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Role of manures and crop residue in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Sudanian zones of West Africa

A. Bationo & A.U. Mokwunye
IFDC-Afrique, B.P. 4483, Lomé, Togo

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Abstract

In the West African semi-arid tropics (WASAT), continuous cultivation leads to drastically reduced levels of soil organic matter. Such reductions in the level of soil organic matter have resulted in decreased soil productivity. The addition of organic materials either in the form of manures or crop residue has beneficial effects on the soils' chemical and physical properties. For many of the countries in this region, the amounts of nutrients in crops and crop residue are often several orders of magnitude higher than the quantity of the same nutrients applied as fertilizers. The return of the crop residue for soil fertility improvement cannot be overstressed. It is essential that more information on the rates of organic matter decomposition as well as the many reactions between products of organic matter decomposition and the soil under WASAT conditions be made available.

Introduction

The demand for cropland in Africa, arising from population pressure, has led to a decrease in fallow periods needed for stable traditional agriculture, causing reduction in crop yields and increased environmental degradation. A major problem for cropping systems in the tropics is the reduction in soil productivity that accompanies most systems of continuous cultivation. This is caused by: lowering of organic matter below the critical level; physical removal of the soil by wind or water erosion; leaching of nutrients, especially in high-rainfall areas and in light textured soils and exhaustion of nutrients through removal by crops. Poulain [9] indicated that organic recycling of crop residue is important because:

1. The amounts of the nutrients in crop residue of developing countries are seven to eight times higher than the quantities of these nutrients applied as fertilizers in these countries.
2. Crop residue is a source of trace elements which are absent in traditional NPK fertilizers.
3. Organic and inorganic materials have a complementary role and their simultaneous use will allow better crop yields. Such use would also cut down on quantities of chemical fertilizers to be imported thus providing savings in scarce foreign exchange.

Organic matter and soil productivity maintenance in the West African semi-arid tropics (WASAT)

Most soils of the WASAT are derived from acidic or aeolian parent materials which are poor in clay and nutrients. A greater part of the native fertility is associated with the organic matter fraction, a fraction which is also very low. The rate of accumulation of the organic matter is dependent to a great extent on rainfall. In a sampling of 30 soils from primarily the millet-producing soils of the WASAT, the organic matter (OM) content was related to rainfall as follows:

$$OM = 0.15 + 0.00085 \quad \text{rainfall} \quad (\text{S.E.} = 0.20; R^2 = 0.48)$$

Management practices that promote the return of crop residue to the soil are aimed at improving the organic matter content of the soil. The benefits of organic matter in the WASAT soils are numerous and have been summarized as follows [4]:

1. Improvement of soil macro-structure.
2. Increased water-holding capacity of the soil.
3. Improved infiltration and erosion control.
4. Prevention of soil hardening.
5. Improved soil cation exchange capacity. This is of particular importance for the sandy soils of the WASAT. For example, for the millet-producing soils of West Africa effective cation exchange capacity (ECEC) is more correlated with the organic matter content of the soil than with the clay content (Figs. 1 and 2).
6. Increased supply of slowly released inorganic nutrients. Since the total nitrogen in the soil is dependent on soil organic matter (Fig. 3), the breakdown of the organic matter ensures a steady release of nitrogen at a time when the established crop can use it. This minimizes losses of readily available nitrate-nitrogen through leaching.
7. Development of a favorable environment for microbial activity in the soil.
8. Prevention of phosphate fixation by iron and aluminum oxides.
9. Certain substances like quinones and benzoquinones which appear in the course of transformation of organic matter may play a specific physiological role and might increase the absorption capacity and length of roots [9].
10. Increase in the resistance of roots to some diseases.

