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Decomposition of a Native Shrub, *Piliostigma reticulatum*, Litter in Soils of Semiarid Senegal

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Developing effective management strategies that restore degraded soils requires an evaluation of the quality of the litter residues. This study relates the chemical composition of the biomass components to the decomposition rates for Piliostigma reticulatum *(DC.) Hochst., a native shrub, under field and laboratory conditions. The rates were determined by mass loss. The changes in the specific surface area of the residue in relation to mass loss ranged from 15 x 10*$^{-5}$ *to 45 x 10*$^{-5}$ *which was similar to crop residues in other studies. At field conditions,* P. reticulatum *mass loss was higher (80% of the initial mass lost over eight months) than that under controlled conditions (50%). Such fast decomposition of residues offers the potential for farmers to stop burning these residues because high amounts of residues will not likely accumulate and cause interference with tillage and planting operations. Further studies are needed on the role of soil fauna on decomposition, mineralization of nutrients from these residues, and the potential for incorporating residues into the system without burning.*

Keywords soil quality, soil organic matter, litter residues, mass loss, management strategies

Maintaining crop residue on the soil surface is an effective method of controlling soil erosion and degradation provided that there is enough plant residue. However, in many areas of the world, insuffkient amounts of residue are produced to provide adequate soil cover and protection. In Senegal, there is little information available on how plant resicl ues, left on the soil surface, affect soil quality (Chopart et al. 1979). Several studies have focused on the incorporation of green manure in the soil

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(Dommergues 1956), crop residues (Chopart, Nicou, and Vachaud 1979; Bernhardt-Reversat 1987; Feller and Ganry 1982) and composting (Feller and Ganry 1982; Ganry and Sarr 1985; Feller, Chopart, and Daucette 1987; Seck 1987). Most of this work aimed to increase crop yield in thc short term, where the major contribution cornes from input of nutrients. However, another important nonnutrient contribution of organic amendments is its role in building soil structure, organic matter and maintaining biological activity. This is important in tmproving and sustaining long-term crop yields.

Although crop residues can have a beneficial effect on soils, very little of the crop residue in Senegal and most of Sub-Sahara is returned to the soil because it is too valuable as a food source for livestock (persona1 communication, A. Badiane, ISRA, Senegal). Consequently, other organic matter sources are needed in Senegal. Even though manure and composting are available, there are insufficient amounts that can be readily collected to apply in all fields of a typical Senegalese farm (Ganry and Guiraud 1979, Pichot, Truong, and Bcunard 1979).

Organic matter management is of critical importance in Senegal because of the low fertility status of soils and the declining yields that may be due to degradation of soils. This is likely occurring because of increases in the rural population and associated intensification of agriculture, e.g., marked decreases in land fallowing for regeneration (Diack et al. 1998). In the absence of appropriate residue management technologies, the parkland system with optimal tree or shrub species, or both, may be an alternative approach for restoring degraded soils. Currently, there is little information available on how traditional shrubs of the parkland systems improve degraded soils.

Piliostigma reticulatum (DC.) Hochst (Breman and Kessler 1995), a shrub species, is commonly found in the major peanut and millet growing regions in Senegal. P. *reticulatum* is a nonnodulating legume and could be considered as a "ratoon cover crop" after the cropping season. In farmers' fields, the aboveground biomass of P. *reticulatum* is cut at the soi1 surface and burned just prior to the rainy season. As it regrows during the rainy season, it is cut again at every weeding. After the growing season, it regrows to hcights of 0.70 to 1.OO m and canopy diameters of 0.75 to 1.75 m and has rooting depth of 2.5 to 3 m with as many as 700 shrubs ha^{-1} (Diack et ai. 1998). *P. reticulatum* biomass could be an Important organic matter source for soils in Senegal with preliminary estimates of >0.5 Mg ha^{-1} aboveground dry biomass (Diack et al. 1998). However, to use these materials rather than burning them, it would be important to dctermine the litter quality and rate of decomposition to effectively manage it from an agronomic perspective. Since P. *reticulatum* is a woody species, it may decompose too slowly and interfere with crop cultural activities. Therefore, understanding how rapidly *P. reticulatum* residues decompose and are lost from a field site, is a prerequisite to the design of effective management strategies for soil improvement.

