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Soil Fertility Management and Compost Use in Senegal's Peanut Basin

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The *Jóór* (Dior) soils of Senegal's Peanut Basin are inherently low in organic matter, limiting yields of millet and other crops and threatening the food security of smallholders. Focus groups and interviews were conducted in eight villages to characterise the site-specific fertility management by farmers in the Peanut Basin. Results of the qualitative survey revealed that farmers base management decisions on a series of fertility indicators that include type, colour, and texture of soil, presence of vegetation, and productivity in previous years. In an effort to equalise fertility across the field, farmers amend areas they classify as less fertile with decomposed manure and household waste from the family *sëntaare* (traditional pile) or with compost from managed piles. On-site measurements of soil in areas of fields amended with compost or *sëntaare* material revealed significant increases in peanut and millet growth over unamended areas, but little difference between the effects of compost and manure. Similarly, chemical analysis revealed increased effective cation exchange capacity (ECEC) and nutrient concentrations (K, Mg and Al) in soils amended with compost or manure. Similarities in the chemical characteristics of compost and *sëntaare* material suggest that development workers could emphasise improved pile management rather than promoting more labour-intensive composting.

Keywords: compost, farmer knowledge, land-use classification, manure, nutrient cycling, semi-arid West Africa

Introduction

As in most parts of semi-arid West Africa, agricultural production and food security in Senegal's Peanut Basin are highly susceptible to climatic variability and spatial shifts in labour and land use. Bordered by the littoral dunes to the west, silvopastoral savanna to the north and east, and extending into the Gambia River basin to the south, this agroecological zone has been the centre of the nation's agricultural activity since the mid-19th century (Tschakert, 2001). The Thiès region, in the heart of the Peanut Basin, lies adjacent to the east of Senegal's capital Dakar, and is the second most populated region in the country. Two-thirds of the population is rural, mostly working in agricultural production. Roughly half of arable land is cropped with millet (*Pennisetum glaucum*) and 40% in peanuts (*Arachis hypogaea*). Cropping also includes cowpeas (*Vigna unguiculata*) and cassava (*Manihot esculenta*). In addition to traditional field crops, the region produces the majority of Senegal's vegetables (ISRA, 1995; TRI, 1989).

As Senegal's urban population outnumbers the rural population this decade (FAO, 2004) and urban centres such as Dakar, Thiès and Kaolack expand, food production in peri-urban areas intensifies. Yet tenure on this land is often threatened by rising land prices or loss of usufruct rights. As a result, peri-urban production is often characterised as 'hit-and-run', when land insecure farmers crop intensively but apply few amendments to regenerate soil fertility (Dreschel *et al.*, 1999). Furthermore, since yields are largely dependent on rainfall, sporadic drought and a steady decline in annual precipitation over the last 50 years contribute considerably to the threat to food security in Peanut Basin (TRI, 1989). In 2002, for example, grain stocks in many villages of the Thiès region had been depleted by July, three months before the new harvest replenished them (CSA, 2002).

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To offset declining yields and stagnant market prices, Peanut Basin farmers in adjacent rural areas annually clear more land for cultivation. Indeed, the total area of under permanent cropping in Senegal has increased more than ten-fold in the four decades since independence (FAO, 2004). Fallow periods that allowed for substantial nutrient restoration have grown shorter or disappeared altogether (Diop, 1999; TRI, 1989; Westley, 1997), leading to a steady loss of soil carbon (Roose & Barthès, 2001; Tschakert, 2001).

This loss of soil organic matter (SOM) is particularly problematic in the Peanut Basin where SOM levels are inherently low. The 70 to 80% of soils classified as *Jóór* (spelled *Dior* in French texts), a sandy soil (Ustipsamment) with little ability to retain nutrients, contain a mostly kaolinitic clay fraction and only 0.3 to 1% SOM. Most of the remaining soils are the more fertile *Deg* (or *Deck*) soils (~Psammentic Haplustalf) and are generally only found in low-lying areas (ISRA, 1995; TRI, 1989). As SOM diminishes due to cultivation, the sandy soils are less able to retain moisture necessary for crop uptake and activation of nutrient-mineralising microbial populations (Diop, 1999).

To improve the productive capacity of their fields, farmers apply organic materials such as manure, crop residues and compost to their fields. The application of such material initially reduces evaporation and erosion (Zaongo *et al.*, 1997), and increases SOM, ultimately improving soil physical and chemical properties (Esse *et al.*, 2001; Ipke *et al.*, 1999; Moukam & Tchato, 1987). Perhaps most importantly, however, moisture-retaining organic amendments provide soil biota with the necessary energy to mineralise organic nutrients needed for crop uptake (Mando & Miedema, 1997), markedly raising yields (Moukam & Tchato, 1987; Zaongo *et al.*, 1997). Some research has demonstrated that annual manure contributions to the organic nutrient pool may actually be greater than needed for uptake by a crop (Ipke *et al.*, 1999), and even minimal applications of 2–4 $\mathrm{Mg\,ha^{-1}}$ are sufficient to increase cereal yields (Brouwer & Powell, 1998; Diop, 1999; Esse *et al.*, 2001; Krogh, 1997; Powell *et al.*, 1999).

