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Research on nutrient flows and balances in west Africa: state-of-the-art[1]

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Abstract

West Africa is poorly endowed when it comes to soil fertility. Unlike for example the Rift Valley area, west African soils never enjoyed volcanic rejuvenation. At low agricultural intensity, this does not matter as nutrients cycle through the soil and the natural vegetation and losses are few. However, the past decades have shown high population increases, the breakdown of traditional shifting cultivation systems, and a rapid decline of land productivity and soil fertility in particular. The present review paper shows how much is known about the severity of this process and the technologies at hand that can stop it. The information provided shows that on the technical side much is known now, but research output still is poorly integrated into development efforts.

Keywords: West Africa; Soil fertility; Integrated nutrient management

1. Introduction

Degradation of land is seen as a reduction or loss of biological and/or economic potential, whereas desertification is defined as land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities (INCD, 1994). Human-induced soil degradation worldwide has affected 1966 million hectares or 15% of the total land area. The Global assessment of soil degradation (GLASOD) project estimates that 65% of the African agricultural land, 31% of permanent pasture land, and 19% of forest and woodland has already been degraded (Sivakumar and Wills, 1995). The same authors recently reviewed the global extent of water and wind, chemical and physical land degradation. They stated that the main causative factors of human-induced soil degradation are deforestation, overgrazing, agricultural activities, overexploitation of the vegetation for domestic use, and (bio)industrial activities. Areas of soil degradation are extensive in sub-Saharan Africa in the regions bordering the Sahara and Kalahari deserts. According to Williams and Balling (1994), 332 million hectares of African drylands are subjected to soil degradation. This represents one third of the entire area of dryland soil degradation in the world.

African soils, and particularly those in west Africa, are much weathered and fragile and mostly of low to

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moderate inherent fertility. In the past, at low population pressure farmers shifted from a cultivated site to an uncultivated one before significant decline in crop yield could set in, thus leaving the fields to replenish soil fertility under natural regrowth. However, with rapid population growth, fallow periods have shortened. Continuous and intensive cropping without restoration of the soil fertility have depleted the nutrient base of most soils. For many cropping systems in the region, nutrient balances are negative indicating soil mining. A basic challenge to agricultural research and development is to better understand and arrest this trend. Many west African farmers are food-insecured. Poverty, environmental degradation, and low agricultural productivity are interlinked and have increased the food gap. To improve the food situation, west African agricultural growth must depend on improved soil productivity rather than on expansion of area under cultivation. The soil fertility in intensified farming can only be maintained through integrated plant nutrient management with efficient recycling of organic materials such as crop residue, compost or manure in combinations with mineral fertilizers and using rotations with legumes (Bationo et al., 1994). This paper reviews the depletion of organic matter and nutrient balances in different cropping systems and presents some key technologies available to combat land degradation in west Africa.

2. Depletion of organic matter and plant nutrient balances in different cropping systems

2.1. Organic matter

Maintaining soil organic matter is a key component of sustainable land use management (Sanchez, 1990). Organic matter acts as a source and sink for plant nutrients. Other important benefits resulting from the maintenance of soil organic matter in low-input agrosystems include retention and storage of nutrients, increasing buffering capacity in low activity clay soils, and increasing water holding capacity. Table 1 includes differences in soil organic matter contents in the different agro-ecological zones of west Africa (Windmeijer and Andriesse, 1993). In the equatorial forest zone with higher rainfall, abundant moisture favors high biomass production, which in turn brings about higher soil organic carbon and nitrogen contents. In the Sudan Savanna, organic carbon and total nitrogen are very low because of low biomass production and high rates of decomposition.

In traditional shifting cultivation, nutrients accumulate during the long period of fallow and some of these nutrients become available to crops when the vegetation is burnt or when the soil organic matter is decomposed. Nye and Greenland (1960) estimated that the annual increase in nitrogen under forest fallow was 30 kg N ha^{-1} in the soil and 60 kg N ha^{-1} in the vegetation. For the savanna ecosystems, the annual increase was 10 kg N ha^{-1} in the soil and 25 kg N ha^{-1} in leaves and vegetation. Under continuous cultivation other nutrients such as Ca, Mg, K and pH decreased (Table 2). In northern Nigeria, Jones (1971) found that after 18 years of continuous cropping, soil organic matter was declining at the rate of 3–5% per annum. More recently Bationo et al. (1994) reported that continuous cultivation in the Sahelian zone has led to drastic reduction in organic matter levels (Fig. 1) and a subsequent soil acidification (Fig. 2). Bationo and Mokwunye (1991) reported that in the Sudano-Sahelian zone, the effective cation exchange capacity (ECEC) is more correlated to

Table 1
Nutrient stocks and other fertility indicators of granitic soils in different agroecological zones in west Africa

Agro-ecological zone	Depth(cm)	pH-H_2O	Organic C (g kg^{-1})	Total N (g kg^{-1})	Total P (mg kg^{-1})	Cation exchange capacity (mmol kg^{-1})	Base saturation (%)
Equatorial	0–20	5.3	24.5	1.60	628	88	21
Forest zone	20–50	5.1	15.4	1.03	644	86	16
Guinea	0–20	5.7	11.7	1.39	392	63	60
Savanna zone	20–50	5.5	6.8	0.79	390	56	42
Sudan	0–20	6.8	3.3	0.49	287	93	93
Savanna zone	20–50	7.1	4.3	0.61	285	87	90

Source: Windmeijer and Andriesse (1993).