The objectives of this study were: (1) to determine decomposition ratés for *P. reticulatum* aboveground residues and roots by mass loss under field and laboratory conditions; (2) to determine the relationships between chemical and physical characteristics of the residues and their rates of decomposition; (3) to determine whether the previous crop affects the residue quality as measured by chemical analysis and rates of decomposition; and (4) to provide guidance for future studies-on management strategies of *P. reticulatum* in farmers' fields to improve the quality of the soils.

Materiais and Methods

Site

The experimental site was located in Paoskoto, Kaolack, a semiarid agroecological zone in the peanut basin, between 13" 35' and 14" 30' of northern latitude and 14"

35' and 16° 45' of western longitude. The region is characterized by a tropical Sudanian climate with an annual rainfall of 700 mm. Temperatures vary between 16°C in December -January and 39°C in April–June.

Soil

A Deck Dior loamy-sand (fine-sandy, mixed Haplic Ferric Lixisol), leached ferrugeneous tropical soil (probably an Ultisol), was used in this study (Table 1). It was collected from the Ap horizon (0-10 cm depth) at a farmer's field that had been under millet (*Pennisetum glaucum* L). The soil was air-dried, crushed to pass 2 mm mesh screen, then stored until use. This field and soil was used for subsequent field and lab incubation studies.

Plant Materials

The *P. reticulatum* materials were randomly collected from each of two farmer's fields which are under a 2-year rotation of peanut (*Arachis hypogaea*, L.) and millet. One field was under peanut and the other under millet the previous year before collecting the residues. P. *reticulatum* residues were separated into different residue types: leaves, stems, and roots.

Chemical Analysis and Mass Ratio of Plant Residue

The relative mass was 17%, 26%, and 56% for leaves, stems, and roots, respectively. The relative mass of aboveground biomass for leaves and stems was 40% and 60%, respectively. Each plant residue component was analyzed for total C and total N contents by dry combustion (Model CHN-600; Leco Corp.). Fructose was determined spectrophoto-colorimetrically (Davis and Gander 1967). Cellulose, hemicellulose and lignin contents were measured by sequential fiber analysis (Goering and van Soest 1970).

Mass Loss Experiment under Laboratory Conditions

The experiment consisted of a randomized complete design with two crop rotations, and three residue treatments with three replications. The three treatments were leaves, stems, and roots. Stems were cut into pieces of 4 to 5 cm long and 5 g of residue were spread out on 100 g air-dry soil in a 15 x 9 cm polystyrene dish and then covered with another 100 g of air-dried soil. The soil was brought to a moisture content of -- 33.3 kPa water potential which equalled 60% water holding capacity, plus 300% of the residue mass (Myrold et al. 1981). After addition of the appropriate amount of water, the incubation dish was covered with a perforated cap to allow aeration. The samples were incubated at 30°C ± 1°C.

Samples were withdrawn on day 3, 7, 14, 28, 56, and 84 of the incubation for mass loss measurement. At each destructive sampling, the incubation mixture was oven-dried at 50°C, for 48 h. When dry, the residues were carefully separated from the soil, gently washed to remove the soil particles, and put back into the oven at

TABLE 1 Soil physical and chemical characteristics

Soil sample	Clay	Silt	Sand	pH	Total organic C	Total N
	%				$g \cdot kg^{-1}$	
0 -10 cm	10.1	5.2	84.7	6.7	4.68	0.45

50°C for 48 h. The residues were weighed, then placed in crucibles for ashing at 500°C for 3 h, and reweighed after ashing. The residue remaining after ashing was assumed to be of soil mineral origin, and this was subtracted from rhe weight of the pre-ashed plant residue.