Active composting of manure with kitchen waste, ashes and crop residues can improve its quality as a soil amendment. Production of a high quality, mature compost requires layering nitrogenous and carbonaceous materials, regular watering and turning of the material. Improved aeration and moisture control increase microbial activity (Tiquia *et al.*, 1996, 2002), thus speeding decomposition, limiting malodorous anaerobic activity, and reducing losses of nutrients to leaching and volatilisation (Sánchez-Monedero *et al.*, 2001; Shi *et al.*, 1999). Applications of small amounts of household compost have led to reports of increases in peanut, millet, and sorghum yields over traditional manure applications (Diop, 1999; Ouédraogo *et al.*, 2001; Westley, 1997).

Extension work conducted by The Rodale Institute (TRI) and the Senegalese Agricultural Research Institute (ISRA) has attracted the attention of many Senegalese farmers since the early 1990s (Diop, 1999), particularly women interested in growing vegetables for supplemental income. In a recent project serving five Peanut Basin villages in Senegal, TRI promoted compost production among women's group members. In the second year of the project, women in the five villages produced over 8000 Mg of compost. Nevertheless, the quantity produced was insufficient. Application rates of compost on millet, peanut, and cowpea fields ranged from 160 to 440 $\mathrm{kg\,ha^{-1}}$, far below the 2 $\mathrm{Mg\,ha^{-1}}$ recommended by TRI. Manure application was higher, ranging from 1.1 to 1.5 $\mathrm{Mg\,ha^{-1}}$, yet still lower than the 4 $\mathrm{Mg\,ha^{-1}}$ recommended rate. Participating women cited labour and manure shortages as the primary limitations to achieving recommended rates of amendment (TRI, 2002).

TRI's experience suggests that despite farmers' efforts to improve soil fertility via the application of organic material, a complex web of environmental and socioeconomic factors limits the ability of current farming practices in the Peanut Basin to adequately regenerate SOM. In addition to insufficient manure stocks, low vegetative biomass production during dry years limits the availability of residues. Since farmers also depend on crop residue and grasses for livestock fodder and construction material, they must prioritise immediate needs over long-term benefits to the soil (Slingerland & Masdewel, 1996; Wezel & Rath, 2002). Outmigration of rural labour, fueled by macroeconomic pressures, also limits the ability of farm households to produce sufficient quantities of compost or to distribute organic amendments more widely (Diop, 1999; Ouédraogo *et al.*, 2001; TRI, 2002). The cost of equipment needed to manage compost production and transport compost or manure to the fields is also a major constraint.

Clearly the need to optimise agroecologically sound and sustainable soil fertility management strategies is pressing. It is important first to understand farmers' perceptions of soil fertility, conservation and management (Enyong *et al.*, 1999; Osbahr & Allan, 2003; Taylor-Powell *et al.*, 1991). Farmers base local soil and land use classifications on various factors such as topography, soil texture, tilth, colour, and water-holding capacity and use these classifications to select site-specific management techniques (Ishida *et al.*, 2001; Kanté & Defoer, 1996; Slingerland & Stork, 2000). Complimenting agroecological research with such local soil knowledge must be prerequisite to the evaluation of regional land management strategies and the promotion of regenerative farming techniques (Talawar & Rhoades, 1998; WinklerPrins, 1999). Since local management strategies are the result of a long process of evolution and testing, and often well adapted to environmental and socio-economic conditions, improving and promoting them is ultimately the most sustainable approach (Ouédraogo & Bertelsen, 1997; Roose & Barthès, 2001; WinklerPrins, 1999).

This study was conducted in an effort to bridge farmer knowledge in the Peanut Basin with appropriate technology management techniques to improve soil fertility. Few studies in the Peanut Basin have attempted to evaluate management practices from an integrated qualitative-quantitative, ethno-agronomic perspective. Our research objectives were to:

1. Characterise fertility management systems currently practiced by farmers working with TRI in the Thiès and Diourbel regions of the Peanut Basin.
2. Observe the manner in which composting technologies promoted by TRI have been adapted to peri-urban and rural farming systems.
3. Determine the effect of compost use on crop performance and soil quality indices.

Methodology

Our study was completed over a three-month period from August to November 2003. During this period we made several visits to eight villages served by TRI (see Table 1), all within 55 km of Thiès (14°48′N 16°56′W). These villages were selected because they were either scheduled for bi-weekly monitoring and evaluation visits by TRI staff or were adjacent to such villages and had participated in TRI projects in the past. While the villages were not selected randomly, they range from 2 to 55 km from Thiès, and are representative of the agricultural systems of the Thiès and Diourbel regions of the Peanut Basin.