The competing uses for crop residue

Experiments conducted by the International Fertilizer Development Center (IFDC) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Sadore and Gobery in Niger have demonstrated that the addition of up to 20 tonnes/ha of manure could result in as much millet production as when chemical fertilizers are used. If available, managing such quantities of organic materials is labor-intensive and requires tools not now possessed by the peasant farmer. One apparently simple means of supplying organic matter to the soil is the use of the non-edible portions of the crop – the crop residue. However, the off-farm needs

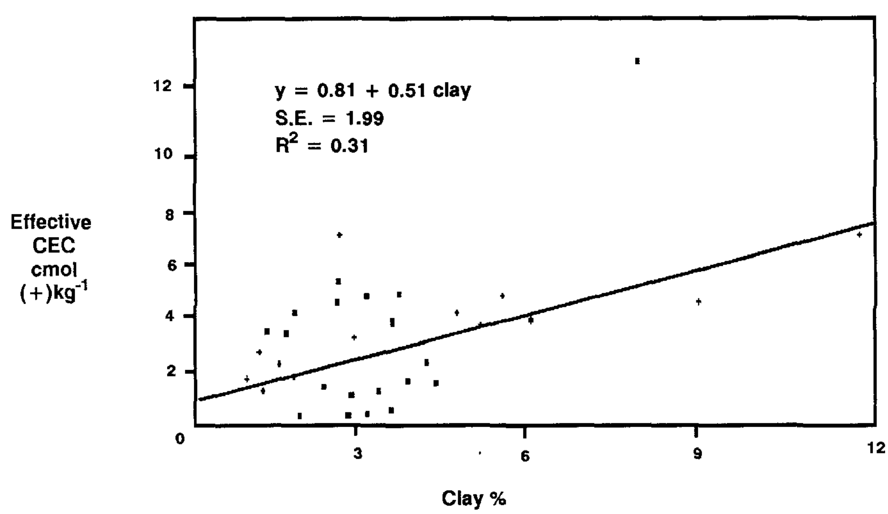

Fig. 1. Relationship between ECEC and clay of selected millet producing soils of West Africa.

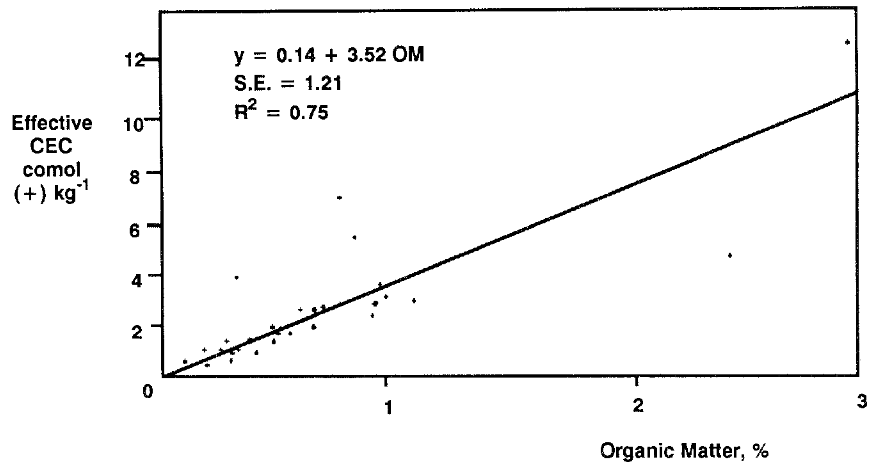

Fig. 2. Relationship between ECEC and organic matter of selected millet-producing soils of West Africa.

