SUSTAINABLE AGRICULTURE: NEW PARADIGMS AND OLD PRACTICES? INCREASED PRODUCTION WITH MANAGEMENT OF ORGANIC INPUTS IN SENEGAL

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Abstract. Farmers in Sahelian countries are confronted with a variety of soil fertility and management problems. During the last two decades, NGOs have worked with farmers and research institutions to develop and test practices that will increase food production, while at the same time enhance the natural resource base.

Since 1987, The Rodale Institute (RI) has worked closely with farmers' associations and government institutions to promote regenerative agriculture-farming systems that prioritize the use of local resources while improving them as they are used to grow food, using agro-ecological methods. The Senegalese Agricultural Research Institute has collaborated in this program as a partner of RI. The Senegal Regenerative Agriculture Resource Center model has been applied as a new and viable approach that builds on traditional knowledge and farmer-to-farmer exchange.

Research results on soil conservation and improvement have shown that fields spread with amended animal manure or compost yield greater harvests than fields farmed with traditional methods.

Key words: animal manure, compost, farmers exchange, local resources, participatory approach, regenerative agriculture, rock phosphate, soil fertility and management, traditional knowledge.

Abbreviations: IFPRI – International Food Policy Research Institute; ISRA – Senegalese Agricultural Research Institute; S-RARC – Senegal Regenerative Agriculture Resource Center; RI – The Rodale Institute; P_2O_5 – Phosphorous; SODEVA – Société de Développement et de Vulgarisation Agricole.

1. Introduction

In Sahel countries, the major constraints to food production are related to soils. In fact, according to a recent monograph published by the International Food Policy Research Institute (IFPRI), soil degradation will be the major threat to developing country food security in the near future (Scherr, 1999). Most Sahel soils are sandy, and consequently low in organic matter. Others are heavier and better in quality, but are subject to intensive use and ultimately exposed to erosion by water and/or wind. In Senegal – in fact, in many other developing countries of Africa – soil erosion and degradation threaten large areas currently devoted to production.

Although environmental issues such as inadequate rainfall and deforestation are equally fragile (The Rodale Institute, 1989), decline in soil quality is perhaps the major challenge. Soils are deep and sandy, with very low clay contents, organic matter, cation exchange capacity (CEC), moisture holding capacity and natural fertility. Soil structures are weak and the soils are naturally acidic. Under natural conditions, scarce nutrients are recycled. Additionally, in recent years much of the vegetation has been almost entirely cleared for

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cultivation. The continuing loss of vegetation and resultant loss of soil organic matter is a primary contributing cause of soil degradation (Charreau, 1974; The Rodale Institute, 1989).

The primary cropping system in the Senegal Peanut Basin is a millet–groundnut rotation. The field is cleared by burning all residues and then cultivated, primarily employing a shallow tillage using animal traction. Pressure of lower yields and insufficient land has caused fallow to decrease dramatically, with the majority of fallow being ‘involuntary fallow’, usually a result of seed shortages (Grosenick, 1990). The use of inorganic fertilizers or pesticides is rare, especially since the removal of subsides for commercial fertilizers in the last decade.

Inorganic fertilizer applications in the Peanut Basin generally do not return expected yields without concurrent improvement of the soil organic matter content (Freeman, 1982). If soil organic matter and clay particles are not present in sufficient quantity to hold nutrients in the soil-rooting zone, the first heavy rains of the wet season will remove added minerals in runoff and leaching. In addition, if fertilizers are added at the time of planting, microbial activity and weed growth may be major sinks for scarce nutrient sources and would compete with crops for mineral amendments. During the short growing season, turnover of immobilized nutrients in these sinks may not occur until well after crop harvest. Research at the Senegalese Agriculture Research Institute (ISRA) has clearly shown that organic amendments to the soil system should accompany inorganic fertilizer applications to make optimal use of chemical treatments (Dancette and Sarr, 1985). Straw incorporation with NPK fertilizer additions helps maintain millet production, given adequate rainfall levels of around 400 mm year^{-1}. Tillage, crop rotations and micronutrient applications may also be needed to make optimal use of NPK amendments. In 1989, The Rodale Institute (RI) staff developed the following framework to examine the process of regeneration of degraded soils in the Peanut Basin of Senegal (The Rodale Institute, 1989).