Qualitative information was collected via informal and semi-structured interviews with individuals, focus groups, and field visits appended to TRI monitoring and evaluation sessions. Almost all participants were members of the village GIE (*groupement d'interêt economique*, or village cooperative) and had participated in some TRI extension activities. Questions focused on local land use classifications, perceptions of fertility, compost production and use, residue and manure management and amendment rates and methods. Initially, early focus groups conducted at Keur Banda, Touba Peycouck, and Thiawène consisted of both men and women. After the first few groups, it became clear that women deferred to men's authority and remained

Table 1 Peanut Basin villages included in qualitative study, August to November 2003

Village	*Département*	*Region*	*Distance from Thiès (km)*	*Focus groups held*	*Interviews conducted*
Touba Peycouck	Thiès	Thiès	2	3	1
Keur Sa Daro	Notto	Thiès	12	0	1
Diouffène	Thiénéba	Thiès	25	2	1
Keur Banda	Thiénéba	Thiès	26	3	4
Taiba Ndao	Thiénéba	Thiès	28	1	2
Mboufta	Tivaouane	Thiès	45	0	1
Ndiamsil	Bambey	Diourbel	54	1	1
Thiawène	Bambey	Diourbel	55	3	4

silent. Later focus groups were largely comprised of women with the exception of Touba Peycouck. Several of the individual interviews were conducted with male farmers.

From these villages, two villages (Thiawène and Keur Banda) were selected for soil and crop analysis. Three farmers from each village's GIE were selected if they had used both compost and manure pile (*sëntaare*) material on the same crop in different areas of the same field on soil locally classed as *Jóór*. Sampling took place in Thiawène on 1st October 2003 from fields cropped with millet. Measurements were taken from four randomly placed 1 m^2 quadrats in each area of amendment: compost, *sëntaare* or none (12 quadrats total per farmer). Within each quadrat, four soil samples (10 cm depth) were collected and composited. To assess crop performance, millet plants were measured to obtain an average height per quadrat. Each farmer's compost and manure piles were also sampled two weeks later on 14th October 2003. In Keur Banda, compost and manure/waste (*sëntaare*) piles were sampled on 30th September 2003, and fields sampled two weeks later on 13th October. Material from these piles had been used to amend fields in June 2003.

Because no Keur Banda farmers had used compost on their millet crops, the sampling protocol was modified for peanut fields. Additionally, because peanuts were not quite at harvest stage, farmers were hesitant to allow the destructive sampling of 12 m^2 of peanuts. As a compromise, three plants from each treatment were removed from each farmer's field. Peanut pods were removed and weighed. The remaining plant biomass (above ground and roots) were shaken to remove excess dirt and weighed. Three peanut plants were weighed, sun-dried for two weeks and weighed again to determine average moisture content. Soil samples were collected as in the other village.

Mean precipitation in the Thiès region during the 2003 rainy season (June through October) was 348 mm (DRDRT, 2004).

While analysis of soil and compost microbiological characteristics would have provided us with a more complete view of soil nutrient dynamics, limited resources allowed only for analysis of select soil phyisco-chemical characteristics. All soil and organic amendment samples were taken to the US for analysis at North Carolina State University, Raleigh, NC. Amendment samples were analysed for total C, N, P, K, Ca, Mg, Na, Fe and S by ICP-emission spectroscopy. Soil samples were sieved and ground to 2 mm. Available P, Ca, K, Na, Mg and Al were determined by Mehlich-3 extraction. Total C was determined by combustion using a PerkinElmer 2400 CHN/O analyser. Effective cation-exchange capacity (ECEC) – the available charge at soil pH – was calculated from the sum, charge and atomic weight of the cations. Nutrient concentrations were converted to $\mathrm{kg\,ha^{-1}}$ based on a depth of 10 cm and bulk density (Db) of $1.3\ \mathrm{g\,cm^{-3}}$, the average Db of all fields at both sites. Data were analysed using PROC GLM with LSD means comparisons (SAS Institute, Cary, NC).

Results and Discussion

Local land use classification

Farmers interviewed in the focus groups classified their soils as *Deg* (∼Psammentic Haplustalf) or the sandy *Jóór* (Ustipsamment) (see Table 2) and first used texture and colour to determine soil type. In almost every group, participants first described *Jóór* soils as being 'soft.' Texture was followed by colour: 'white/light-coloured,' 'reddish,' or 'yellow.' *Deg* soils, on the other hand, were, without fail, described first by their dark colour. Following colour, farmers described *Deg* soils as 'hard.' In one village, the word *xur* was used interchangeably with *Deg*. A *xur* is a low-lying area, a basin where *Deg* soils are generally found.

While concepts of soil fertility are primarily centred on productivity, farmers use the same indicators of soil type to describe fertility. A fertile or productive soil is considered 'to have strength,' and is first described as dark. A soil that has 'lost strength' is recognised by its light colour, and referred to with the same words used to describe a *Jóór*. Indeed, farmers view *Deg* soils as inherently more fertile due to their darker colour and superior water-holding capacity. During interviews they generally qualified a statement such as 'Deg soils are more fertile' with the caveat that rainfall must be sufficient. They usually added that during drought conditions, *Jóór* soils are more productive.