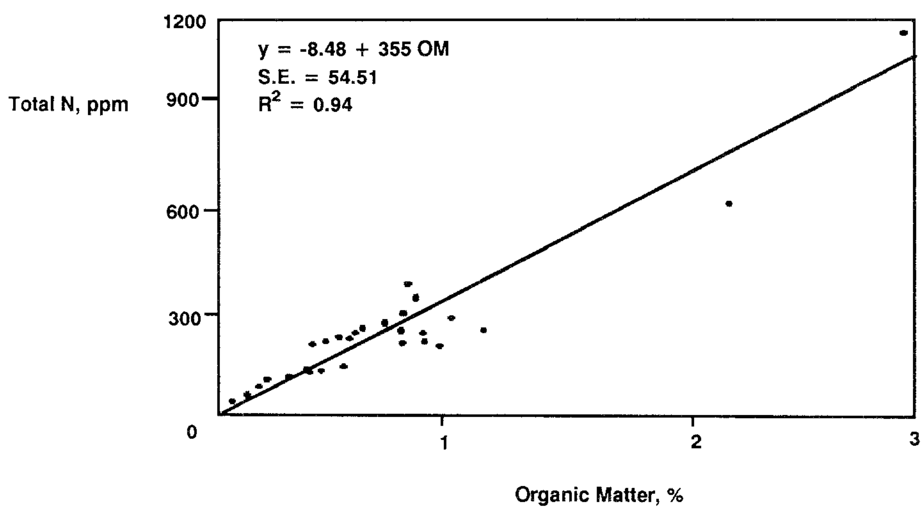

Fig. 3. Relationship between total nitrogen and organic matter of selected millet-producing soils of West Africa.

for these materials might surpass the need for the farmer to retain these materials on the farm in order to build up the soil fertility. In the long run, the amount of nutrient returned to the soil from crop residue is dependent on how the latter is disposed of after harvest [1]. A schematic representation of the different methods of crop waste management and how each method returns residues to the soil is depicted in Fig. 4. Some of these uses are summarized below.

Domestic fuel and in-situ field burning

In the Sahel and Sudan savanna, dry straw is burnt as domestic fuel for cooking. Where the ash is returned to the land as is the case with compound farms, nutrient cations are added to the soil. Field burning of crop residue to clear the land is a common practice. But burning of crop residue results in considerable loss of carbon and such nutrients as nitrogen and sulfur.

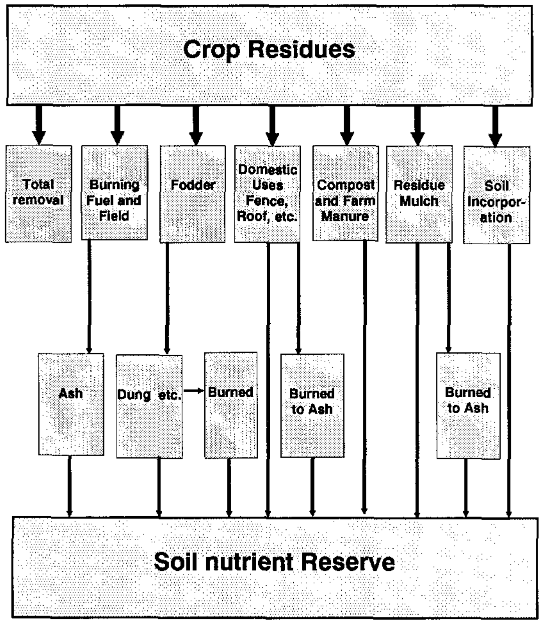

Fig. 4. Nutrient recycling between crop residues and soil.

Charreau and Poulain [3] reported that 20–40 kg N ha^{-1} and 5–10 kg S ha^{-1} are lost by field burning. Farmers see the burning of fields as a means to destroy insects and diseases but the frequent burning also leads to physical and biochemical degradation of soils [4]. Most of the soil micro-organisms, particularly Rhizobia, are destroyed by the intense heat. There are other domestic uses for crop residue such as fencing and roofing. The materials are subsequently burnt and some of the ash is returned to the compound farms.

Cattle feed

Legume residue and cereal stover are used as cattle feed but some of the nutrients in the residue are voided in the animal excreta. Balasubramanian and Nnadi [1] estimated that the retention of feed N in the animal body is only 4%–10% in beef cattle and 13%–28% in dairy cattle. Unfortunately, in the WASAT, the animals are not stabled and the nutrients contained in the droppings are not effectively utilized in the arable farms. Integration of agriculture with livestock is much needed to solve this problem.

Composting and production of farm-yard manure

Composting and the production of farm-yard manure can result in the decrease of the C/N ratio in crop residue thereby reducing the process of nitrogen immobilization which generally occurs when straw is applied to soils. The lack of water during the dry season, high labor requirement for processing and transport, competition for the crop residue for other uses, lack of integration of agriculture with livestock and farmers' ignorance of the benefits of composts limit the use of this system to improve soil fertility.

Mulching and incorporation of crop residue

Mulching with crop residue can reduce wind and water erosion by controlling surface runoff and the effects of rain drops on the soil surface. Mulching has other benefits including the control of soil temperature. In the WASAT, millet straw left on the soil surface is known to protect young seedlings from sandblast which precedes each storm.

