Residue decomposition and termite activity. Nutrient cycling implications for cropland productivity in the West African semi-arid tropics (WASAT)

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Résumé.

L'objectif principal de cette étude est d'examiner le taux de décomposition des résidus organiques attaqués par les termites, étant donné qu'au Niger, les pailles de mil et les fèces des animaux sont sans doute les plus importants des amendements disponibles pour les petits paysans. Trois types de sacs (20 x 20 cm) renfermant des litières ont été testés : ils ont 100 microns, 2 et 7 mm de maille et ont été remplis soit de fèces de mouton ou de tiges de mil coupées à 3 cm. Les sacs ont été soit enterrées à 10 cm de profondeur dans le sol , soit déposées en surface sur les lignes de plantation du millet à 1 mètre de distance(Pennisetum glaucum). Les sacs ont été retirés au 16ème, 30ème, 44 ème ou 115 ème jour après leur mise en place pour évaluer les pertes de résidu et observer les dégâts dus aux termites dans les sacs de maille de la taille des termites (2 et 7 mm).

Quelque soient le mode de placement et le type de sac, la MO des morceaux de paille de mil disparut plus vite (k = 0.0092) que le fumier de mouton (k= 0.0080) . Parallèlement, les activités de termites fut supérieure dans les pailles (2.2) que dans le fumier de mouton (1.5).

Les pertes de MO furent plus rapides dans les sacs enterrés (k= 0.0078) que dans ceux laissés en surface (k= 0.0071). Pourtant l'activité des termites est supérieure dans les sacs placés en surface du sol (3.7) que dans ceux qui furent enterrés (1.3). Quelque soit le type de placement ou de fumier, la MO se décompose plus rapidement dans le sac à maille de 7mm (0.0012), suivi par les sacs à maille de 2 mm (0.0107) et les sacs de 100 microns (k= 0.0057) qui refusent l'accès des termites. L'activité des termites est plus vive dans les sacs de 7 que de 2 mm de maille. En Afrique occidentale semi-aride tropicale, les termites peuvent jouer un rôle important dans le recyclage des nutriments dans ces systèmes à faible apport extérieur basés sur le mil et l'élevage.

Mots - clés . Niger, Termites, Fumier de mouton, Paille de mil, Recyclage des nutriments, Maille des sacs, Mode de placement.

Abstract

The principal objective of this study was to examine the rate of organic residue (millet stalks and livestock manure which are perhaps the most important soil amendements available to farmers of Western Niger) decomposition as influenced by termite. Three litterbag types of 20 x 20 cm with mesh sizes of 100 microns, 2 and 7 mm filled with sheep dung or millet stalks chopped to 3 cm length were used. Bags were either burried 10 cm in soil or placed at soil surface in strips planted to pearl millet (*Pennisetum purpureum*) 1 m apart. Bags were removed on the 16, 30, 44, 115th days after placement to determineresidue loss rate and to visually rank termite comminution activity in the 2 and 7 mm mesh bags. Across placement and bag mesh-size, millet stalks OM disappeared faster (K=0.0092) than sheep dung (k=0.0080) while there was more termite activityin stalks (2.2) than in dung (1.5). OM loss was fasterin buried bags (k= 0.0078) than in those placed at the surface (k= 0.0071). However termite activity was higherin bags placed at the soil surface (3.7) than in those burried in soil (1.3). Across placement and amendment type, OM decompossed fasterin the 7 mm bags (k= 0.012), followed by 2 mm bags (0.0107) and in 100 µ bags (0.0057). Termite play a key role in recycling nutrients in low external input millet based mixed farming systems.

Key-words : Niger, Termites, Litterbags, Millet stalks, Sheep dung, Nutrient cycling

Introduction

A characteristic feature of the Sahel of West Africa is the abundance of different species of termites *Isoptera* (Kowal and Kosam, 1979) with a range of foraging behaviours (Kooyman and Onck, 1987). Termites represent as much as 65 % of soil fauna biomass in soils of dry tropical Africa (Goffinet, 1973). Most species of termites consume dead organic matter such as wood, leaves, dry grass, crop residues, animal dung etc. and collect large amounts of organic material for the construction of funguscombs (Kooyman and Onck, 1987).