In addition to the preceding year's yield, plant health during the growing season itself serves as another indicator of soil fertility: dark green growth and the formation of thick heads. Abundant grass and broadleaf weed growth is

Table 2 Indicators of soil fertility used by farmers in eight Peanut Basin villages (Wolof terms in italics)

Fertility indicators	*More fertile/productive*		*Less fertile/productive*	
	To have strength	*dafa am doole*	*To have lost strength*	*dafa nééw doole*
Soil type		*Deg/Deck**		*Jóór/Dior*
Colour			White/light	*Wééx*
	Black/dark	*Ñuul*	Reddish	*Xonq*
			Yellowish	*Soon*
Texture	Soft	*Ñooy*	Hard	*Deger*
Crop performance	Dark stalks/stover	*Ñax dafa ñuul*	Yellowish crops	*Ñax dafa wéèx*
	High yields		Low yields	
Vegetation	Grass/weeds	*Ñax*	*Striga hermonthica*	*Nduxum*
	Acacia albida	*Kàdd*		

*With sufficient rainfall

another indicator of soil fertility, with the exception of parasitic witchweed (*Striga hermonthica*), whose presence farmers associate with poor fertility. Farmers unanimously recognised the fertilising properties of leguminous *Acacia albida* trees, whose soil ameliorating properties have been extensively researched (Payne *et al.*, 1998; Weil & Mughogho, 1993).

Organic amendment management

Crop residues form an integral part the fertility management, albeit indirectly as they mostly cycle through manure (see Figure 1). Peanut stover is collected and saved as animal fodder to be used in the household during the dry season or sold. Following millet harvest, all green leaves are peeled from the stalks and fed to livestock. One respondent explained, 'We peel off the green leaves and feed them to our animals. They make manure for us that then goes back on the field.' Thick, sturdy stalks are selected and cut in the field for use as fencing around the family compound (see Figure 2). Broken or rotten fencing is added to compost piles or *sëntaare* piles. The stalks remaining in the field are broken at the surface, trampled, and grazed by livestock until field preparation the following year. The remaining undecomposed residue is removed at that time and piled along with all weeds and shrubs. Any edible or medicinal plants are gathered for use, and the piles of residue are burned in the field. The ash is not spread.

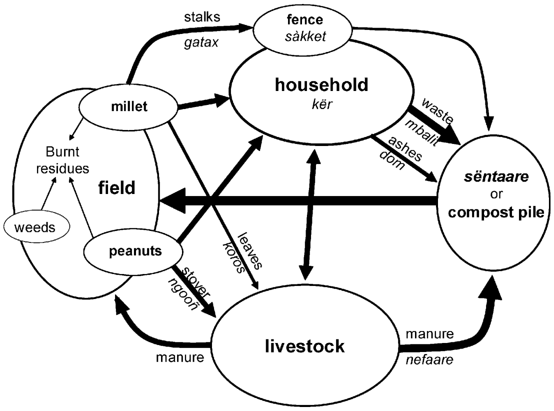

Figure 1 Schematic diagram of residue and waste cycling in surveyed Peanut Basin villages. Wolof terms appear in italics

Figure 2 *Sëntaare* (manure and trash pile) in Thiawène in front of millet stalk fence

Throughout the year, manure is collected from small livestock tethered or corralled in the family compound. Stabling of animals within the family compound increased rapidly throughout Senegal in the 1980s due to extension efforts by ISRA, which promoted the practice as a means of fattening livestock, increasing milk production and curbing overgrazing (Fisher *et al.*, 2000). Manure originates primarily from goats, sheep and horses; cattle are generally tended outside the village by a contracted herder. When asked why cattle ownership was uncommon, farmers noted that cattle populations had declined due to disappearing fallows, reflecting national statistics indicating stagnant cattle production over the last two decades (FAO, 2004) and generally attributed to the droughts of the 1980s and to diminished fallows (Westley, 1997). As noted in other studies of manure application in semi-arid West Africa (Haque *et al.*, 1995; Wezel & Rath, 2002; Williams, 1999), access to manure in this study was a largely a function of the quantity and type of livestock a farmer owns.

Women rake manure daily into a pile (*sëntaare*) in or next to the family compound (see Figure 2). Household waste, cooking ashes, and broken millet stalks are also added. Most farmers said they did not water or turn the pile. When field preparation begins in May or June, material from the pile is loaded onto a cart. Those who would cart away *sëntaare* material after two to four months noted that the piles were hot and smelled foul, suggesting anaerobic decomposition or ammonification of N. Those who waited six to 10 months claimed that pile did not smell and had become 'soil'.

All villages in our survey were selected because of their association with TRI and most of the focus group participants had attended composting trainings. Two villages, Mboufta and Ndiamsil, had been the site of extensive composting field trials in the early 1990s. At that time, labour-intensive pit composting was emphasised. In these villages, composting had been almost entirely abandoned at the time of this survey. In the remaining villages studied, TRI emphasised less-labour intensive pile composting (see Figure 3). While pit composting continued in the women's group gardens as during the recent TRI extension project, many of the participants practiced pile composting at home as well. Pile composting in Thiawène, Keur Banda and Touba Peycouck was widespread at the time of the survey.