The lack of draft (animal or tractor) power in rural farms of WASAT limits the ability of the farmers to incorporate crop residue and other organic wastes. It must be borne in mind that the incorporation of carbonaceous residues low in N may immobilize the available N in the soil and affect adversely early plant growth.

Some research results on crop residue management

The amount of nutrients removed by millet grain and straw when no P is applied and when P is applied at 13 kg P/ha is reported in Tables 1 and 2. Except for phosphorus, the quantities of other nutrients available for recycling are higher in the millet straw than in the grain. In the case of potassium, the production of 1,264 kg ha^{-1} of millet grain removed from the soil 5.59 kg K ha^{-1} while the amount in the straw was 73.48 kg K ha^{-1}.

Using an average harvest index of 30%, and a total annual millet straw production of about 20,258,000 mt for West Africa an estimated total

Table 1. Nitrogen, phosphorus, potassium, calcium and magnesium uptake by Pearl Millet when no P is applied and when P is applied as single superphosphate at 13 kg P/ha^{-1}, at Govery, Niger. Rainy season, 1987

	P applied, kg/ha			
	0	13	SE	CV
Grain yield, kg ha^{-1}	471	1,264	183.4	39.46
Straw yield, kg ha^{-1}	2,248	4,938	740.0	37.23
N content in grain, %	1.72	1.73	.231	21.20
N content in straw[a], %	0.71	0.80	.924	47.69
N uptake by grain, kg N ha^{-1}	8.12	22.30	3.898	47.99
N uptake by straw, kg N ha^{-1}	15.35	37.22	6.472	45.20
P content in grain, %	0.18	0.25	0.020	16.31
P content in straw[a], %	0.03	0.03	0.000	27.70
P uptake by grain, kg P ha^{-1}	0.82	3.08	0.366	36.76
P uptake by straw, kg P ha^{-1}	0.62	1.34	0.197	36.43
K content in grain, %	0.48	0.44	0.135	45.90
K content in straw[a], %	1.77	1.40	0.394	37.92
K uptake by grain, kg K ha^{-1}	2.10	5.56	0.899	43.70
K uptake by straw, kg K ha^{-1}	41.44	73.48	21.209	64.36
Ca content in grain, %	0.14	0.03	0.096	145.19
Ca content in straw[a], %	0.09	0.39	0.163	99.18
Ca uptake by grain, kg Ca ha^{-1}	0.50	0.45	0.320	105.38
Ca uptake by straw, kg Ca ha^{-1}	4.33	22.58	10.676	162.16
Mg content in grain, %	0.15	0.13	0.028	28.25
Mg content in straw[a], %	0.25	0.21	0.028	17.21
Mg uptake by grain, kg K Mg ha^{-1}	0.65	1.70	0.244	38.65
Mg uptake by straw, kg K Mg ha^{-1}	5.54	10.42	0.191	47.04

[a] Straw is the stover plus glume.

of 65,267,224 mt of N, P, and K would be removed from the millet producing soils each year (Table 3).

The need for a better management of crop residue is apparent. Whatever residues are left over after meeting the domestic and cattle needs must be returned to the field if the rate of depletion of soil fertility is to be reduced. It is a common observation that the level of soil fertility decreases as the distance between the homestead and the field increases – the result of inability to return crop residue to far-off fields. In 1983, at the ICRISAT Sahelian Center at Sadore, Niger, a trial was set up to study the effect of crop residue and fertilizer on pearl millet production. Crop residue (4 tons ha^{-1} pearl millet stover) was added to the soil surface in the first year to prescribed plots. In subsequent years the residues produced were simply placed on the plot surface. After 3 years, addition of crop residue alone had resulted in statistically the same amount of millet grains as plots to which fertilizers had been applied. Addition of crop residue plus fertilizer increased millet grain yield fifteen fold over the control (Fig. 5).