Mass Loss Experiment under Field Conditions

Leaves, stems, and roots constituted the three residue types for this experiment. One hundred g of air-dried residues were placed into a 25 x 25 cm bags (2 mm mesh) and sealed as litter bags. The samples were incorporated (3 July 1997, beginning of rainy season) into the top 10 cm of a field in a 3 x 2 factorial experiment with three *P. reticulatum* residue types (stems, leaves, and roots) and two P. *reticulatum* residue sources (from peanut or millet field) with three replications. This field was previously under millet (source of *P. reticulatum*) but was under peanut when buried bags were in the field.

Samples were withdrawn monthly and eight months after placement of residue bags into the soil. At each destructive sampling, the residues within the litter bags were oven-dried at 50°C for 48 h. When dry, the residues were taken off from the litter bags and processed in the same way as the iaboratory experiment to determine the mass loss.

Soil water potential during the season was -- 1000 MPa in July, 1997, then increasing to its highest level in September at --0.5 MPa, and then decreasing to -50 MPa in October, followed by a steady decline to 120 MPa by February, 1998.

Specific Surface Area-to-Mass Ratio

Specific surface area-to-mass ratios were represented by a k value uith a dimension of ha kg^{-1} of residue. Specific surface areas for leaves and stems were measured using a digital-planimeter (Model Ottplan 700/710, A. OTT GMBH, Kempten, Germany). As decomposition proceeds, the ratio between the specific surface area and the mass remaining was calculated over time The equation used to çonvert residue mass to surface cover (Gregory et al. 1985) is expressed as:

$$C = 1 - e^{(-km)}$$

where C is thc fraction of the surface cover remaining; m is the mass (kg ha^{-1}) of residue present on the surface; and k a constant. The constant k was derived from the following equation :

$$k = -\log(1 - C)/m.$$

Statistical Analysis

Statistical analysis of the data was done to determine differences among treatments, using MSTAT-C, Version 1 (MSTAT-C, 1991, MSU, MI). Comparisons between treatment means were computed at the $P = 0.05$ and $P = 0.01$ levels, using the Duncan's multiple range test procedure.

TABLE 2 Initial chemical composition of *Piliostigma reticulatum* residues collected from a peanut or millet field

Previous field crop	Residue type	Total C	Total N	Fructose	Cellulose	Hemicellulose	Lignin
		$g\,kg^{-1}$					
Peanut	Leaves	483b*	13.8a	18.7c	241c	22c	242b
	Stems	536a	7.5b	42.3a	448a	62b	220c
	Roots	529a	6.3b	30.4b	382b	96a	264a
Millet	Leaves	474c*	12.3a	20.1c	202c	50c	247b
	Stems	500b	7.7b	40.8a	379a	90b	228c
	Roots	545a	7.0b	37.7b	420b	123a	294a

* In each column. values followed by the same letter, are not significantly different by the Duncan's multiple range test at $P = 0.05$.

Results and Discussion

Initial Chemical Composition for the P. reticulatum Residues

The mean concentrations of total C and N, fructose, hemicellulose, and lignin (Table 2) were significantly different between P. *reticulatum* residue types as expectcd. However, the prcvious crop generally had a significant ($P < 0.05$) effect on the chemical properties for most residue types. The analysis of the structural componers. cellulose, hemicellulose, and lignin, although showing some differences in means between the field source of the shrub residue these were not statistically different when comparing each individual residue (Table 2).