Table 2
Percentage of soil fertility decline over 50 years in farmers' fields under continuous cultivation in the savanna zones of Nigeria

Zone	Exchangeable cations			
	Ca	Mg	K	pH
Sudan	21	32.0	25.0	4.0
Northern Guinea	18.6	26.8	33.0	3.8
Southern Guinea	46.0	50.6	50.0	10.0

Source: Adapted from Balasubramanian et al. (1984).

organic matter than to clay, indicating that a decrease in organic matter will decrease the ECEC and subsequently the nutrient holding capacity of those soils. In a study to quantify the effect of changes in organic carbon on cation exchange capacity (CEC), De Ridder and Van Keulen (1990) found that a difference of 1 g kg^{1} in organic carbon results in a difference of 4.3 mol kg^{1} in CEC. Greenland and Nye (1959) observed that under shifting cultivation in the forest regions, the alternation of cropping and fallowing resulted in relatively small fluctuations in soil humus at about 75% of the maximum level. In many parts of the humid tropics of Africa, the rainforests have

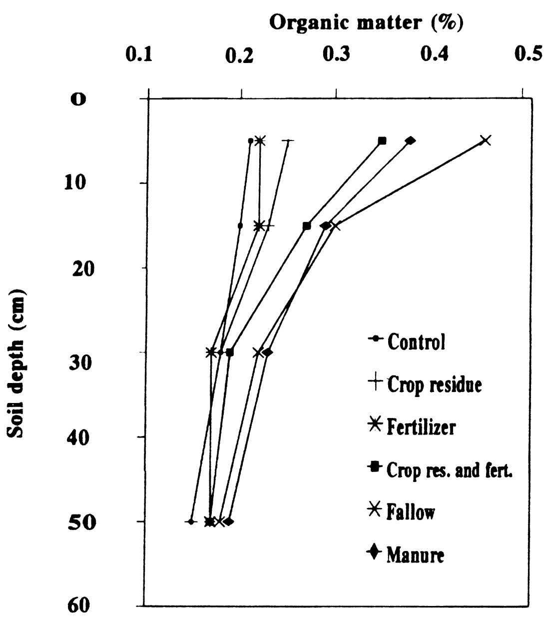

Fig. 1. Effect of different management systems on soil organic matter content, Sadore, Niger, 1991 rainy season. (Source: Bationo et al., 1994).

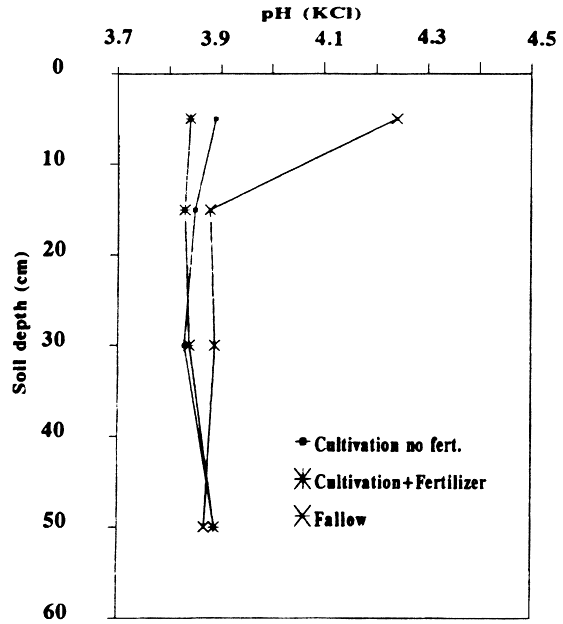

Fig. 2. Effect of different management systems on soil pH at various depths, Sadore, Niger, 1991 rainy season.

disappeared under high population pressure giving rise to derived Savanna ecosystems. For such ecosystems, low carbon accumulation from grasses results in carbon contents in the profile that are less than 50% of the equilibrium level (Greenland and Nye, 1959).

In many tropical cropping systems, few if any agricultural residues are returned to the soil. This leads to a decline in soil organic matter which frequently results in lower crop yields or soil productivity (Woomer and Ingram, 1990). Brams (1971) showed that in an alluvial soil in Sierra Leone, the organic matter level diminished from 3.5% to 3.1% within 2 months after clearing even before rice was planted. Adepteu and Corey (1977) showed that in 1 year of cropping (two crops), the organic matter content of an Alfisol in the western region of Nigeria declined by 30%.

Because of lack of synchrony between nutrient released by organic matter decomposition with plant growth demand, a lot of nutrients are lost. The significance of the loss of organic matter is understood clearly if it is realized that in the surface horizons of tropical African soils, soil organic matter contains practically all of nitrogen and about 20–80% of phosphorus (Adepteu and Corey, 1977). Decomposition of organic matter results in the release of these nutrients for, among other things, crop use. Adepteu and Corey (1977) observed that the 30% loss of organic matter in the trial conducted in western Nigeria resulted in the release of about 1000 kg ha^{-1} of N from a site that had been under fallow for 15 years. About 55 kg ha^{-1} of P was mineralized from the organic matter. It was noted, however, that in spite of the large quantities of N mineralized, the second crop of maize responded to nitrogen fertilizer. This was an indication that a lot of the N mineralized was not available for the crop and might have been lost through a combination of leaching, volatilization, and denitrification. It was also observed that 55 kg P ha^{-1} mineralized from organic P was one fourth of the organic P in the surface soil. The amount of organic P released was three times the amount of P taken up by the maize crop. Mueller-Harvey et al. (1985) found that during a 22 month cropping period, 25% of P, 32% of N, and 44% of sulfur originally present had been lost. As pointed out by Myers et al. (1994) synchrony can be promoted by manipulating plant demand (controlling planting date, duration of crop to be grown, use of crop with different growth patterns in multiple cropping systems) or by controlling the quantity and quality of organic inputs.