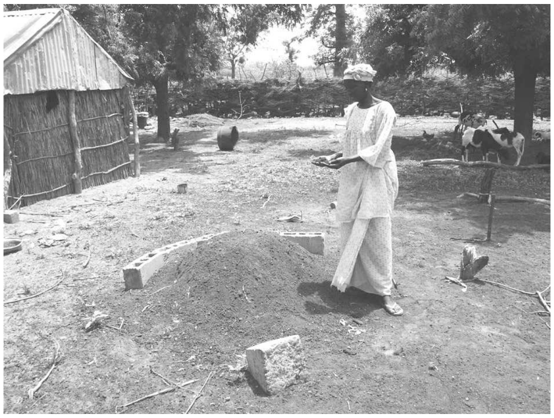

Figure 3 Keur Banda farmer with mature pile compost

While the feedstocks of both compost piles and *sëntaare* piles are essentially identical, management of the two piles differs greatly. A *sëntaare* pile is left unattended, while a compost pile is turned and watered regularly. Additionally, carbonaceous and nitrogenous materials are layered when first making a compost pile to facilitate aeration and guarantee a relatively uniform blend.

Unlike the *sëntaare* pile, the use of which is supervised by the male head of household, compost production and use is usually managed by women. When asked if the male head of household owns the compost, female respondents unanimously stated that he did not, but acknowledged that if he asks for it, they are obliged to comply. Farmers responded that *sëntaare* piles, on the other hand, were the property of the male heads of household. Women said that their husbands rarely refused them access to the pile, but acknowledged that the husband's crops had priority over hers. Similarly, Westley (1997) reported that conflict over manure was rare but that some women joked about having to steal their husband's manure. Indeed, it may be that women only express discontent with the gender division of labour and control of resources through implicit forms of critique such as humour, since several women in our study commented that their primary responsibility was to their families. Similarly, Fisher *et al.* (2000) reported that despite a 20% increase in their workload, 95% of women interviewed in the Kolda region felt that stabling livestock had improved their family welfare.

Because it is more labour intensive, compost production and use was much lower than *sëntaare* use in the study villages, supporting previous data (TRI, 2002). Compost production averaged two donkey cartloads ($\sim 1.5\ \mathrm{m}^3$ each) in households that actually made compost, while families relying on *sëntaare* manure used seven to 12 cartloads on average. The majority of organic material was applied to fields close to the household. Farmers prioritise application based on their crop selection. Fields where grain crops (millet and sorghum) are to be planted take priority. Peanuts and cowpeas generally follow cereals in rotation and are generally left unamended, and rely solely on the residual fertilising effect of the preceding year's manure. Some farmers also noted the yield benefits of rotating cowpeas with grain, an effect of atmospheric N fixation.

Based on the soil fertility criteria discussed previously, farmers add manure or compost to areas of fields they deem less fertile in an effort to equilibrate fertility across the field. Cartloads are dumped and farmers manually scoop and broadcast material using shovels or large enamel washbasins. A couple of participants stated that they amend half of the field one year, and the other half another year, often corresponding with crop rotation, based on the suggestion of extension workers. More often, however, management is site-specific. If the field is mixed *Jóór* and *Deg* soils, the sandy *Jóór* receives the amendment. In most cases, however, the entire field is *Jóór*. Farmers then localise application, amending lighter-coloured areas, areas with high witchweed populations, or areas that yielded poorly in previous years. Site-specific management based on variations in the soil catena or previous poor crop performance suggests that local land use classifications and farmer knowledge adequately address the fertility constraints on micro-topographical, field and landscape scales.

Compost and *sëntaare* pile chemical properties

Concentrations of C, N, P, K, Ca, Mg and Fe in *sëntaare* pile samples tended to be higher than in compost in both villages (see Table 3). While the small sample size was unable to reveal statistical difference, the trend was likely due the advanced stage of decomposition of the compost, resulting in a 20% drop in C and possibly a loss of labile nutrients to leaching or volatilisation. Sulfur (S) concentrations in *sëntaare* pile samples in Keur Banda (0.9 g S kg^{-1}) were higher ($p < 0.05$) than in Thiawène (0.5 g S kg^{-1}), however (data not presented). This could be due to differing levels of soil S and subsequently differing rates of S uptake by forage species. Soil samples were not analysed for total S.

Analysis of variance revealed significant differences between farmers in levels of P and Fe and slight differences in Mg, likely attributed to varying rates and sources of manure used by each farmer during compost production. Each farmer adds whatever type of manure is available to his or her pile. Recalcitrant carbonaceous material was visibly greater in some farmers' compost and *sëntaare* piles than in others. The coefficient of variance (CV) for C, N and P between farmers was extremely high, suggesting a large variability in feedstocks. Some farmers surveyed had only a single goat, while others had several heads of different species. Because of differences in nutrient concentrations between manures, and because some farmers

Table 3 Mean chemical characteristics of compost and *sëntaare* manure at Keur Banda and Thiawène