2. Conceptual model for soil degradation and regeneration in Senegal

In Senegal, regenerative agriculture strategies in the Peanut Basin have resulted in positive agro-ecological, biophysical, and socio-economic impacts. A conceptual model of land regeneration begins with the soil in a state of severe deterioration (Figure 1a). After years of intensive cultivation for maximum production, the soil organic matter has been reduced to negligible levels by the effects of mechanized tillage and consequent wind and water erosion of fine material from the topsoil. The soil has lost its ability to retain moisture and essential nutrients such as nitrate (NO_3) and phosphate (P_2O_5) due to low clay and soil organic matter binding capacity. With the first heavy rains, high erosion and surface runoff transport a large quantity of the minerals applied as inorganic fertilizers (NPK) from the root-soil system, thereby severely restricting the utility of chemical inputs for improving plant nutrient uptake and crop yields.

Microbial populations, which have been inactive during the dry season, undergo an explosion of biological activity with the initial moisture inputs to the soil. These highly opportunistic micro-organisms compete efficiently with the young crop plants for nutrients that are suddenly liberated from the small amount of residual organic matter that is rapidly decomposing. Thus the nitrogen (N) and phosphorous (P_2O_5) are immobilized during

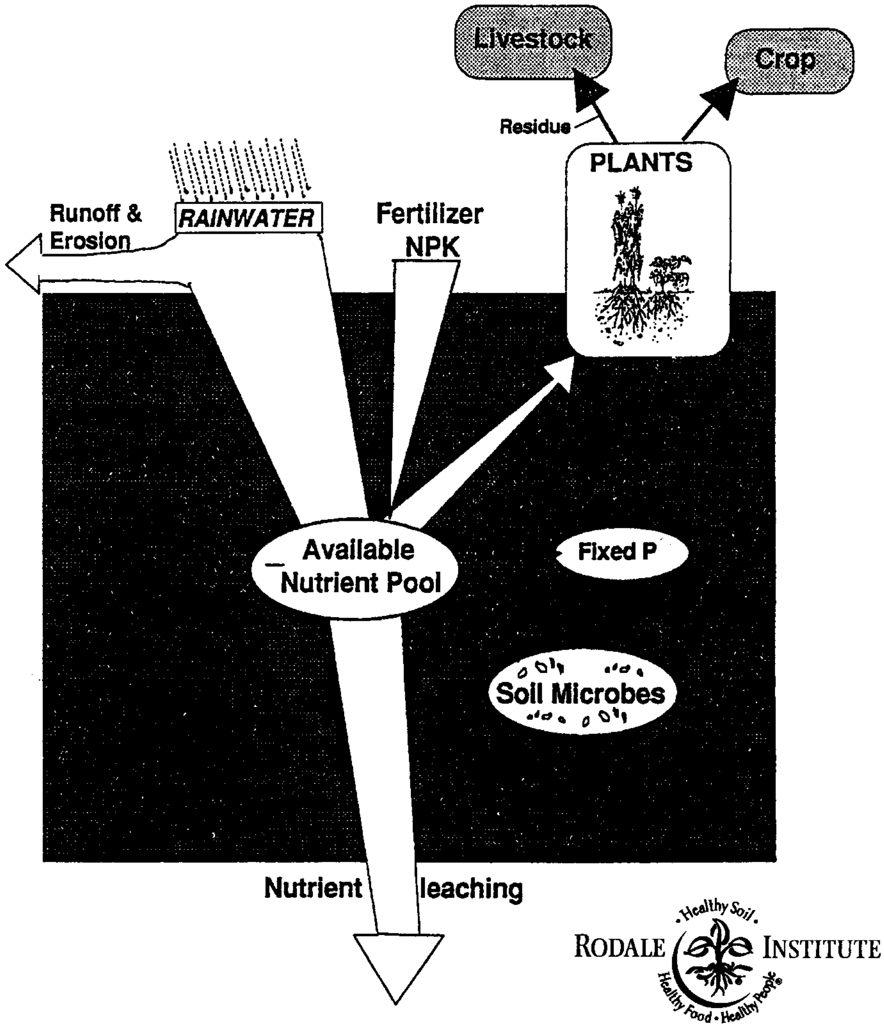

Figure 1a. Model of soil degeneration.

periods that are critical to plant growth and development. Available soil P is further removed from the plant roots by fixation with aluminum and iron complexes that are abundant in the acidified soil profile. Crop yields decline in a deteriorating cycle of nutrient extraction from the soil system. Very little organic material is returned to the soil since crop residues are burned or removed and fed to livestock. The overall moisture conserving capacity of the soil has been lost with the soil organic matter, and crop yields are tightly coupled to annual rainfall amounts. Drought years may result in crop failures.

To reverse this cycle of degradation, regeneration of soils in the Peanut Basin would follow the model shown in Figure 1b. The focus of the rehabilitation process is on building the pool of soil organic matter to levels that increase moisture infiltration and water holding capacity of the soil, thereby reducing surface runoff and erosion. Construction of soil and