Changes in Mass Loss under Field Conditions

Under field conditions, 82% of the roots (Fig. la) was lost during an 8-month period whereas 78% of stem residues was lost and only 40% of the leaves disappeared for thc residue that originated from a field where peanut was pervious crop. During the first month of decomposition, the stem mass loss was greater (~ 42%)

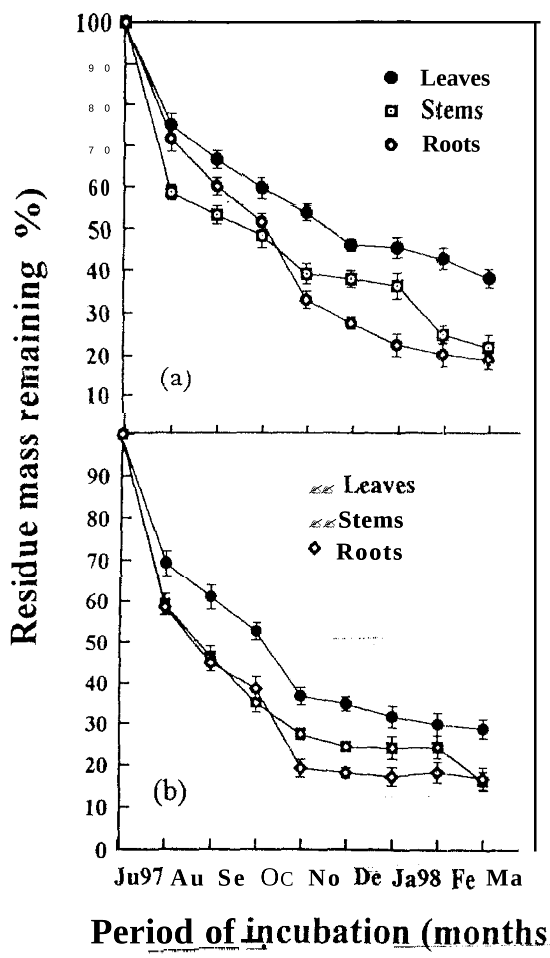

FIGURE 1 Decomposition of *P. reticulatum* residues that originated from a peanut field (a) or millet field (b), under field conditions. Bars represent standard deviations.

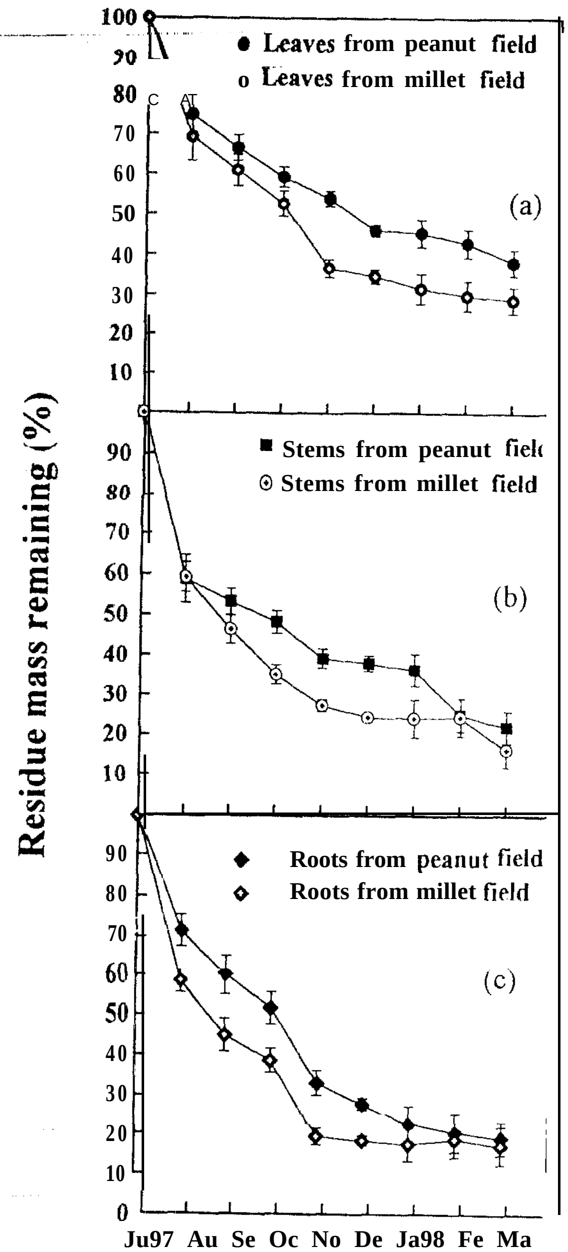

FIGURE 2 Field decomposition of *P. reticulatum* (a) leaves, (b) stems, and (c) roots originating from either peanut or millet fields. Bars represent standard deviations.

than that for the roots (~ 28%) and the leaves (~ 25%). *P. reticulatum* residue stems and roots originating from the millet field had equal cumulative mass losses of 82% (Fig. 1b) compared to leaves which had 70% losses. After one month, stems and roots lost 42% of their mass, while the leaves lost only 32%.