2.2. Nutrient balances in different cropping systems

Nutrient balances are quantified by assessing the variations of organic matter and plant nutrients in the soil over time or by subtracting the nutrients outputs from the nutrient inputs in the soil systems. Although the internal nutrient fluxes are considered as the main limitation of the first method, the quantification of the different inputs and outputs is the main limitation of the second.

In west Africa, country totals obtained from a continental study by Stoorvogel and Smaling (1990) show that nutrient outputs generally exceed nutrient inputs. The study, commissioned by FAO on N, P, and K balances for 35 crops in 38 sub-Saharan African countries revealed that the mean annual losses per hectare were approximately 22 kg N, 2.5 kg P, and 15 kg K in the period 1982–1984 (Fig. 3, Stoorvogel and Smaling, 1990; Stoorvogel et al., 1993). Table 3 shows the aggregated nutrient budgets for some west African countries. In Burkina Faso, current estimates indicate that in 1983, for a total of 6.7 million hectares of land cultivated, soil nutrient mining amounted to a total loss of 95 000 tons of N, 28 000 tons of P_2O_5 and 79 000 tons of K_2O, equivalent to US$ 159 millions of N, P, and K fertilizers. In Mali, Van der Pol (1992) reported

Table 3
Country N–P–K budgets in 1983

Countries	Arable ('000 ha)	Fallow (%)	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Benin	2972	62	14	1	10
Burkina Faso	6691	50	14	2	10
Cape Verde	N/a				
Cameroon	7681	50	20	2	12
Gambia	326	29	14	3	16
Ghana	4505	24	30	3	17
Guinee	4182	68	9	1	6
Guinea-Bissau	N/a				
Côte d'Ivoire	6946	31	25	2	14
Liberia	745	15	17	2	10
Mali	8015	72	8	1	6
Mauritania	846	79	7	0	5
Niger	10 985	47	16	2	11
Nigeria	32 813	18	34	4	24
Senegal	5235	53	12	2	10
Sierra Leone	1842	43	12	1	7
Togo	1503	49	18	2	12

Source: Stoorvogel and Smaling (1990).

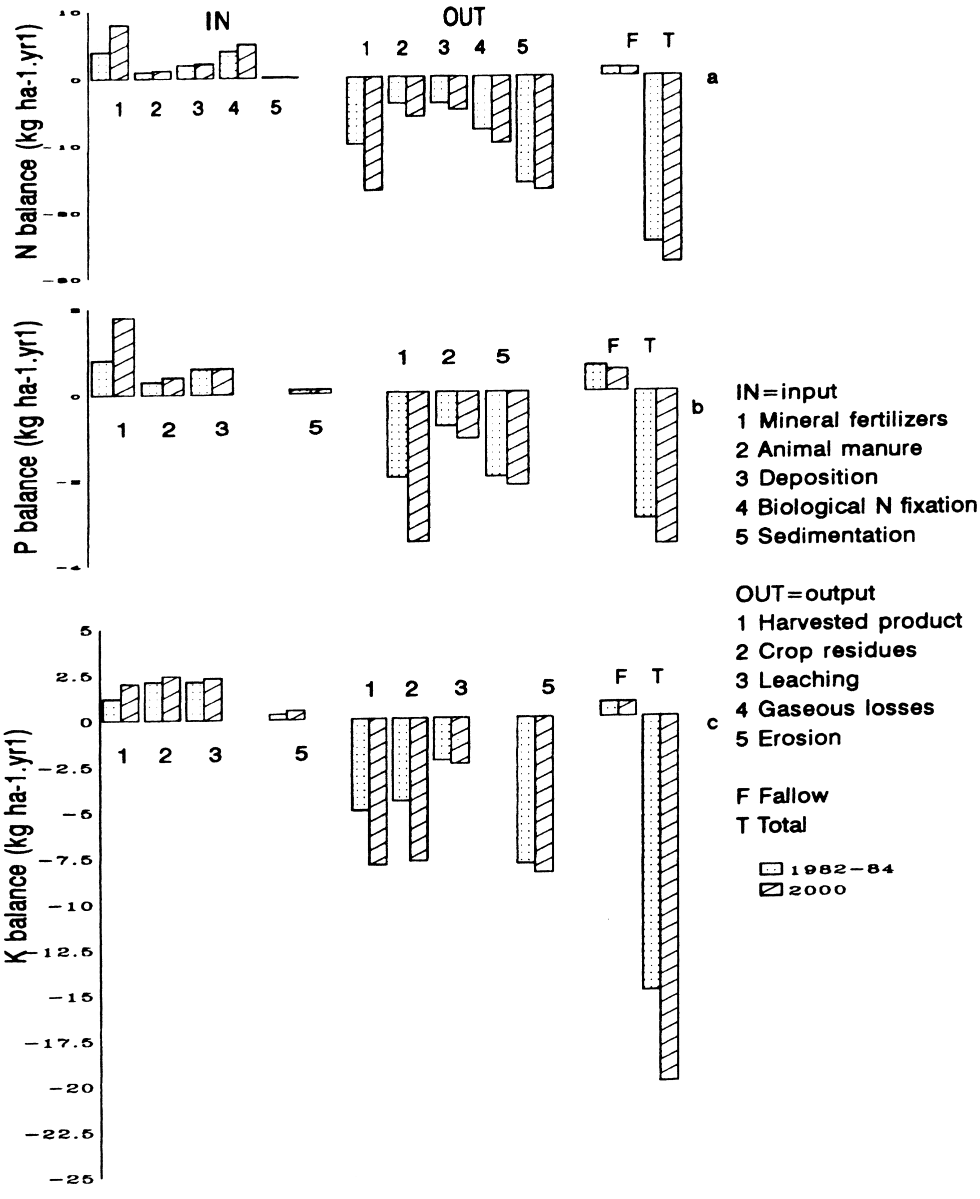

Fig. 3. Nutrient Balance for sub-Saharan Africa. (Source: Stoorvogel et al., 1993).