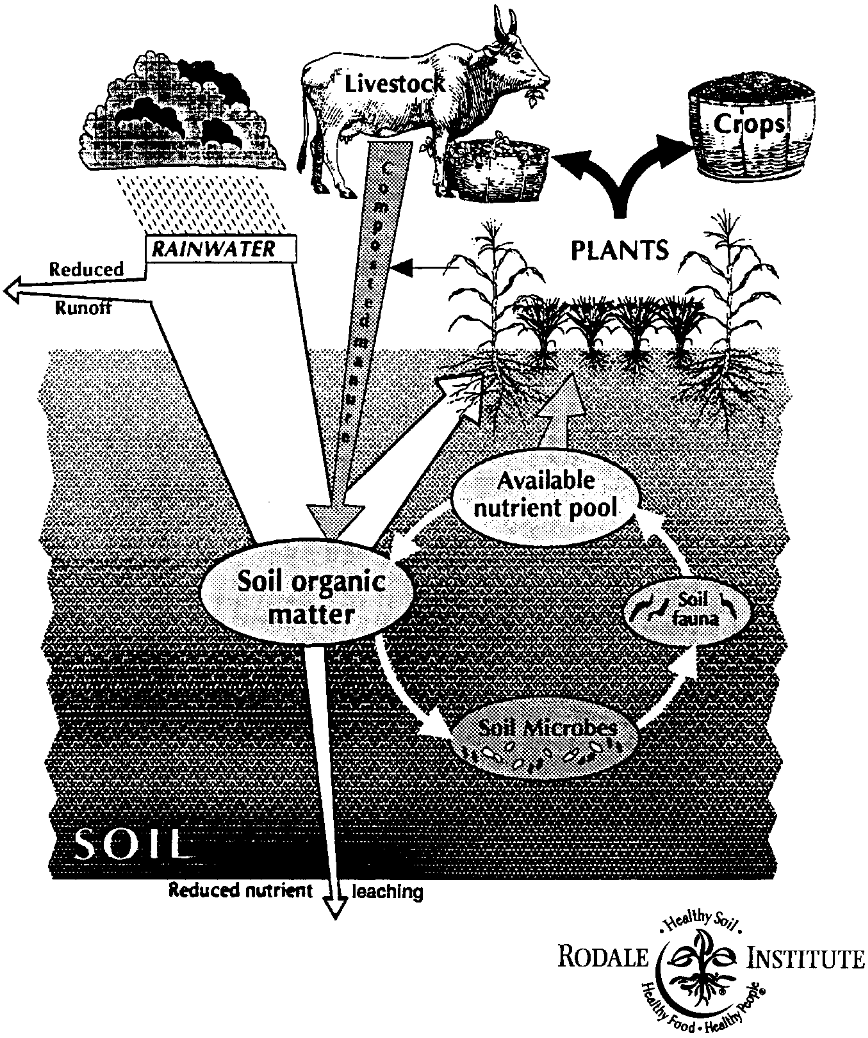

Figure 1b. Model of soil regeneration.

water conservation structures such as windbreaks, living hedges and rock walls in and around fields would accompany initial organic matter amendments to the soil.

As trees and leguminous crops add organic debris to the soil, and livestock are integrated into the recycling process to accelerate nutrient mineralization, improved soil moisture content would favor the development and maintenance of an active soil biological community, whose effect is to complete the cycling and turnover of essential plant minerals such as N and P.

Microbial populations of bacterial and actinomycete would rapidly decompose active soil organic matter components. Rather than immobilizing scarce nutrients in a microbial biomass sink (as occurs in Figure 1a), the development of consumer populations of protozoa and soil fauna which feed on micro-organisms and excrete mineral waste products would assure that N and P are made available for plant root uptake. After several seasons of rebuilding the soil ecosystem and nutrient cycles, crop yields would increase, and more organic material could be invested in the soil to continue the regeneration process. Rainwater runoff, soil erosion, and nutrient leaching would be greatly reduced as the resultant infiltration rates improved. Crop yields would be somewhat uncoupled from annual rainfall amounts. Droughts, while having a negative impact on yields, would not automatically lead to crop failure.

3. From model to field – Farmer Participation and the Regenerative Agriculture Resource Center (RARC) concept

In farming systems research, on-farm trials play a key role in the development and verification of appropriate technologies. Keeping the farmers, who must ultimately make decisions concerning adoption or rejection, involved provides an opportunity for them to become the primary developers and evaluators of these technologies.

This participatory model of on-farm research, demonstration, and technology transfer is the basic foundation of RI's work globally. The Institute's model has four basic principles:

1. Research – both replicated cropping systems experiments and on-farm participatory working partnerships with farmers.