Geiger et al. [6] found that after 5 years of the addition of crop residue, the levels of Ca, Mg, and K had increased significantly in the top soil (0–20 cm). It was suggested that the enrichment was the result of nutrient cycling involving the basic cations released during decomposition of the straw as well as the ability of residue to trap dust which has a different nutrient composition compared with surrounding surface soil. It was also found that the organic matter levels in the soil did not increase significantly after 5 years with the addition of crop residue.

Manu et al. [7] studied the dynamics of P after 5 years of crop residue addition, and found that labile P increased significantly. Lower values for exchangeable Al and Fe were found and it was speculated that the decomposition of the crop

Table 2. Sodium, manganese, iron, copper, and zinc uptake by Pearl Millet when no P is applied and when P is applied as single superphosphate at 13 kg P/ha^{-1}, at Gobery, Niger. Rainy season, 1987

	P applied, kg/ha			
	0	13	SE	CV
Grain yield, kg ha^{-1}	471	1,264	183.40	39.46
Straw yield, kg ha^{-1}	2,248	4,938	740.00	37.23
Na content in grain, ppm	133.9	165.60	17.78	19.47
Na content in straw[a], ppm	476.9	392.50	74.30	25.80
Na uptake by grain, g ha^{-1}	60.4	204.14	24.63	35.94
Na uptake by straw, g ha^{-1}	1,055.3	1,981.84	436.34	50.34
Mn content in grain, ppm	15.2	14.70	3.81	40.08
Mn content in straw, ppm	123.0	80.30	19.39	28.18
Mn uptake by grain, g ha^{-1}	7.3	18.31	4.67	70.42
Mn uptake by straw, g ha^{-1}	281.9	400.32	104.30	51.31
Fe content in grain, ppm	73.3	146.20	15.08	29.32
Fe content in straw, ppm	190.1	264.30	61.10	44.97
Fe uptake by grain, g ha^{-1}	34.9	76.03	8.24	26.79
Fe uptake by straw, g ha^{-1}	417.4	1,281.78	280.30	62.82
Cu content in grain, ppm	7.8	22.10	3.53	62.55
Cu content in straw, ppm	6.5	6.30	1.84	45.27
Cu uptake by grain, g ha^{-1}	3.8	15.88	5.66	114.25
Cu uptake by straw, g ha^{-1}	14.2	32.27	7.95	62.17
Zn content in grain, ppm	23.7	27.80	2.92	18.45
Zn content in straw, ppm	26.9	9.90	3.21	23.90
Zn uptake by grain, g ha^{-1}	11.1	36.86	8.74	70.30
Zn uptake by straw, g ha^{-1}	58.6	49.50	9.77	27.65

[a] Straw–stover plus glume.

residue could result in the release of organic acids which complex Al and Fe and render them inactive as agents for phosphorus fixation.

Another experiment was set up in 1984 at Sadore to study the effect of manure applied once every three years on the yield of pearl millet and on the solubility of Parc W phosphate rock. The chemical analysis of the manure was as follows: pH (H_2O) = 8.0, pH KCl = 7.7, Bray P1 = 0.102%, Total P = 0.405%, Total N = 1.21% and Total Organic Matter = 32.1%. By 1985, the addition of 5 t/ha of manure in 1984 doubled millet yield as compared with the con-

Table 3. Estimated uptake of N, P, K by pearl millet grain and straw in West Africa. A harvest index of 30% is used to estimate the total straw harvested

Elements	Tons
Total grain harvest	6,077,400
Total straw harvest	20,258,000
Total N uptake by grain	10,453,128
Total N uptake by straw	14,464,212
Total P uptake by grain	1,093,932
Total P uptake by straw	567,224
Total K uptake by grain	2,892,842
Total K uptake by straw	35,795,886

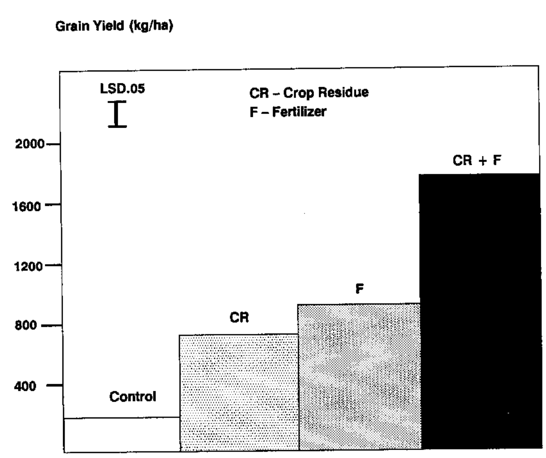

Fig. 5. Millet grain yield response to fertilizer and crop residue application (Sadore 1985).