that farmers extract, on average, 40% of their agricultural revenue from the soil mining. The significance of these figures is alarming when it is realized that

- the productivity of these soils in their native state is already low because of low inherent levels of plant nutrients
- sub-Saharan Africa consumes fertilizers at the lowest rate in the world which is approximately 8 kg of nutrients per hectare (Table 4)
- in the area of structural adjustment, there is intense pressure on the governments to remove subsidies on fertilizers without suitable alternative policies to sustain even the current low levels of use of plant nutrients.

Table 4
Fertilizer use and trends in fertilizer consumption 1975–1990 per region in Africa

Region	Fertilizer use	Fertilizer consumption in Africa from 1975–1990					
	1990 (kg ha $^{-1}$)[a]	1975 ('000 t)	1980	1985	1990	Annual growth (%)[b]	('000 t)
Sudano-Sahel	5.3	158.1	128.1	173.1	167.5	0.9	1.6
Coastal west Africa	10.4	129.9	251.0	397.3	460.0	4.9	22.8
Central Africa	1.1	27.6	45.6	73.7	19.1	2.6	0.5
East Africa	8.0	108.5	142.3	216.7	229.8	4.8	11.1
Southern Africa	14.6	268.5	391.4	359.6	353.6	1.7	6.1
Sub-Saharan Africa	8.4	692.6	958.5	1220.4	1230.0	3.4	41.0
North Africa	59.6	878.3	1273.4	1598.8	1566.0	4.0	62.0
South Africa	59.3	772.7	1064.3	865.3	780.6	1.1	8.6
Africa	19.1	2343.6	3296.2	3684.6	3576.6	2.7	95.4

[a] Use per hectare is calculated by dividing fertilizer consumption in 1990 in nutrients tonnes by hectares of arable land and land under permanent crop in 1989 (these are both latest statistics available).
[b] Growth calculated over 1990 consumption level.
Source: Van Reuler and Prins (1993).

Table 5 shows the nutrient balances of a 17 year maize–cotton–groundnut–sorghum rotation in Senegal. The calculated plant nutrient budgets are always negative for N, P and K when the fertilizers are not applied. In Burkina Faso in a long-term trial on agronomic evaluation of different P fertilizers, Lompo (1993) calculated phosphorus and calcium budgets. Table 6 indicates that except for the control treatment, the P budget of the other treatments was positive. Moreover, it was found that the less soluble the P source, the more positive was the balance. The Ca balance was negative not only for the control treatment but also when TSP was applied. Even with cash crops where most of the fertilizers are applied, nutrient balances can be negative. In northern Cameroon, in a cotton sorghum rotation trials, Gigou (1982) obtained negative K balances in cases where no crop residues were returned. In Burkina Faso a positive calcium balance was obtained only when limestone and phosphate rock were applied (Table 7).

3. Available technologies to combat nutrient depletion in west Africa

Several studies in the sahelian zone of west Africa have concluded that low fertility rather than rainfall is the major constraint for the production of food grain and natural vegetation (Breman and de Wit, 1983; Van Keulen and Breman, 1990; Table 8). This is because of natural soil infertility and the very low level of fertilization to replace nutrients removed in the soil system. It is important to differentiate between the technologies that save nutrients from being lost from the agroecosystems such as erosion control, restitutions of residues, agroforestry and recycling of household wastes and manure from those that add nutrients to the agroecosystem, such as the application of mineral fertilizers and amendments, organic input from outside the farm and N-fixation (Table 9).

3.1. Soil and water conservation

In the Sudano-Sahelian zones of west Africa prominent indigenous soil and water conservation techniques include stone bunds on slopes, contour stone bunds, stone terraces, stone lines, earth bunding, and planting pits (Savonnet, 1976; Reij, 1983; Roose, 1990). Impressive land management using contour bund stones, planting pits in the Yatenga region and permeable rock dams in the region of Koungoussi can be observed in Burkina Faso. Vlaar and Wesselink (1990) reported a sorghum yield increase up to 1500 kg ha $^{-1}$ due to permeable rock dams.

Table 5
Nutrient balances (INPUT–OUTPUT) of a rotation maize–cotton–sorghum–groundnut in Nioro-du-Rip (Senegal) 1963–1979

Terms of balance	N (kg ha ^{1})			P_2O_5 (kg ha ^{1})			K_2O (kg ha ^{1})			CaO (kg ha ^{1})		
	FOTO	F1T1	F2T2	FOTO	F1T1	F2T2	FOTO	F1T1	F2T2	FOTO	F1T1	F2T2
Crops removal	628	1040	1192	155	207	248	654	403	418	178	204	198
Fertilizers	0	+364	+778	0	+321	+916	0	+349	+573	0	3	+726
Manure	0	0	+42	0	0	+21	0	0	+44	0	0	+48
Nitrogen fixation	+234	+319	+294	0	0	0	0	0	0	0	0	0
Dust and rain deposit	7	7	7	46	46	46	73	73	73	354	354	354
Balance (17 years)	387	350	71	109	+160	+735	581	+19	+272	+176	+150	+930
Losses or gains annuals means	23	21	4	6	+9	+43	34	+1	+16	+10	+9	+54

Source: Tourte et al. 1971; Sarr, 1981; Rabot, 1984.
F0: No fertilizer.
F1: 200 kg ha ^{1} of NPK.
F2: 400 kg ha ^{1} of NPK + Taiba PR.
T0: Hand cultivation.
T1: Animal traction.
T2: Animal traction with end of season tillage and incorporation of manure.
Note: Nutrient losses by leaching, denitrification and erosion are not taken into account.