2. Farmer and network activities with active farmer involvement, farmer trainers, on-farm demonstrations, field days, and farmer conferences, including NGOs and government institutions.
3. Partnerships with government agencies, universities, and other non-profit organizations, and the agri-business sector.
4. Education activities with agriculture professionals, as well as gardeners, farmers, children, and the general public.

With the above model in mind, The RI RARC project began work in 11 Senegalese villages in 1987. Working in different arrangements with various NGOs and government organizations, Institute staff collaborated with farmers in these villages to identify what these farmers perceived as the primary soil based constraints. In some villages, soil erosion was identified; in others, declining soil fertility drew the most attention. Initially, work concentrated on these two components of the model: (a) holding the existing soil in place, and (b) improving the quality of the conserved soil.

4. Soil regeneration in the Peanut Basin of Senegal

Successful soil regeneration was achieved in Senegal through the introduction and integration of soil conservation, livestock husbandry and crop production, use of manure and rock phosphate, and composting. Each of these practices is discussed in the following paragraphs.

4.1. Soil conservation

The severe land degradation in arid and semi-arid regions of Africa rendered some areas no longer able to sustain crops and other vegetation. In Senegal, in the village of Tatene (Thies region), almost half of the arable land has not been cultivated for production for several decades. In many cases all productive soil has been washed away either by wind or water erosion, exposing rocks on the surface. The Senegal RARC works with farmers to fight the battle against soil erosion. In the region of Thies, topsoils have been non-existent in some farmers' fields due to severe wind and water erosion. At the village of Tatene, a significant amount of land has been left without cultivation because of this. Villagers have also noticed that few of the indigenous species that grow between rocks actually grow above ground level.