The previous crop affect (Fig. 2a) was a significant ($P < 0.05$) of the origin of leaf residue with a 70% loss of leaves from the millet field compared to 60% loss of

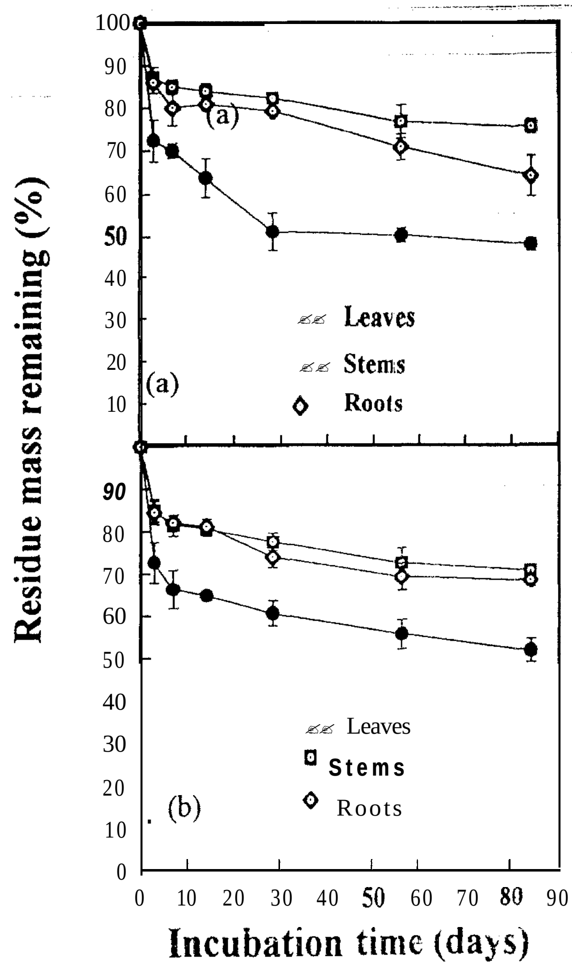

FIGURE 3 Laboratory decomposition of *P. reticulatum* residues, originating from peanut field or (b) millet field. Bars represent standard deviations.

leaves from the peanut field. No significant difference was noted (Fig. 2b) betwe loss of stem mass originating from the millet field (82%) or the peanut field (79"; Root mass loss also (Fig. 2c) was not significantly different from millet field (82 and peanut field (80%).

Under field conditions, the decomposition ratcs for all the *P. reticulatum* residues (Fig. la, lb, 2a, 2b, and 2c) followed an exponential 3-phase pattern. The rapi mass loss during the first month was probably due to a high total N content, a hig level of readily available C in the fonn of extractable sugars or, a combination of both. Kinetically, the mass loss from the residues exhibited a linear dependence o the chemical composition of the residue during this period. The rapid disappearance of these soluble compounds was probably due to a quick build up of the microbial activity, which would increase the mass loss. Also, the readily available C and N components in the crop residues might provide the initial energy and nutrients necessary to activate the microorganisms that are responsible for the degradation of the less readily available components of the residue.

The leveling off phase for mass loss occurred from two to four months whic is likely when mainly recalcitrant materials remains. During this period, hemicellulose is likely the main fraction available to the microorganisms (Collins et al. 1,990; Sto

1993). As the decomposition proceeds, the rate of mass loss slows down, following an exponential curve, probably due to the recalcitrance of the remaining residue. After four months of decomposition, the remaining residues entered a third phase during which the slowly available residue components dominated in the substrate. Lignin, which is one of the most resistant plant compounds, was probably the major remaining componcnt during this phase of dewmposition.