Treatment	**n**	***Total***									***pH***	***CN***
		C	***N***	***P***	***K***	***Ca***	***Mg***	***Na***	***S***	***Fe***		
		g kg^{-1}										
Sëntaare	7	59.4	5.4	1.3	1.9	8.5	2.1	0.3	0.8	0.9	7.6	10.9
Compost	10	49.5	4.1	1.1	1.5	6.4	1.8	0.4	0.6	0.8	7.8	12.1
ANOVA	df											
Treatment	1	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	*
Village	1	NS	NS	NS	NS	NS	NS	NS	*	NS	†	NS
Farmer (Village)	8	NS	NS	*	NS	NS	†	NS	NS	*	NS	NS
CV %		53.8	57.4	24.4	64.7	43.4	38.0	35.4	34.5	13.1	4.8	11.5

*Indicates significance at $p < 0.5$, †at $p < 0.10$, NS not significant ($p > 0.10$). Farmer × village was NS.

simply added more manure than others, nutrient concentration in the *sëntaare* piles likely differed. Additionally, compost maturity varied between farmers. Older, more mature compost may have experienced some leaching which could have led to lower nutrient concentrations.

Compost pH was significantly higher than *sëntaare* pile pH in both villages, supporting previous research findings that the composting process generally raises the pH of a substrate due to hydrogen lost as ammonia (NH_3) or water during the mineralisation of ammonium (NH_4^+) to nitrate (NO_3^-) (Sánchez-Monedero *et al.*, 2001). In Keur Banda, compost averaged pH 8.0, and *sëntaare* manure pH 7.8, while in Thiawène, *sëntaare* manure averaged pH 7.0 and compost pH 7.5. Again, feedstock variability may have led to marginally higher pH of organic amendments in Keur Banda.

Compost C : N was significantly higher than *sëntaare* pile C : N. This can be attributed to lower total C levels associated with degradation of soluble C during the composting process, as well as leaching losses of N (Bernal *et al.*, 1998a; Tiquia *et al.*, 2002). Higher C : N in compost compared to *sëntaare* piles may reduce the amount of N lost to volatilisation (Ekinci *et al.*, 2000). Low C : N in manure has been reported to lead to increased leaching losses of N when stockpiled and in the field (Brouwer & Powell, 1998; Petersen *et al.*, 1998). Additionally, active thermophilic composting generally leads to an increase in plant-available N (PAN) concentrations (Bernal *et al.*, 1998b; Sánchez-Monedero *et al.*, 2001), as well as humic matter and ECEC (Bernal *et al.*, 1998b; Tomati *et al.*, 2000), thus limiting leaching potential of PAN and other nutrients.

Analysis of material from compost and *sëntaare* piles in the two villages suggests only slight difference between the nutritive qualities of the two amendments. According to descriptions of compost preparation by TRI staff and publications (Diop, 1999; TRI, 1994) and by farmers interviewed in the eight villages (see section on organic amendment management), compost piles contain the same feedstocks as *sëntaare* piles: manure, household waste, ashes and crop residues. Management of the piles differs considerably, however. Improved aeration via the initial layering of feedstocks and active turning and watering of a compost pile can lead to rapid decomposition of waste materials. In contrast, surveyed farmers responded that *sëntaare* piles generally remain static for several months. It is possible that composting may generally increase the rate of at which waste materials fully decompose, but that after several months, chemical indices may not differ significantly from the traditional management techniques described by farmers.

Millet at Thiawène

In the three Thiawène farms sampled, millet was taller in areas amended with compost than in *sëntaare* manure-amended areas (see Figure 4a). While not statistically significant in this survey, the trend toward better crop performance in compost-amended areas is consistent with previous research in the Peanut Basin (Diop, 1999; Sène & Guéye, 1998; TRI, 1990; Westley, 1997).

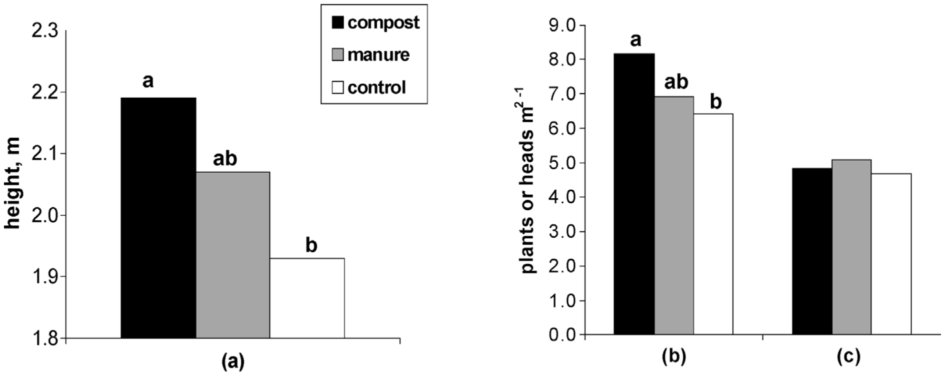

Figure 4 Effect of amendments on millet in Thiawène, 1st October 2003: (a) height (m), (b) plant density, and (c) head density. Bars with the same letter are not significantly different at $p < 0.05$

As anticipated, mean millet height was significantly higher in portions of fields amended with compost and *sëntaare* manure than in unamended portions, likely due to the priming of soil biota and subsequent release of available nutrients. The compost-amended plants in one farmer's field (A. Mbaye) were visibly greener and taller, cited by several other farmers as 'proof' that compost worked better than *sëntaare* manure. Stalks were visibly thicker in compost-amended areas, and spindly (with grain heads <3 cm thick) in unamended areas. There was no significant difference in millet height between farmers, regardless of differing rates of *sëntaare* manure or compost application and variability in the nutritive quality of compost and *sëntaare* manure. Average plant densities in *sëntaare* areas were significantly higher than controls, but the number of harvestable grain heads plant^{-1} and heads m^{-2} were not different across treatments (see Figure 4b and c).