In 1989, Rodale staff initiated an erosion control program in Tatene (Thies region), in collaboration with SODEVA (Société de Developpement et de Vulgarisation Agricole). Farmers in the region of Thies are encouraged to build rock walls along contour barriers to halt erosion, and use leguminous trees both as windbreaks and to improve the soil organic matter content and fertility. With these two technologies, farmers are seeing increased crop yields and reclaiming land that had once been unusable. The use of stone barriers and trenches along contours improved water holding capacity, retained significant amounts of top soil, enhanced seed germination of indigenous plant species that were believed to be lost, and put back into cultivation seriously degraded lands that had not been used for several years (Table I).

After three years, the establishment of stone barriers resulted in a 10–12 cm retention of soil particles. The soil's water holding capacity at the site increased to 19.3% from 3.8% by the second year, as compared to uncontrolled sites, which remained at 2.2%. Today, crops are being planted on the site and farmers are able to graze their animals in those fields after harvest. After four years, approximately 50 ha of land were put back into production. The improved water holding capacity and retained topsoil significantly enhanced the germination of 'lost' plant species (species which community members had not seen for many years). Over the last three years, most of these lands have been claimed by their original owners after they have seen the improvement made on site. During the last few years, we have

TABLE I. Efficiency of stone barriers at Tatene (Thies region), 1990–1992.

Treated areas	Water holding capacity, %		Soil particles retention, cm	Biomass production, g m^{-2}	
	1990	1991		1991	1992
I	2.2	2.2	0.3	179.9	120
II	3.5	10.5	1.3	151.8	896
III	3.6	14.2	1.8	101.4	1,588
IV	3.8	19.3	2.7	138.5	2,500

Treated areas I = plot without stone barriers, II = plot with 1 stone barrier, III = plot with 2 stone barriers, IV = plot with 3 stone barriers. Plot sizes were l00 m^2 (10 m × 10 m) for millet and 90 m^2 (10 m × 9 m) for groundnuts.

observed a significant amount of food being produced from this area without the use of external inputs such as synthetic fertilizers.

4.2. INTEGRATION OF LIVESTOCK AND CROP PRODUCTION

The regenerative system adopted in the Thies region consists of preventing both water and wind erosion, introducing leguminous trees and shrubs as windbreaks and as sources of organic materials, inter-cropping or rotating leguminous and cereal crops, and the use of manure and/or compost. The integration of livestock into the system is an option, albeit one that could be very challenging because of animal grazing, which significantly affects the establishment of forage species introduced as windbreaks and destroys the barriers to erosion.

Cereal-based farming systems are most common in Senegal. Mixed cropping strategies have been used by many farmers to minimize the risk of crop failure. Cowpea intercropped with millet provides additional fodder for animals, contributes to reduced erosion, increases the organic matter content of the soil, and most importantly, provides communities with at least one crop (cowpea) harvest when millet does not make it to maturity because of insufficient rainfall. When both crops are harvested under normal circumstances, there is evidence of yield benefit. Even though the yields of the component crops (millet and cowpea) may be slightly reduced compared to their yields when grown alone, the total yield of these two crops per land area can be higher in intercropped plots (Koenig, 1990).

Integrated crop–livestock systems reduce risk, contribute to the sustainability of small-holder farmers, improve diet through addition of protein, increase income opportunities, and contribute to the restoration of soil organic matter. In order to improve the nutritional security of rural Africans, low input sustainable production systems must be developed (Swaminathan, 1987). In Senegal, systems combining the use of leguminous crops and live-stock raising are efficient ways of contributing to food security, income generation, and soil regeneration. Such systems can maintain the viability of soils and promote social equity and community well being. Leguminous crops fix atmospheric nitrogen, provide fodder for animals and grain for human consumption, while livestock husbandry contributes to soil regeneration and provides income opportunities. Combining sustainable farming practices with incentives for economic growth is necessary for food security and poverty reduction in developing countries.