Table 6
Phosphorus and calcium balances for sorghum production using different sources of P fertilizers, Saria (1981–1987)

Treatments	Plant nutrients balances (kg ha ^{1})	
	Phosphorus	Calcium
Control	98	14
Phosphate rock	+62	+74
Partially acidulated phosphate rock	+52	+20
Triple super phosphate	+42	104

Source: Lompo, 1993.

Nicou and Charreau (1985) have extensively reviewed IRAT's research on tillage and reported that soil tillage in the Sudano-Sahelian zone can result in the yield increase varying between 22% and 103%. In studying the effect of preplanting tillage on the establishment and early growth of pearl millet, Klaij and Hoogmoed (1989) concluded that the good seedling survival rates because of ridging treatment suggests that ridging is effective in reducing wind erosion. Michels (1994) reported that the coverage of millet seedling by wind blown soil severely hampers millet establishment by almost 50%. In the Sudano-Sahelian zone, soil tillage effect could be temporary, and not

Table 9
Restoring soil fertility in west Africa: technical options and their impact on the nutrient flows

Technology	Adding/saving
01. *Mineral (soluble) fertilizers*	
Increased use	Adding
More efficient use	Saving
02. *Mineral soil amendments*	
Rock phosphates	Adding
Lime and dolomites	Adding+Saving
03. *Organic inputs*	
From within the farm	Saving (mainly saving)
From outside the farm	Adding
04. *Improved land use systems*	
Rotations, green manures	Adding+saving
Fallows, woody species	Adding+saving
05. *Soil and water conservation*	Saving
06. *Integrated nutrient management*	Adding+saving

Source: Smaling et al. (1996).

Table 7
Phosphorus sources and dolomite application impact on the calcium balance in kg ha ^{1} (1988–1990)

Years	NK control		NPK (BP)		NPK (UV 42)		NPK (TSP)	
	( )	(+)	( )	(+)	( )	(+)	( )	(+)
1988	5	+391	+16	+410	+10	+411	8	+382
1989	9	13	+17	+13	+10	+4	6	-14
1990	4	6	+21	+17	+15	+13	4	6
1991	18	15	+8	+7	+3	+1	16	24
Total 1988–1991	36	+357	+62	+447	+38	+429	34	+338
Total 1981–1991	150	+243	+136	+521	+61	+452	141	+231

( ) Without dolomite (+) with dolomite.
Source: Lompo, 1993.

Table 8
Water use (WU), grain yield (Y) and water use efficiency (WUE) of pearl millet with and without fertilizer application at three sites in Niger during the rainy season of 1985

	Sadoré			Dosso			Bengou		
	WU (mm)	Y (kg ha ^{1})	WUE (kg ha ^{1} mm ^{1})	WU (mm)	Y (kg ha ^{1})	WUE (kg ha ^{1} mm ^{1})	WU (mm)	Y (kg ha ^{1})	WUE (kg ha ^{1} mm ^{1})
Fertilizer	382	1570	4.14	400	1700	4.25	476	2230	4.68
No fertilizer	373	460	1.24	381	780	2.04	467	1440	3.0
SE	3.7	162	0.44	3.0	103	0.26	15.2	126	0.22

Source: ICRISAT (1985).

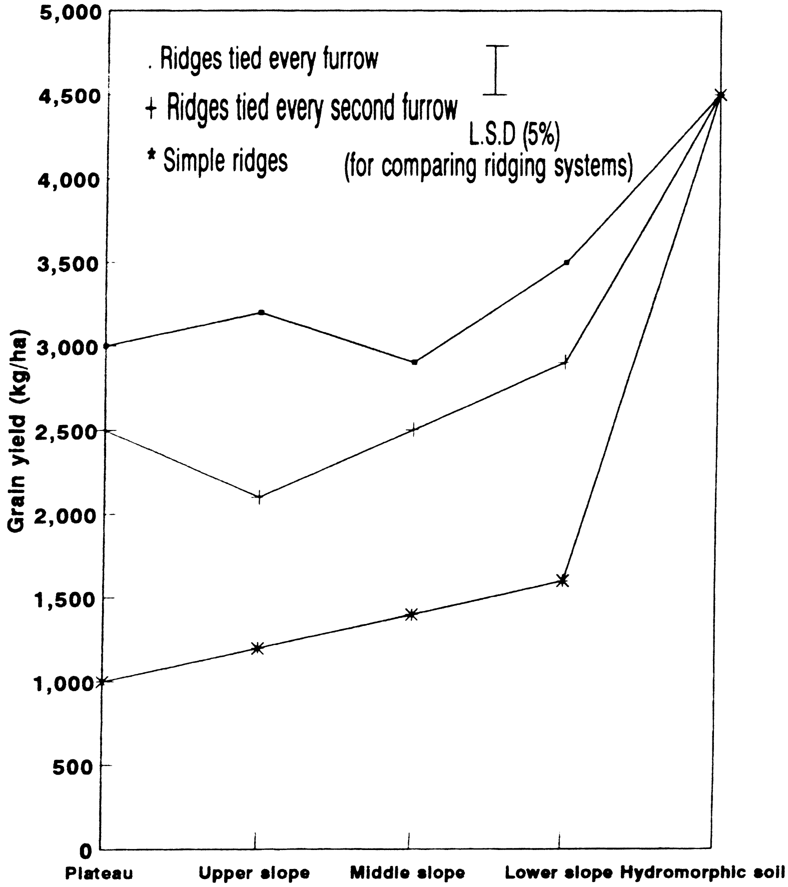

Fig. 4. The effect of crop position along the toposequence and of tied ridges on the grain yield of maize. Kamboinse, 1981. (Source: Rodriguez (1987)).