Peanuts at Keur Banda

Following the same trend as millet, average above- and below-ground peanut plant biomass (DM) in the three farms surveyed tended to greatest in areas amended with compost (see Figure 5a). Peanuts grown on compost yielded significantly higher biomass than those grown in unamended plots. Mean pod fresh weight in amended treatments was significantly greater than control (see Figure 5b). Analysis of variance also revealed significant farmer and farmer × treatment effects, due to the large variability in pod weight between farmers. The significance of this variance is likely due to the fact that one farmer (S. Ndiaye) had planted his peanuts more closely together, leading to stunted early season growth. Genotype differences in the local varieties used by farmers could account for additional variation. As with millet in Thiawène, the trend of improved growth performance in compost-amended peanuts is consistent with controlled experiments in the region (Diop, 1999; Westley, 1997).

Analysis of soils amended with compost and *sëntaare* manure

In our survey area, soil bulk density (Db) averaged 1.3 g cm^{-3} across treatments. Total soil C ranged from 2.6 to 6.0 Mg C ha^{-1} (see Table 4). Total N levels were generally too low to be detected by a CHN analyser ($<0.04\%$). Differences in total C between the two villages may also be related to differences in management between peanut and millet crops. While amended areas were not significantly higher in total C than unamended areas, Westley (1997) reported that soils sampled from controlled experimental plots in neighbouring Ndiamsil amended with compost or manure had higher ($p < 0.005$) total C concentrations than unamended controls. This difference was likely masked in our survey due to a host of factors that can increase variance – differences between fields, farmer rates of application and physicochemical differences in the composts and manures applied by each farmer.

Compost increased K in the soil solution by 30% while *sëntaare* manure increased available K by 14%. Mg increases were also significant and 38% greater in manure-amended soils, and 89% greater in compost-amended. Changes in Ca and Al concentrations were also significant. Contrary to our expectations, Al levels in compost-amended areas were higher than in unamended parts of the field. Generally, reductions in Al in compost-amended soils are

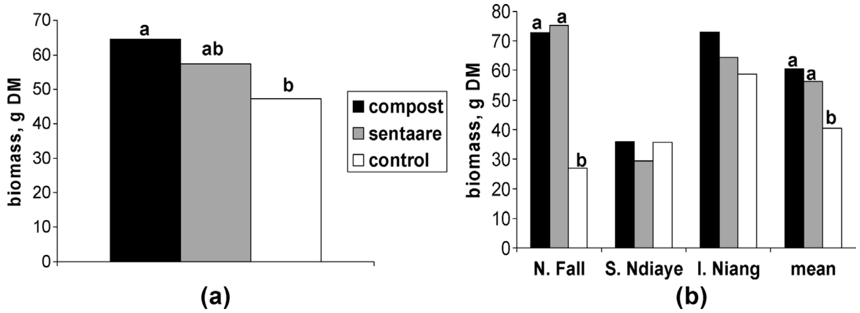

Figure 5 (a) Mean effect of amendments on peanut biomass and (b) farm-specific management effect on peanut pod weight, Keur Banda, 13th October 2003. Bars with the same letter are not significantly different at $p < 0.05$

Table 4 Mean chemical characteristics of field soil amended with *sëntaare* manure or compost and unamended soil at Keur Banda (13th October 2003) and Thiawène (1st October 2003)

	Db	*Total C*	*Available*						*ECEC*
			P	*K*	*Ca*	*Mg*	*Na*	*Al*	
	g cm^{-3}	*kg ha^{-1}*							*cmol kg^{-1}*
Sëntaare	1.35	4,283	36	120ab	439	92ab	81	183ab	4.31ab
Compost	1.32	5,041	56	136a	583	126a	79	205a	5.28a
None	1.34	2,809	26	105a	342	67b	68	181b	3.69b
LSD	NS	NS	NS	26.2	NS	47.2	NS	21.6	1.42
ANOVA variable									
Treatment	NS	NS	NS	†	NS	*	NS	†	†
Village	NS	NS	NS	NS	NS	NS	†	NS	NS
Farmer (village)	NS	†	NS	†	NS	*	**	***	NS
CV %	4.1	49.5	60.0	16.3	44.9	37.2	17.1	8.5	27.1

***indicates significance at $p < 0.001$, **at $p < 0.01$, *at $p < 0.05$, † at $p < 0.10$, NS not significant ($p > 0.10$).
Village variable tested using Type III MS error term for farmer (village). Means in the same column followed by different letters are significantly different at $p < 0.05$. Farmer × village was NS.

associated with the liming capabilities of organic matter (Mokolobate & Haynes, 2002). It is possible that soil Al taken up by previous crops that were subsequently fed to livestock or recycled. Aluminium may have become concentrated in compost and *sëntaare* piles with repeated additions of manure and/or crop residues, and eventually returned to the field, raising soil Al. Nevertheless, a trend appeared in which compost and *sëntaare* manure-amended soil Ca levels were 28 to 70% greater than those found in unamended soil. Again, this trend is unusual, as Ca generally binds with Al, lowering available Al levels and reducing the risk of Al toxicity (Mokolobate & Haynes, 2002).