In the village of Ndiamsil, farmers fatten cattle, goats, and sheep to increase household income and manure availability. The project created a small fund allowing participating farmers to make an initial livestock purchase. Results proved successful when, in 1995, five out of six farmers in this community were able to profitably sell their livestock, and four of the six were able to totally reimburse the community fund. Cattle were fattened for four months and sold at local weekly-markets; thereafter, farmers started subsequent fattening cycles.

Stall feeding of cattle is a logical component for better management of off-farm resources. However, feed shortages during the long dry season could be a challenge. In association with this program, the Senegal RARC is helping farmers establish mixed cropping plots of millet and cowpea. Not only are farmers seeing an increase in yields and an improvement in soil fertility as noted above, but also they are able to produce more fodder for their livestock and increase their income opportunities. Farmers have tested different techniques to accelerate the animal fattening process using locally available resources. One technique, which worked particularly well in Ndiamsil, is to mix water with 500 g of ground millet grain and feed this mixture to the stable cattle twice a day, morning and night. This has resulted in an average daily gain of 935 g (outstanding). In another community (Baback), the average daily gain was 840 g. At Baback, the feed mix consisted primarily of leaves of wild plants, peanut hulls, and dried cowpea residues. As part of the cattle-fattening program, feed gardens have been established by many farmers in family compounds, as well as in waterlogged areas of their farms. Gardens consist of alternating rows of grasses (*Andropogon gayanus*) and fast growing leguminous trees (*Gliricidia sepium* and *Leucaena leucocephala*). Results from three years of applied study on feed garden harvest in one community (Samba Dia with 450–600 mm of rain) in the region of Thies suggest that planting seedlings rather than direct seeding legume tree species will result in better biomass production of individual plants (at least three times greater). *Gliricidia sp*. outperformed *Leucaena sp*. by at least 300%, regardless of the planting method used. Thus, when labor is a constraint, direct seeding of *Gliricidia* to establish forage feed gardens could be recommended.

Farmers report that with the increase in available fodder they are able to stable their cattle, making manure collection easier. Farmers then compost the manure and apply it to their fields, thus improving soil fertility. One farmer from Ndiamsil told us that to stable just one cow for four months provides sufficient manure for one hectare of cropland.

From 1990 to 1995, the Senegal RARC conducted research trials in Ndiamsil to test the soil fertility benefits of using natural rock phosphate in combination with animal manure. The trials showed that manure is very effective when used in combination with natural rock phosphate on millet crops and millet/cowpea intercropping. As a result, the company that processes rock phosphate in the Thies region through fertilizer companies has now made it accessible to farmers at a reasonable price. In 1998, the government of Senegal launched a nationwide application of rock phosphate as a capital investment to help farmers establish a more favorable condition for soil regeneration.

Studies conducted in the region of Thies (Sagna-Cabral, 1988) have indicated that insufficient and low quality manure could be a limitation for widespread use of these practices. Composting manure and crop residues could improve nutrient concentration, improve the quality of the end product, and reduce the huge amount of raw manure (10 t ha 2years^{-1}) needed for soil regeneration and substantial yield increase. The raw manure could be amended with rock phosphate or composted with crop residues.

4.3. MANURE AND NATURAL ROCK PHOSPHATE

Manure amendments have been reported to increase soil P and K concentrations in the Peanut Basin, but questions remain as to whether the timing of early nutrient release from organic fertilizers coincides with peak plant demand periods (Freeman, 1982). If nutrients are being flushed from the entire soil system with the first heavy rains, this may help to explain why early plowing of manure into the soil does not lead to increased millet yields relative to surface application. The organic matter and nutrient content of sandy soils can be improved significantly when animal manure or compost is applied. The addition of natural rock phosphate to these materials has significantly increased yields.

