species appears to be higher in the semi-arid zone, their distributions under both ecological zones did not follow any definite pattern.

Conclusion

The culturable aerobic bacteria and fungal communities in this study responded variously during the course of decomposition of the plant residues. Ecological setting was observed to impact significantly on bacterial communities, with the semi-arid agroecozone being more supportive of bacterial proliferation than the arid zone. Fungal communities were similarly affected by the two climatic conditions.

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