In the Kisii district of Kenya, Kooyman and Onck (1987) estimated that 30-90 % of the litter on farmers' fields was removed by termites. The highest percentages were recorded on fields planted with maize and other annual crops. In central Nigeria, it was found that only 24% of the annual litter production of primary woodland was removed by termites (Collins, 1981a). It was also observed that among termite species, food preferences were probably based on the physical and chemical properties of the residues (Wood, 1978).

Along with other soil macro-fauna, termites predominate in residue decomposition and redistribution of soil organic matter through their foraging and burrowing activities (Anderson and Wood, 1984). Cultivation practices, especially burning of forests and grasslands prior to cultivation and types of crops grown can affect the population density of termites. Burning reduces the level of their food source and litter. Kooyman and Onck, (1987) observed highest species comminution activity in maize fields and the highest species diversity in grassland. They attributed this to the abundance of litter in the first case and the lack of cultivation in the later. Also, abundance and spatial distribution of termites has been related to variations in soil types, tillage practices, vegetation and climate (Pomeroy, 1977; Brouwer, *et al.*, 1991).

For instance, during the wet season, termite foraging activity is known to be higher at the soil surface than in the soil (Wood and Johnson, 1978). In a Sudan savanna environment, Wood and Johnson (1978) observed that surface foraging by termites (*Microtermes* spp.) was restricted to the wet season. In a Northern Guinea savanna zone of West Africa, surface foraging by *Microtermes* spp. was stimulated after heavy rainfall and sharply declined at the end of the wet season (Wood and Johnson, 1978).

In the Sahel of Western Niger, millet residues and livestock dung are important amendments applied to soil to sustain millet yield (Powell *et al.*,1992). Livestock dung is either applied to soil surface through overnight corralling of livestock on cropland or by hand spreading of dung collected from stall-fed animals. The incorporation of dung into soil by primary tillage is a rare practice (Ikpe *et al.*, 1999). Although termites are known to have a dominating influence in the decomposition process in the Sahel, their role in nutrient cycling in these crop-livestock systems is poorly understood.

The objectives of this field study, using litterbags of varying mesh sizes were to: (i) examine the rate of residues disappearance as affected by mesh size of litterbags, (ii) determine the effect of placement on the rate of residue loss and, and (iii) identify termite species that predominate in the comminution process.

Materials and Methods

Site description

The field incubation experiment was established at Sadore, 45 km southeast of Niamey, Niger, at the experimental station of the ICRISAT Sahelian Centre (13^0 29' N and 2^0 18' E). The soils of the experimental site are classified as psammentic Paleustaff: sandy, siliceous, isohyperthermic (West *et al.,* 1984), and a representative of the soils used for millet cultivation in this area. The top soil (0-15 cm) has 91% sand, 5.3% clay, a pH (H_2O; 1:1) of 4.9, CEC of 1.3 meq 100 g^{-1} soil, base saturation of 42%, organic carbon content of 0.17%, total N of 190 mg kg^{-1} soil, and available P (Bray-1) of 2.6 mg kg-1. The field capacity for water is about 14% (v/v). The climate of the area is characterized by a short rainy season from June to September and a pronounced dry season for the remainder of the year. Monthly rainfall and temperature data are presented in Fig.1 (a & b).

Experimental details

Three litterbag types of 20x20 cm with mesh sizes of 100μ (microns), 2mm and 7 mm were used. Bags were filled with 25g dry matter of either intact sheep dung (feaces) or millet stalks cut to 3cm length. Bags of 100 μ and 2 mm mesh-sizes were placed at 1m intervals either on the soil surface or at approximately 10cm depth at the onset of the wet season. The 7mm bags were placed only on the soil surface. Millet (*Pennisetum glaucum* L.) was sown 1 m apart between litterbags.