In some parts of Africa, the use of rock phosphate has been proven to be as effective as the use of regular phosphate fertilizer (Bationo et al., 1986). Substantial sources of natural rock phosphate exist in west Africa (Mali, Niger, and Senegal). Rock phosphate composting has been shown to increase the available P for plant uptake to levels comparable to single superphosphate responses (Batino et al., 1986). Research is needed in the Peanut Basin on the best use and combination of manure and chemical inputs. The objective of these efforts should be to increase nutrient use efficiency within the cropping systems, as outlined in Figure 1b.

Two methods of manure management have been tested in the Senegal Peanut Basin by the SRARC of RI in collaboration with the ISRA-Bambey at Ndiamsil: manure amendments with rock phosphate and composting with crop residues.

One study was conducted to evaluate the effects of adding natural phosphate rock (Taiba-37% P_2O_5) to animal manure on crop yield and soil conditions. Seven farmers participated in this study and each of them applied the same set of treatments to millet and groundnut, in completely randomized block design with 3 replicates (Table II). The first year each farmer had a crop of millet and a crop of groundnut and maintained a millet–groundnut rotation, which is the common practice in the Peanut Basin. Groundnut yields are presented in Table II to illustrate the effect of different treatments on crop yield.

The 4 treatments were:

- a check plot without manure;
- 2 t of manure per hectare (t ha^{-1}) every two years;
- 2 t of manure per hectare (t ha^{-1}) + 30 kg P_20_5 (as phosphate rock) every two years;
- Farmers' practice (more or less than 2 t ha^{-1} 2 $years^{-1}$). Depending on manure availability, farmers applied doses that were more or less than 2 t ha^{-1}.

Results obtained after the first cropping season indicated a significant increase in the yield of both crops when natural phosphate rock was added to the animal manure. Millet and groundnuts did not respond significantly to the applied manure. Probably the decomposition process did not yet reach a level that could release nutrients and make them available for uptake by crop plants. However, manure alone applied on the soil surface is expected to provide a better environment for individual seeds. Consequently, a better crop stand

TABLE II. Groundnut yields as affected by manure and rock phosphate applications, Ndiamsil, Department of Bambey, 1991.

Treatments	Peanut hay, kg ha^{-1}	Grain yield, kg ha^{-1}
Control plot	500	340
Manure 2 t ha^{-1} 2 $years^{-1}$	505	485
Manure 2 t ha^{-1} + 30 kg P_2O_5 2 $years^{-1}$	580	680
Farmers' practice	590	440

was observed in all plots that received it. Nutrient concentration and manure handling are very important for optimum benefits from its application. Composting manure and crop residues might improve nutrient concentration and reduce the huge amounts of manure (10 t ha^{-1} 2 $years^{-1}$) needed for soil regeneration and a substantial yield increase.

4.4. COMPOSTING

Composting is an old practice still being used in a traditional way by African farmers. The use of compost has a great potential in developing countries, particularly in Senegal where farmers cannot afford chemical fertilizers that are no longer subsidized. Several compost making techniques have been tested in Senegal. Senegalese women in particular are learning to make compost and they have been pleased with the results. A woman at Gade Khaye, a village near Thies, Senegal, found that fertilizers were 'burning' and killing vegetable seedling in her garden. In 1993, she used compost instead and did not lose her crop again. Composting has become the most popular topic for training sessions held by RI Senegal project. More than a third of the trainees were women interested in growing vegetables to eat and sell. Their families benefit directly from improved nutrition and extra income. In addition, producing vegetables at home saves women the long trip to distant markets several times a week. Also, money once spent on fertilizers now buys extra seeds or can be used in times of emergency, such as when a child falls ill.

Monies saved and earned from vegetable production are often held by women's groups as a pool of credit for individual women. They may open small stores, start craft businesses or buy a millet-grinding mill.