enough to ensure high water infiltration rates throughout the growing season in soils where surface sealing or compaction occurs. This explains the response to tied-ridge under all tillage methods at Saria and Kamboinse Research Station (Rodriguez, 1987). Maize grain yield responses to tied ridges were found to be high in all locations along the toposequence at the Kamboinse station, except for the hydromorphic soil of the bottom land (Fig. 4).

Roose (1989) reviewed the results of 30 years of research at ORSTOM and CIRAD on soil and water conservation and concluded that the major factors in curbing erosion are vegetation cover, cultural practices and slope management. Table 10 gives the researchers' findings on runoff and erosion rates in the region as a function of rainfall, slope gradient, and land use.

3.2. Cropping systems

3.2.1. Agroforestry

Two agroforestry technologies are alley cropping for food production and alley farming for food and animal productions (Kang et al., 1990). As much as 30% of the N required by the crop can come from the leguminous hedgerow trees (IITA, 1985). Annual N field from five prunings of Gliricidia and Leucaena hedgerows in Nigeria was 170–250 kg N ha^{-1} as opposed to 40–85 kg N ha^{-1} in the non-leguminous species *Acioa Bartic* and *Alchormea Cordifolia* (Kang et al., 1990). Maize grain yield increases were obtained with the use of Leucaena prunings (Fig. 5).

Valet (1985) reported that barrier hedges in Sine Saloum, Senegal, sharply reduced water and wind erosion. In the Maggia valley of Niger, windbreaks

Table 10
Runoff and soil loss data for selected locations in west Africa

Country	Location	Mean annual rainfall (mm)	Slope (%)	Treatments	Runoff (%)	Soil loss (tonnes ha^{-1} year^{-1})
Benin	Boukombe	875	3.7	Millet conventional	11.7	1
Niger	Allokoto	452	3	Village	16.3	8
Nigeria	Samaru	1062	0.3	Sorghum,cotton	25.2	3
	Ibadan	1197	15	Bare soil	41.9	229
				Bare soil	13.5	40
				Maize–maize	2.6	0
				Maize–cowpea	1.7	4
Senegal	Sefa	1300	1.2	Cowpea–maize	39.5	21
		1241	1.2	Bare soil	22.8	69
		1113	1.2	Groundnut	34.1	83
Burkina Faso	Ouagadougou	850	0.5	Sorghum	40.6	10.2
				Bare soil	2.32	0.6
				Crop	2.5	0.1
Cote d'Ivoire	Bouake	1200	0.3	Forest	15.3	18.3
	Abidjan	2100	7.0	Bare soil	38.0	108.2
Mali	Niono		1.3	Bare soil	25.0	NA
Niger	Sadore	560		Millet	1.5	NA
				Millet	0.2	NA
Sierra Leone	Mebai	2000		Bare soil	11	
Sierra Leone	Mabai	2000		Unfertilized maize	8	

Source: Bationo et al. (1996).

have been shown to improve pearl millet yield by 15% (Dennison, 1986). In the Integrated Rural Development Project of Keita, Niger, Grall (1986) and Carucci and Cupers (1986) reported significant positive effects of windbreaks on crop yield although the sustainability was doubtful (Pretty, 1995). Michels (1994) reported a significant sand flux reduction by different types of windbreaks within a 10 m distance from the windbreaks and an increase in organic carbon and total N in the topsoil at a distance of 1 m from the windbreak in comparison with the control plot.

3.2.2. Intercropping and rotations

Intercropping of cereals and grain legumes is often mentioned as having many advantages over monocultures (Ofori and Stern (1987); Cattan and Schilling (1990)). Bationo et al. (1996) showed the beneficial effects of cereal-legume rotations in different agroecological zones of the Sahel (Fig. 6). In these fragile ecosystems, continuous cropping of pearl millet resulted in lower yields across all N rates. Tarawali et al. (1992) reported that the yield of maize following a leguminous fodder bank nearly doubled that after a natural fallow at all nitrogen levels.

3.3. Mineral fertilizers

There is ample evidence that the judicious use of mineral fertilizers can bring about substantial crop yield increases (Mokwunye and Vlek, 1986; Pieri, 1989; Van Reuler and Jansen, 1989; Van der Heide, 1989; Vlek, 1990; Mokwunye, 1991; Sedogo, 1993; Delvaux et al., 1993). The use of fertilizers will increase not only the total above-ground biomass and make available more crop residue for mulching (Table 11) but will also increase the root biomass

Table 11
Effect of fertilizer application on Millet biomass production in a Millet/Sorghum intercrop in the Savanna region of Togo

Biomass components	Yield (kg ha^{-1})	
	No fertilizer	Fertilized
Roots	446	1527
Stalks	812	3539
Leaves	336	1235
Grains	81	509

Source: Unpublished data, IFDC-Africa, Soil Fertility Restoration Project.