Treatments (litterbag type, residue and placement) were factorial combined and placed in strips. The experimental design was a split plot arrangement with treatments arranged in strips fitted into randomized complete block with four replicates. Date of removal of litterbags formed the main plots, while a factorial combination of litterbag types, litter source and bag placement were assigned to subplots. Quadruplicate bags were removed on the 16^{th}, 30^{th}, 44^{th}, 68^{th} and 115^{th} days after placement. The degree of sheep dung and millet stalk comminution by termites was visually ranked in the 2mm and 7mm mesh-sizes bags. Litterbags were retrieved during the day, between 10.00 and 14.00 hrs. Rankings were 0 = none, 1 = low, 2 = average, 3 = above average and 4 = high comminution. The N, P and K contents were determined on sheep dung and stalks before incubation in the field. Prior to organic matter (OM) determination of dung and stalks by ashing in a muffle furnace overnight at 400^0 C, the remaining stalks and dung were washed to remove soil and dried in a oven for 48 hours at 60^0 C. Subsamples of residues (dung and stalks) were ground to pass 1mm screen prior to digestion in sulphuric acid (micro-kjeldhal). The concentrations of nitrogen and phosphorous in the extracts were determined with autoanalyzer (Technicon, 1977) while those of potassium were read using flame emission spectrophotometer (Table 1). Cellulose, hemicellulose and lignin concentrations in the residue were determined by the method of Goering and van Soest (1970) while total non-structural carbohydrates (TNC) were analysed using the phenol-sulphuric acid method of Guiragossian *et al.,* (1977). Decay rate constants (k) of OM during decomposition of residues were determined by single exponential relationship $y = 100e^{-kt}$ using the non-linear (Proc NLIN) technique (SAS, 1985).

Table 1: Concentrations of organic matter, total non-structural carbohydrates, hemicellulose, cellulose, lignin, N, P, and K in millet stalks and sheep dung (g kg^{-1}).

Organic Amendments	Organic Matter	Total Non-Structural Carbohydrates	Hemi-cellulose	Cellulose	Lignin	N	P	K
Sheep dung	867.8	69.0	112.2	241.7	109.1	13.8	2.6	8.2
Millet stalks	955.6	99.4	213.8	501.3	132.6	7.2	1.3	15.0

Results

Results obtained from this experiment (Table 2) showed that surface millet stalks placed either at soil surface or buried, mesh size of litterbags notwithstanding, disappeared from litterbags faster (k = 0.0092) than sheep dung (k = 0.0080) while residues buried in soil decomposed faster (k = 0.0078) than those placed at the soil surface (k = 0.0071), mesh-size of litterbags notwithstanding. Decomposition rate of either dung or stalks, placement notwithstanding, was fastest in the 7mm mesh litterbags (k = 0.012), followed by the 2mm mesh bags (k = 0.0107), and lastly by the 100 μ mesh ones (k = 0.0057).

This scenario seems to coincide with that presented in Fig. 2 (b & c). The disagreement with Fig. 2a is likely as a result of other factors like soil moisture differential, higher temperature in soil, better contact of organic amendments with soil and a fuller enzyme complement assembled by the differential contribution from the various members of the decomposers community in soil than at the soil surface (Cassman and Munns, 1980; Hargrove *et al.,* 1991; Swift *et al.,* 1979).

Discussion

Besides residue comminution by termites, an array of factors are known to determine the rate of residue decomposition. Different organic components possess a varying resistance to microbial degradation, e.g. in the order of decreasing decomposability: glucose > cellulose > lignin. Other substances, such as polyphenolics, decrease N availability by interacting with the N-mineralization processes. Based on these observations, different authors have tried to relate residue N release capacities with residue quality, in terms of measurable characteristics (water-soluble fraction, C/N ratio, lignin content, lignin/N ratio, polyphenol/N ratio, among others) (Melillo *et al.,* 1982; Fox *et al.,* 1992; Palm and Sanchez, 1991; Oglesby and Fownes, 1992; Kachaka *et al.*, 1993). Most of these studies were carried out under controlled laboratory conditions optimal for microbial activity. Therefore, residue decomposition under field conditions in various agroecosystems can shed more light on the role of soil micro and macro-fauna in the decomposition process.