Effective CEC of compost-amended soil was greater than ECEC of unamended soil, similar to differences reported by Ouédraogo *et al.* (2001). Soils amended with organic matter-rich compost or manure tended to have higher ECEC, largely due to large Ca and Al fractions. Following the application of an amendment such as compost, organic matter binds cations in the soil solution, freeing up exchange sites in the soil particle (Wong *et al.*, 1998). This relationship may help explain why nutrient concentrations in compost-amended soils tended to be greater than in *sëntaare*-amended areas, unlike the higher concentrations of nutrients observed in the *sëntaare* pile (Table 3). Higher C concentrations in the compost-amended soil may have resulted in more stable humic complexes in the compost, increasing the adsorption capacity of the soil. Similarly, more stable humic complexes with smaller pore size may have retained more moisture, stimulating greater microbial-mediated release of nutrients.

Conclusions and Recommendations for Future Work

Overall, it is likely that farmers' compost or *sëntaare* manure application actually mitigated some differences in soil fertility on a field-scale. In other words, unamended portions of the field – our baseline or control – may have been inherently more fertile and thus received no compost or manure. By adding compost or manure, the farmers may have increased the soil fertility to a level relative to what they perceived as the most fertile. Indeed, this is the intended effect of site-specific management. If a farmer notices that crops are stunted in a particular area of a field, he or she will likely apply compost or manure in an attempt to improve fertility and equalise yield across the field.

Controlled experiments in the Peanut Basin have revealed that applications of compost and manure increase crop yields and total soil C concentrations (Diop, 1999; Sène & Guéye, 1998; TRI, 1990; Westley, 1997). However, various social, economic and environmental constraints often limit the ability of on-farm research to yield such cut-and-dry results. A larger sample of farms could reduce variability and reveal differences with greater accuracy, allowing us to draw more significant conclusions and extrapolate our conclusions to other *Jóór* soils in the Peanut Basin. One of our objectives was to evaluate the effects of compost application on crops and soils in the Peanut Basin. While we were unable to reveal statistical differences in total soil C and available nutrient concentrations between amendments, trends in our data support previous research. The application of both compost and waste from the traditional household piles resulted in improved millet and peanut growth and increased availability of some soil nutrients. Future research might focus more closely on the soil ecology of the Peanut Basin to better understand the complex interplay of wetting-drying cycles, soil micro-organisms, organic matter, and nutrient dynamics.

An additional objective of this survey was to better understand Peanut Basin farmers' perceptions of fertility and to provide a 'snapshot' of their resulting management practices. Were extension workers to understand that farmers' fertility management strategies are based more on selective amending of priority crops and equilibrating less fertile soil rather than on the even distribution of limited amendments, they might find it necessary to reevaluate the promotion of a particular technique. With such an understanding, they might work more effectively with farmers to creatively modify existing management practices.

Another objective was to characterise farmers' adaptation of composting technology to socio-economic and environmental constraints. The majority of focus group and interview participants shifted from pit to pile composting either during or following involvement by TRI technicians. They cited lack of labour as the major constraint limiting compost production. Indeed, labour also seems to be the primary limitation to *sëntaare* manure use. Often more than half of fields were left unamended, yet many *sëntaare* piles were unused in all of the villages we visited. Several women complained that they had no means of transporting compost or manure to their fields other than by carrying it in a washbasin or by borrowing a cart, similar to claims made by farmers in Mali, Niger and Burkina Faso (Enyong *et al.*, 1999; Ouédraogo *et al.*, 2001). Nevertheless, farmers in our study were all acutely aware of the benefits derived from compost and manure application, and eagerly maintained that compost produces better results than *sëntaare* manure. If farmers were to actively manage *sëntaare* piles by turning or watering them monthly, they could ultimately produce satisfactory compost using a less labour-intensive process than that proposed by extension workers.

In the future, project workers might consider focusing on improved *sëntaare* management as a sustainable alternative to composting. Additionally, finding ways to facilitate transport of manure or compost to the field – particularly for women – could be a primary concern for development projects. Indeed, analysts often contend that food security in semi-arid West Africa and elsewhere in the developing world is often more a function of access and distribution than production (Altieri & Rosset, 1999; Pretty, 2002). Similarly, maintaining soil fertility in the Peanut Basin appears to also be more dependent on access to transport and labour than on availability of organic inputs. Nevertheless, the trend towards increasing SOM with organic amendments in the region's sandy soils is a promising testament not only to the extension activities by non-governmental organisations such as TRI, but also to the perseverance and adaptability of Senegalese farmers to increasingly challenging socioeconomic and ecological instability.

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