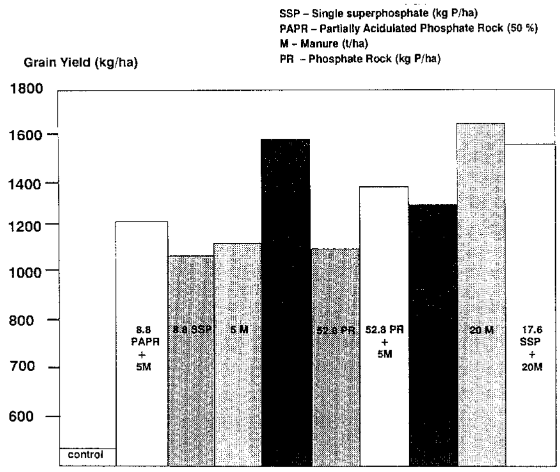

Fig. 6. Millet grain yield response to different sources and rates of phosphorus and manure (Sadore 1985).

trol. When the manure rate was increased to 20 t/ha, there was no need for additional mineral fertilizer (Fig. 6). The data in Table 4 suggest that the mixture of manure with phosphate rock did not significantly increase the performance of the rock. Chemical analysis of the soils after the applications of the treatments in 1984 and 1985 showed that all the soil fertility parameters measured were improved (Table 5) especially when the manure treatments were applied.

The study by Fauck et al. [5] on the evolution of soil fertility at Sefa in Senegal after 15 years of continuous cultivation and the study by Pichot et al. [8] on the long-term management of a ferruginous soil at Saria in Burkina Faso have demonstrated that 25%–50% of the soil organic matter generally disappears during the first two years of cultivation. The decrease in organic matter is also accompanied by substantial drops in the contents of the exchangeable bases (Ca, Mg and K). This results in progressive acidification of the soil and an increase in the contents of Fe and Al. The importance of manure is to ameliorate this situation. At Farako-ba in Burkina Faso, continuous use of mineral fertilizers was not adequate to maintain the production of

Table 4. Effects of manure and phosphorus from different sources on Pearl Millet grain yield, at Sadoré, Niger, 1988

Treatments	Grain yield (tons ha^{-1})
Control	0.362
8.7 kg P ha^{-1} as single superphosphate (SSP)	0.734
5 tons manure P ha^{-1}	0.723
8.7 kg P ha^{-1} as SSP + 5 tons manure ha^{-1}	1.093
39.3 kg P Parc W phosphate rock ha^{-1}	0.485
39.3 kg P Parc W phosphate rock ha^{-1} + 5 tons manure ha^{-1}	0.952
17.5 kg P ha^{-1} as SSP	0.851
20 tons manure ha^{-1}	1.457
17.5 kg P ha^{-1} as SSP + 20 tons manure ha^{-1}	1.508
SE	±0.089
CV (%)	27.9

Note: The manure had 0.405% total P and 1.21% total N

Table 5. Changes in soil nitrogen, pH, organic matter, and Bray P_1 in 1987 after additions of manure in 1984 and 1986

Treatments	Total N (%)	pH		Organic matter (%)	Bray P_1 (ppm)
		H_2O	KCL		
Control	153	4.98	3.88	0.29	5.33
5 tons manure ha^{-1}	202	5.37	4.25	0.39	10.31
17.5 kg P ha^{-1} as SSP	148	5.05	4.03	0.30	15.50
20 tons manure ha^{-1}	285	6.21	5.03	0.58	22.90
SE	15	0.14	0.16	0.06	2.58
CV (%)	18.7	5.18	7.42	29.63	37.46