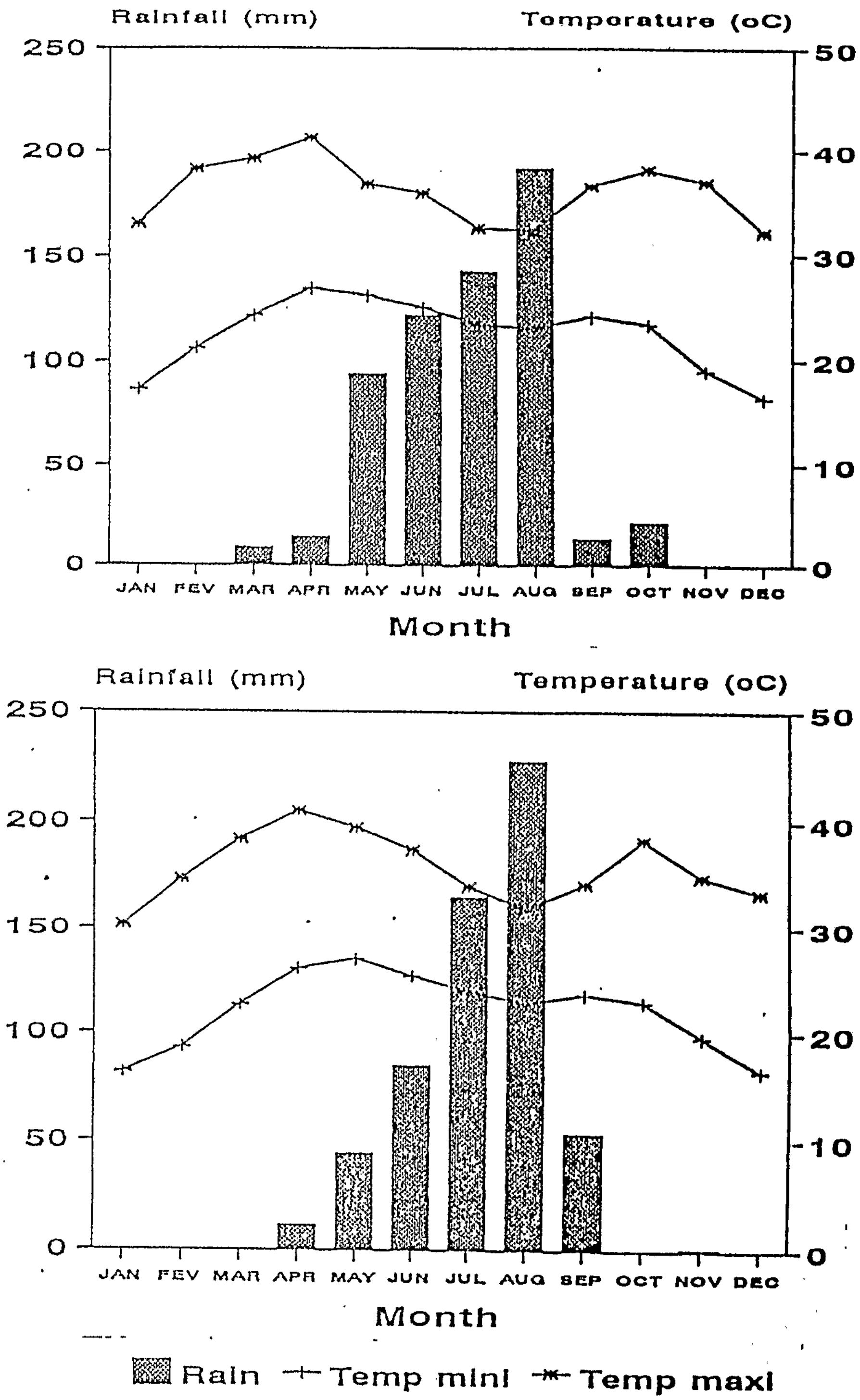

Fig. 1 Monthly rainfall and temperature data. Sadore, Republic of Niger. (a) 1991 (b) 1992