In another village, Keur Banda, women found that making compost using RI's methods was too difficult for them. Most of the men in the village worked elsewhere and could not help the women dig the 4-foot-deep pit required to hold the compost materials, usually millet stalks, ash and manure. The women worked with the staff to figure out an easier method. Using and modifying methods of composting allows women working together in Senegalese villages to grow more vegetables and improve health and finances for themselves, their children and their communities.

Farmer-managed trials were conducted at seven different locations in the department of Bambey at Ndiamsil, to evaluate the response of millet and groundnut crops to the application of compost and manure. The compost was made out of animal manure mixed with plant residues (millet stalks, grasses).

Table III shows that the average yield obtained from the five years of data indicate at least 42% and 45% increases for millet and groundnut, respectively. Millet and groundnut yields were higher when manure or compost was added. Results of this trial indicate that farmers could obtain an increase of more than 242.6 kg increase of millet grain in each hectare of land if they put in at least 2 t of manure (Table III).

Grain yield could be significantly increased when compost is added to the soil as a main practice for soil fertility management. In this case, 673.2 and 705.6 kg increases for millet and groundnuts were obtained respectively, in each hectare of land.

Yield increase under the conditions of the experiment is probably not only due to the supply of nutrient elements from the decomposed material. Rather it could also be due

TABLE III. Groundnut and millet grain yields in Ndiamsil, 1991–1995.

Treatment	1991	1992	1993	1994	1995	Average
Groundnut yield (kg ha^{-1})						
Control	469	236	383	170	455	342.6
2 t ha^{-1} manure	736	360	652	502	870	624.0
4 t ha^{-1} manure	676	361	671	527	933	633.6
2 t ha^{-1} compost	1,014	668	1,327	848	1,384	1,048.2
4 t ha^{-1} compost	992	577	893	988	1,388	967.6
Millet yield (kg ha^{-1})						
Control	458	174	330	252	465	335.8
2 t ha^{-1} manure	780	332	529	544	707	578.4
4 t ha^{-1} manure	890	361	689	531	673	628.8
2 t ha^{-1} compost	1,248	765	1,250	762	1,020	1,009.0
4 t ha^{-1} compost	1,055	611	1,038	1,054	1,404	1,032.4

Adapted from Westley, 1997.

to the physical barrier resulting from the application of the compost material on the soil surface, which reduced wind erosion during the dry period prior to the rainy season and improved soil moisture conservation needed for good crop establishment.

This was also observed in the previous experiment when animal manure was applied. However, application of composted manure and crop residues should be made at a time when plant nutrient uptake is at a maximum level to avoid leaching and volatilization. The compost making process could also be time consuming, labor intensive, and could require a huge amount of water. For this reason, rainy season composting is mostly recommended. It does not require addition of water if the process is started at the beginning of the rains. This method also does not require turning. However, in case of excessive rain a significant amount of nutrients is lost.

Now composting is moving into the cities of most African countries. City composting is more complicated and faces different constraints than village composting. In the cities, conditions are not good for making pits; so metal containers might be used. Water, a major ingredient in compost, might have to be carried a long distance to the city site. And it will be more difficult to add water to the containers than to a pit. In addition, a lot of screening needs to be done to city waste before it is composted. Certainly, in both cities and villages, composting can be a major contribution to improving food production. It is encouraging to see city garbage turned into compost that ends up on city gardens instead of in city dumps.

5. Conclusions

To maximize the sustainability and regeneration potential of the vulnerable soils of Senegal, their productive capacity must be restored. This requires a combination of soil conservation and regeneration. The implication of the conceptual model of soil degradation and regeneration can be summarized as follows: the soil biological community of degraded soils must be rehabilitated and subsequently maintained and managed through investments of organic matter and soil moisture conservation. Simply put, every management step is focused primarily upon improving the soil ecosystem in favor of moisture and nutrient retention and availability. This regenerative strategy represents a major shift in emphasis from a short term production oriented strategy to a long term rehabilitative strategy in which farmers invest in the soil resource as a first priority, and subsequently receive the long-term benefit of increased crop yields and sustained production in a much healthier environment.

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