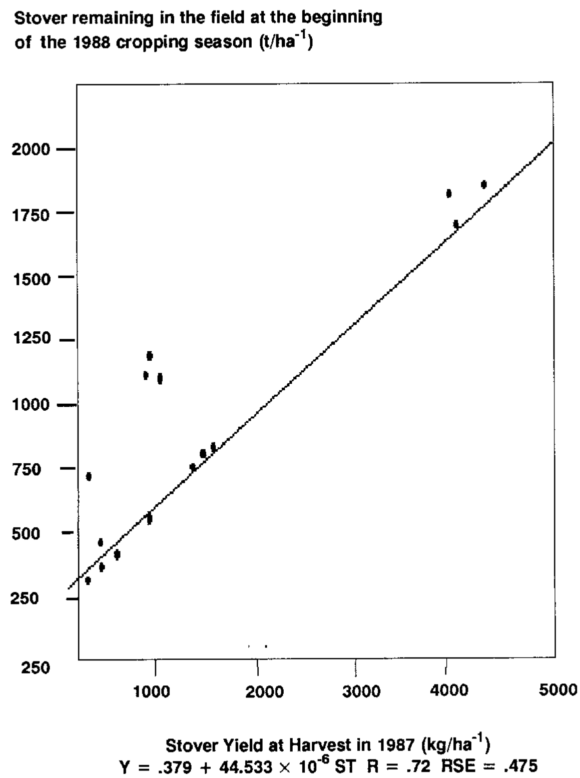

Fig. 7. Relationship between pearl millet stover yield at harvesting in 1987 and pearl millet stover remaining in the field at the beginning of the 1988 cropping season at Gobery, Niger.

maize without the application of manure (V. Bado – Personal Communication).

On-farm evaluation

Farmer-managed trials were set up in 1986 in the village of Gobery in Niger to test the traditional practice of no fertilizer application against the use of phosphorus and nitrogen fertilizers. The fertilizers were applied at the rate of 13 kg P/ha and 30 kg N/ha. At the beginning of 1988 season, the crop residue remaining on each plot of this experiment was measured. Where fertilizers had been applied, significantly higher quantities of residue were still left on the soil surface (Table 6). The use of fertilizers allowed farmers to increase stover yield. The increased production enabled them to use whatever quantities were required for the many competing purposes

Table 6. Effect of fertilizer sources and methods of fertilizer application on the amounts of residue left on the soil surface at Gobery, Niger, 1988

Treatments	Stover remaining (t ha^{-1})
Traditional – no fertilizer	0.686
SSP BI + N BI	1.682
SSP BI + N HP residual	0.858
SSP HP + N HP	1.669
SSP HP + N HP residual	0.986
SSP BI	1.297
SSP BI residual	1.081
PAPR BI + N BI	1.835
PAPR BI + N BI residual	1.098
SE	±0.129
CV (%)	42.7

BI = Fertilizer broadcast and incorporated.
HP = Fertilizer placed on the millet hill.
SSP = Single superphosphate.
PAPR = Partially Acidulated Phosphate Rock.
Fertilizers were applied at 13 kg P/ha and 30 kg N/ha.

with significantly higher quantities left behind to act as mulch for the young seedlings in the subsequent season. This is definitely one way that fertilizer use can aid in the sustainability of agriculture in this region. Figure 7 gives the relationships between the stover yield at harvest in 1987 and stover remaining in the field at the beginning of the 1988 rainy season.

Conclusion

The data from Sadore all but confirmed the importance of organic materials if the soils of the west African semi-arid tropics are to be continuously cropped. Moisture studies indicated that there was no difference in the soil moisture content of the plots that received crop residue. Since the trial was only five years old, one would not expect changes in the soil's physical properties. What is apparent is that the classical reasons for the good performance of soils to which organic matter has been added cannot be used exclusively to explain the findings at Sadore. In this ecosystem, very little is known about the dynamics of organic matter in the soils. Since the bulk of N, P and S are tied up in organic materials, it is necessary to study the rate of the organic matter decomposition which parallels the rate of release of these nutrients to the soil. Finally, it is important to recount the experience of the farmers at Gobery. Because they used fertilizers, they were able to produce enough residue to meet the various on-farm and off-farm demands.

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