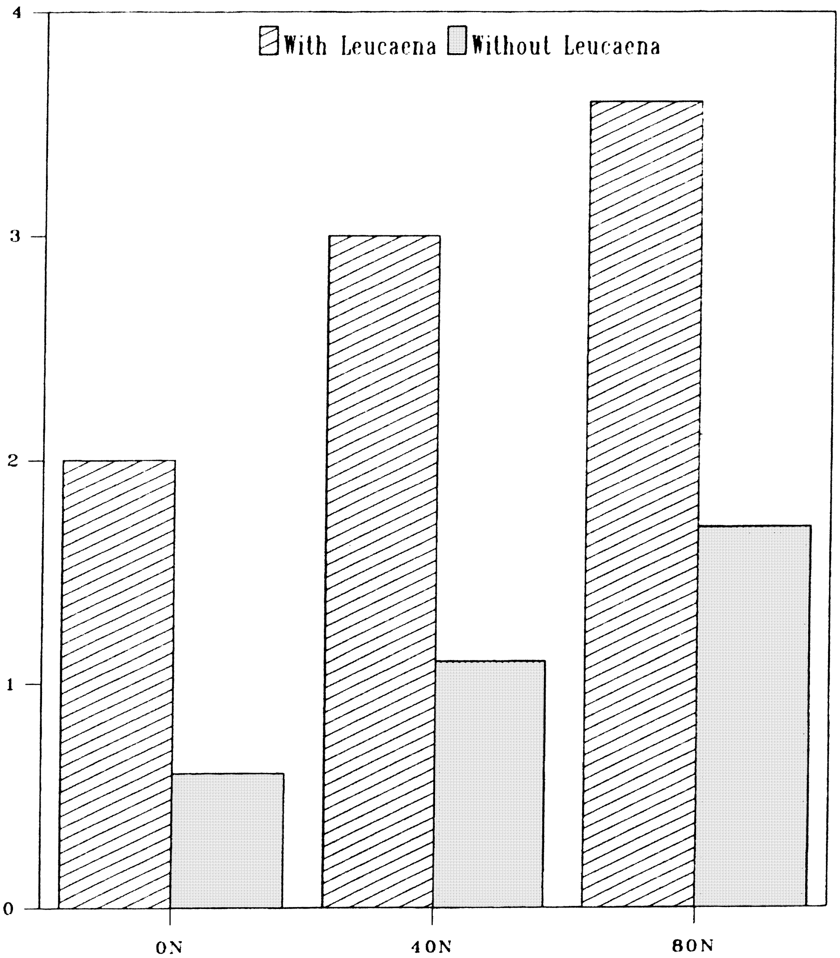

Fig. 5. Effect of Leucaena and nitrogen (kg ha^{-1}) on maize grain yield (ton ha^{-1}), Ibadan, Nigeria. (Source: IITA, 1985).

(Table 12) and this can result in an increase of soil organic matter (Table 13).

3.4. Organic amendments

In the Sahelian zone, Bationo and Mokwunye (1991) reported drastic yield increases with the application of crop residue. Although it is recognized that the application of manure is an integrated part of soil fertility restoration (Penning de Vries and Djiteye (1982); Breman and Niangado (1994)), the major constraint is its availability (McIntire et al., 1992; Williams et al., 1995). Powell and Williams (1994) showed the greater advantage of recycling both manure and urine in the cropland when urine can also be 'harvested' by crop residues with high C/N ratio used as bedding in stalls and kraals. Green manure legumes such as Mucuna spp. can accumulate up to 100 kg N ha^{-1} and will also suppress weeds (Giller and Wilson, 1991; Juo and Kang, 1989).

3.5. Mineral soil amendments

Gerner and Mokwunye (1995) summarized the recent results on the use of local phosphate rock (PR) to restore the soil fertility and increase soil productivity. In west Africa, phosphate rock from Tahoua (Niger), Parc-W (Niger), Kodjari (Burkina