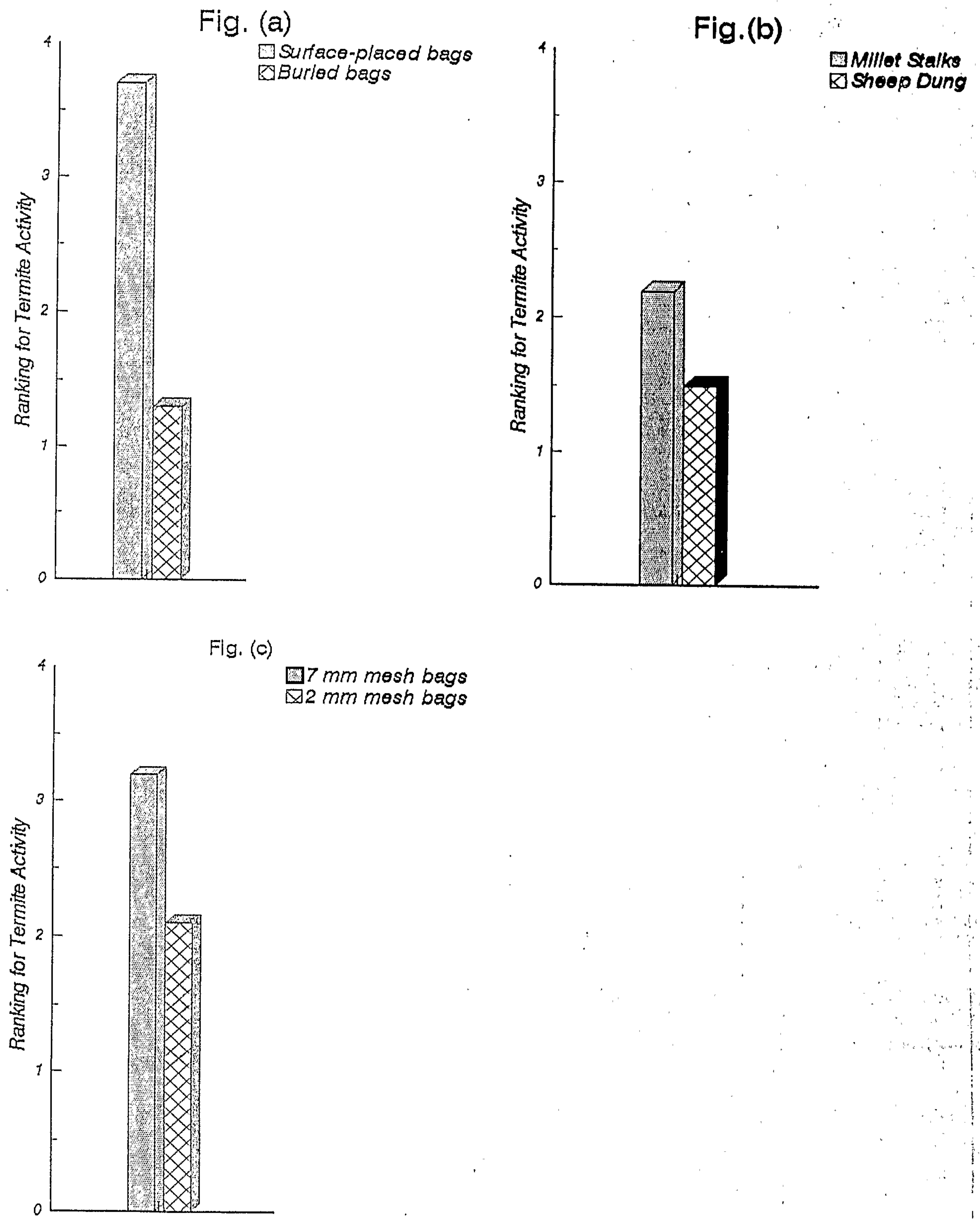

Fig. 2 The effects of placement, residue quality and mesh size of litterbags on the comminution pattern of termites during the wet season