The rate of lignin degradation is less affected by changes in temperature and nitrogen availabiliiy than other major plant components during decomposition (Sarkanen and Lucwig 1971). Another factor for slow decomposition is that lignin decomposers are relatively slowly growing microorganisms (Witkamp and van Der Drift 1963). As result, the rate of mass loss follows a steady-state for the rest of the decomposition process.

Root and stem residues from the peanut field (Fig. la) have undergone greater cumulative mass loss than the leaves. This is probably due to higher fructosc content in the roots and stems than in the leaves of P. *reticulatum.* The physical and chemical composition of the residues and, particularly soluble C in the form of fructose, constitute the most important--factors controlling decomposition rates (Knapp, Elliott, and Campbell 1983). Residue decomposition is a process in which the rate transformation is proportional to the qualitative amount of residue available to thc rnicroorganisms. Our decomposition patterns (exponential decreases) were similar to other decomposition studies and Papendick (1978), Knapp et al. (1983), Stott et al. (1986), Stroo et al. (1989), Collins et al. (1990) and Jensen (1994).

Changes in Mass Loss under Laboratory Conditions

Thc *P. reticulatum* leaves that originated from the peanut field (Fig. 3a) lost a greater amount of mass (50%) than the roots (35%) and the stems (24%) in eight months. During the first month, leaf residue mass loss was significantly different (~28%) than both stems and roots (~ 13%). Leaf mass loss was 48% whereas for the roots and the stems originating from the millet field, mass loss was only 30% (Fig. 3b). The first month of decomposition showed a greater mass loss for the leaves (~28%) than either stems or roots (~ 15%) for residues of the millet field.

Unlike the field study, no significant effect on the residue cumulative mass loss was notcd as a funct: on of the source of residue. Leaf residue mass loss from peanut. field was 5 1% while tha.t from the millet field was 49% (Fig. 4a). Mass loss of stems from the peanut field was 25% which was not significantly different from that of the millet field (28%) (Fig. 4b). Root mass loss from the peanut field was 35% while that from the millet field was 30% (Fig. 4c).

Under laboratory conditions, the same pattern of rates of decomposition was obscrved as the field study. However, the decomposition rate of the leaves seemed greater than the stems or roots, which is the opposite of the field data. This may be relatcd to several factors such as prehandling of the soil by air drying and sieving the soil in the lab study. Another factor is that lab conditions excluded large fauna. Morcover, the soil is sandy and has very low total C and N contents (Table 1). Because of this low fertility level, soil microorganisms are probably relatively dormant. The discontinuous distribution of organic resources in soils causes soils to have a large dormant population, which is rich in species and has an ability to survive stress (Jenkinson and Ladd 1981). According to Lavelle (1996), this resting time can last from months to years.

Therefore, redistribution of microorganisms and organic substrates by invertebrates and roots that mix the soil and add water and readily available substrates to the soil may be important in activating microbial activity and decomposition. These invertebrates could be divided into three major functional groups: micropredators, litter transformers, and ecosystem engineers (Lavelle 1996). We did not check whether any of these major functional groups were present in the soil.

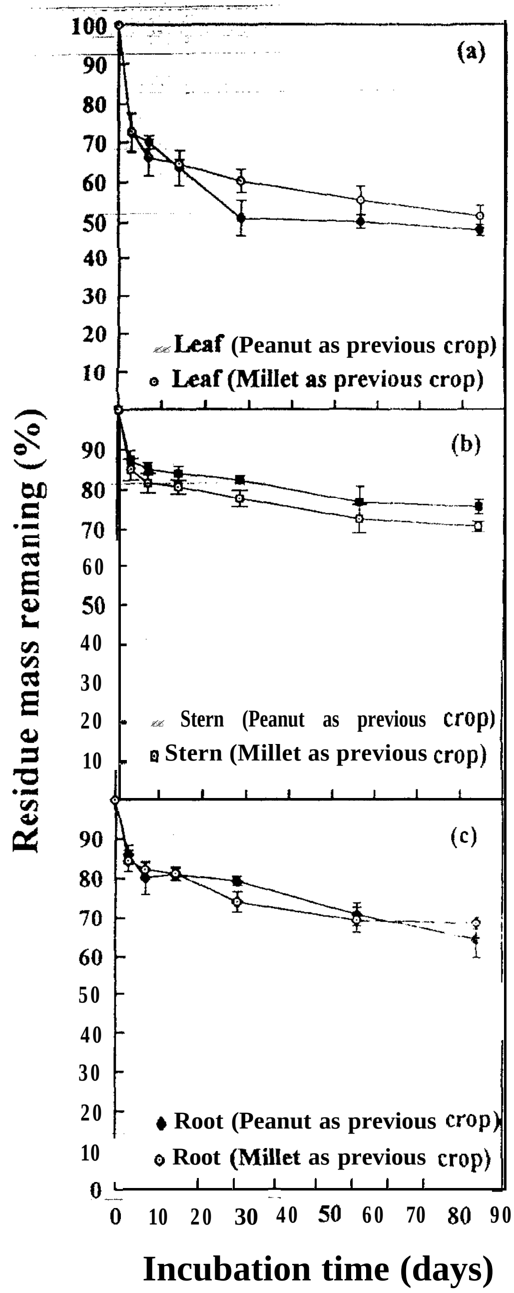

FIGURE 4 Laboratory decomposition of *P. reticulatum* (a) leaves, (b) stems, and (c) roots originating from peanut or millet fields. Bars represent standard deviations.

iiowever, based on their size, the micropredators are the smallest invertebrates, protozoa and nematodes of the microfauna (average size <0.2 mm). At the next level, litter transformers include the small *Oligochaeta enchytraeidae* and arthropods of the mesofauna (<2 mm) and macrofauna (>2 mm) that serve as incubators for microbial activities. The third group is composed of few large invertebrates, mainly earthworms, (*Lumbricus terrestris)* and social insects, e.g., ants (*Formica sp.*) and termites (*Termitis terrestris*). Qualitative field observations indicated the presence of termites.

Based on the screen mesh size (2 mm) at which the soil has been sieved, our soil could certainly contain micropredators and litter transformers as functional groups. That may explain the loss mass loss observed under laboratory conditions as compared to higher decomposition rates obtained under field conditions. Leaf residues degraded much faster than stems or roots in the lab study. In the absence of ecosystem engineers in the lab study, high N content of the leaves may have been more important in the lab study because decomposition was largely done by the microbial community (Fig. 3a and 3b).

Changes in Specific Surface Area-to-Mass Ratio of the Residues

Changes in the rate constant (k) developed from data shown in Fig. 5a and 5b were highly significant for the leaves for both peanut and millet fields. For the stems, the k value was rather low and stayed at a steady-state over time. This is duc to a greater decomposltion rate of the leaves than the stems under iaboratory conditions.