In the present study, sheep dung contained almost 14 % N and lesser amounts of structural carbohydrates (hemicellulose, cellulose and lignin) than millet stalks (Table 1). However, weight loss was faster in bags with millet stalks than in those with sheep dung. The physical properties of the organic amendments under study varied considerably. When sheep dung is dry and intact, it is hard, glossy, water repellent and resistant to crushing under pressure (when buried in soil) than the stalks. More importantly, moisture can easily leach the interior of the stalks thereby retaining more moisture for microbial activity than manure (Ikpe *et al.*, 1995). Tian (1992) observed that termites were attracted to plant residues placed on soil surface as mulch, primarily for shelter from desiccation. Plant residues of low quality such as millet stalks were particularly attractive to termites. Thus, the physical attributes of millet stalks over sheep dung may have attracted more termites to them and consequently stalks disappeared faster than dung.

Table 2: Rates of organic matter decomposition during field incubation of 115 days.

Organic Amendments	Mesh size of Litterbags	Placement	Decay Rate Equations	R^2
Millet stalks	100µ	Soil surface	$Y = 100e^{-0.003t}$	0.67
Millet stalks	2mm	Soil surface	$Y = 100e^{-0.008t}$	0.83
Millet stalks	7mm	Soil surface	$Y = 100e^{-0.014t}$	0.93
Millet stalks	100µ	Buried	$Y = 100e^{-0.006t}$	0.72
Millet stalks	2mm	Buried	$Y = 100e^{-0.015t}$	0.91
Sheep dung	100µ	Soil surface	$Y = 100e^{-0.002t}$	0.59
Sheep dung	2mm	Soil surface	$Y = 100e^{-0.006t}$	0.84
Sheep dung	7mm	Soil surface	$Y = 100e^{-0.010t}$	0.87
Sheep dung	100µ	Buried	$Y = 100e^{-0.012t}$	0.59
Sheep dung	2mm	Buried	$Y = 100e^{-0.014t}$	0.79
SEM			±0.0006	

All models were significant at < 0.001 probabilty level.

The faster loss of weight in residues buried in soil than those placed on soil surface was attributed to the favourable micro-environment for microbial decomposition and the closer contact of the residues with soil. In the Sahel environment, the 4-5 months of the wet season enhances intense microbial activity (Ikpe *et al.,* 1995). However, greater termites activity during the wet season on soil surface and the washing out of particles of residues smaller than the mesh-size of litterbags due to comminution by termites during heavy rainfall are other important factors that may likely explain the disappearance of residues on soil surface. Since intense rain events are a common feature of Sahelian environments, rainfall is a potentially important agent of litter loss from soil surface, particularly after litter comminution by termites has passed a certain stage. While weight loss from the 100 μ mesh bags gives an estimate of loss due to decomposition (plus feeding by some micro-arthropods) and loss due to leaching, the present study did not distinguish weight loss from larger mesh bags due to litter removal by termites (macro-fauna) and that due to washing out of litter by rainfall.

There was higher termite activity in the 7mm mesh bags than in those with mesh size of 2mm. This was likely due to the greater access to termites into the 7mm mesh bags than the 2mm mesh ones. Although termite mounds of the genus *Macrotermes* dot the landscape in the Sahel, three genera of termites were identified in the litterbags. These were: *Microtermes* spp., *Microcerotermes* spp. *and Odontotermes* spp. (Chris Kooyman, 1992) personal communication.

Conclusion

Termites comminute organic amendments applied to cropland in the Sahel. This role enhances the mineralization of amendments and the subsequent release of nutrients to synchronize with crop demands. Termite foraging activity particularly in surface-applied amendments during the wet season, may result in loss of nutrients. Primary tillage and the incorporation of amendments into soil can reduce the foraging of applied amendments by termites and thus enhance soil fertility and crop productivity. However, longer term experiments to study nutrient dynamics in no-till and conventional tillage systems in the mixed farming systems of WASAT are warranted.

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