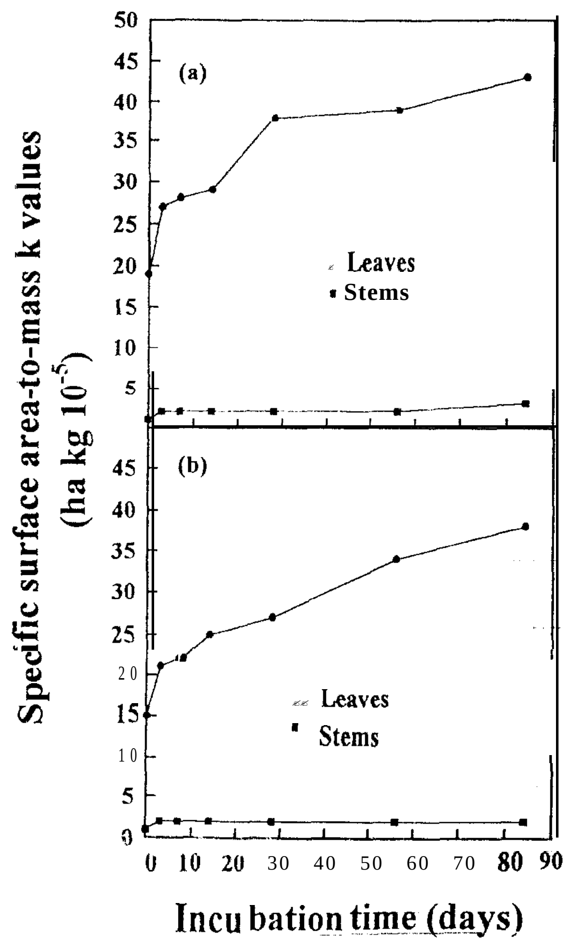

FIGURE 5 Change in specific surface area-to-mass (k) value for *P. reticulatum* residues originating (a) from peanut or (b) millet fields.

Values of k for *P. reticulaturn* residues, varied between 15 $\times 10^{-5}$ and 45 $\times 10^{-5}$ and are close to those obtained for most crop residues. Stott (1994) found a mean k value of 23 $\times 10^{-5}$ for maize while Diack (1994) noted for sorghum, peanut, and cotton, k values of 19 x 10^{-5}, 29 x 10^{-5} and 48 x 10^{-5} respectively. The use of a specific surface area-to-mass ratio is important for developing soil management strategies.

Indeed, an increase in k during decomposition indicates that the rate of organic matter input into soil is changing which should mean an increase in soil quali ty and greater protection against erosion. An increase in k over time means a fast mass loss of the residue with a relatively slow decrease in specific surface area. When k changes slowly over time, this means that not only mass loss is nonsignificant, duc in part to the quality of the residue, but also because the specific surface area changes little. Since we placed the residues just under the soit surface, previous work (Stott 1994) would indicate that decomposition rates would be the same il' we placed the residues on surface. Thus when k values are low, the soil surface will provide a good cover and therefore better protection from erosion. The surface area-to-mass relationship can be closely related to the levels of residues and, considerable decomposition of mass may occur before a large decrease in area is tneasured (Steiner, Schomberg, and Morrison 1993).

For residues having a high proportion of leaf material, there may be tremendous loss in mass with Little loss in cover, because leaf material decomposes rapidly and is light compared to stem material (Stott 19933. Stems will lose mass, not surface area. Soil cover can be achieved by an optimal quantity of biomass required to cover the soil, a quantity based on the quality level of that biomass because the loss of residue mass and surface cover are simultaneously a function of the quality of biomass. For the type of degraded soil in Senegal, soil cover is critical because the long dry season of eight to nine months. As one assures a soil cover with *P. reticulatum* residues, one can accumulate organic material in the soil and thereby increases soil organic matter over time.

Perspectives

Under field conditions, *P. reticulatum* lost up to [illegible]% of its residue mass. This decomposition rate was higher than that under laboratory conditions. This might be explained by the role of soil fauna, which may have been involved under field conditions but were excluded under laboratory conditions. The study suggests an important role that the large soil invertebrates play in decomposition. The results showed that all components of *P. reticulatum* are rapidly decomposed under field conditions and should be a good source of organic matter for restoring degraded soils. It follows that addition of these residues would stimulate microbial activity and improve soil structure. By-products of decomposition which favor the stable organic matter are important for forming aggregates, thus improving soil quality. This would aid water infiltration and retention. The rapid decomposition of residues offers the potential for farmers to stop burning these residues because high level of residues will not likely accumulate and cause interference with tillage and planting operations. However, further studies are needed on the role of soil fauna in decomposition, mineralization of nutrients from these residues, and potential to incorporate residues into the system without burning.

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