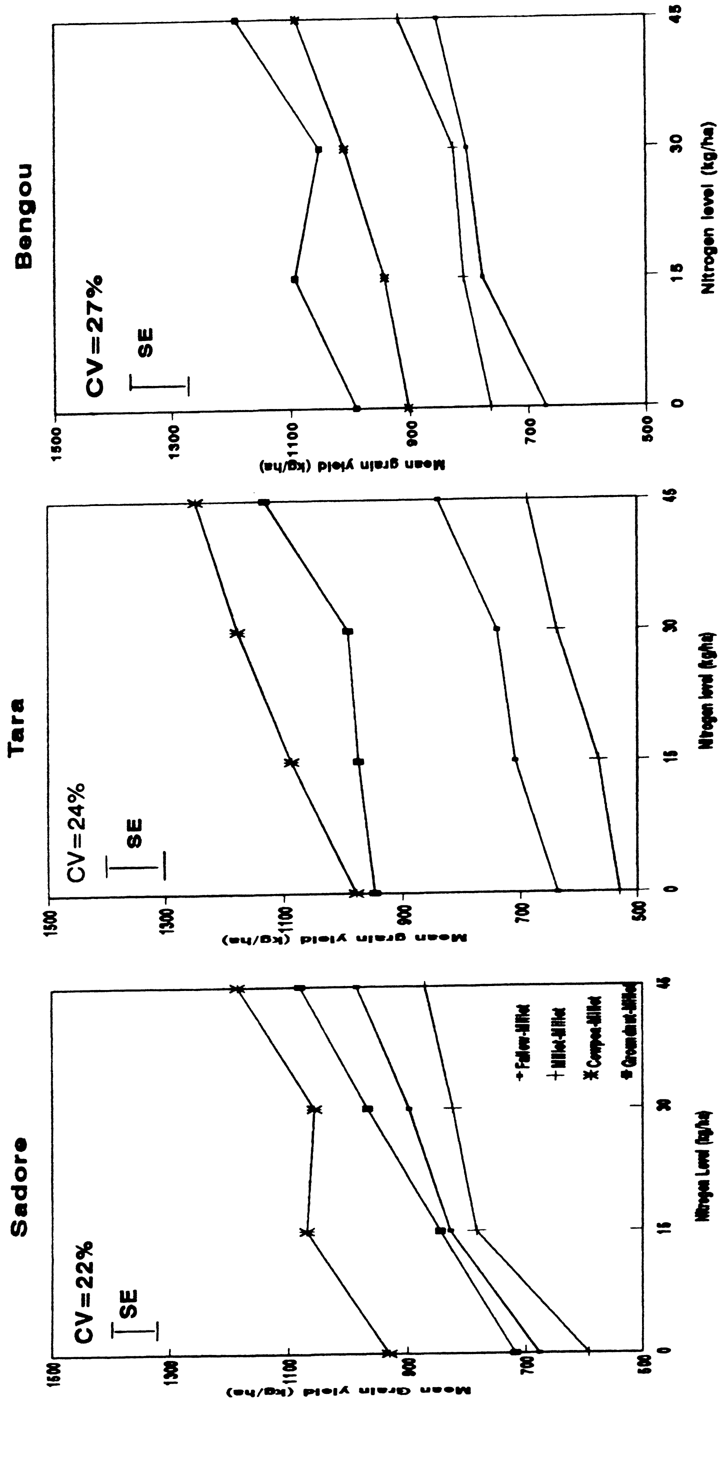

Fig. 6. Effect of nitrogen and cropping systems on pearl millet grain yield at Sadore, Tara and Bengou, Niger. Means over 4 years (1989–1992).

Table 12
Effect of nitrogen fertilizers placement and soil tillage on maize root development at Nioro-du-Rip, Senegal

Fertilizer[a] Tillage[b]	No fertilizer Without	Surface applied Without	No fertilizer With	Surface applied With	Incorporated (0–18 cm) With
Soil profile (cm)			Root (g/dm^3)		
0–10	0.167	0.310	0.104	0.296	0.401
10–20	0.088	0.154	0.161	0.152	0.195
20–30	0.099	0.182	0.146	0.174	0.229
			Grain yield (kg ha^{-1})		
	496	2162	1642	3726	3985

Source: Chopart, 1975.
[a] 200 kg ha^{-1} 10-21-21+150 kg ha^{-1} urea.
[b] Tillage with animal traction.

Table 13
Effect of fertilizer on organic carbon (%) at different sites in Senegal

Essais	F0		F1		F2	
	0–8 cm	8–30 cm	0–8 cm	8–30 cm	0–8 cm	8–30 cm
Thiénaba	1.68	1.68	1.60	1.58	1.67	1.51
Nioro	2.92	2.67	2.99	2.79	3.31	3.14
Boulel	2.22	1.97	2.38	2.11	2.33	2.19
Sinthiou	2.49	2.63	3.82	3.67	3.69	3.47
Vélingara	4.38	3.93	4.17	3.76	4.66	3.64
Missirah	2.87	3.14	3.22	3.13	4.21	3.72
Séfa	5.03	4.51	5.56	5.08	4.47	4.06
Average	3.1	2.9	3.4	3.2	3.5	3.1

Source: Rabot, 1984.
F0: No fertilizer.
F1: 200 kg ha^{-1} of NPK.
F2: 400 kg ha^{-1} of NPK with 400 kg ha^{-1} of Taiba phosphate rock.

Faso), Hahotoe (Togo) and Tilemsi (Mali) have been characterized and evaluated in different agro-ecological zones. Tahoua and Tilemsi PR are found to be suitable for direct application. Partial acidulation of the others rocks improves considerably their agronomic effectiveness. The advantage of using limestone to correct soil acidity have been reported by several researchers (IITA, 1985; Jallah et al., 1991; Lompo, 1993).

3.6. Integrated plant nutrient management

Interventions aimed at redressing distorted nutrient budgets imply the development of integrated nutrient management systems, conceptualized as the judicious manipulation of the nutrient input and output processes. Table 14 summarizes the results of soil fertility management trials established at IFDC's benchmark sites in Togo. Both N and P effects are marked at all sites. Response to K was observed only in the coastal zone. Response to S was observed only in the northern zone. The highest yields were obtained where fertilizers were used in combination with organic inputs and lime. Long-term soil fertility management trials have been established in different agro-ecological zones. Fig. 7 shows response of pearl millet to different treatments in the Sahelian zone, whereas Fig. 8 presents the results of long-term sorghum trials in the Sudano-Sahelian zone (Sedogo, 1993). Fig. 9 then shows the effect of nutrient inputs on maize in the

Table 14
Average maize grain yield after 3–6 years of soil fertility management trials at different sites in Togo

	Davié	Amoutchou	Tchitchao	Kaboli	Koukoumbo	Mean
1. Control	1842	2199	1009	1414	1656	1510
2. TSP+N+K	3272	3815	1712	3204	3857	3172
3. N+K	2529	2696	1353	2095	2823	2319
4. SSP+K	3024	2523	1344	2703	2535	2426
5. Treatment 2+ Mg+Zn	3432	3844	2327	3535	3515	3331
6. SSP+N	2340	3631	2150	4418	4062	3320
7. SSP+N+K	3514	3971	2576	4015	4748	3765
8. Treatment 7+lime (500 kg every 3 years)	3255	4096	2400	4022	5195	3880
9. Treatment 7+Mg+Zn	3502	4207	2251	4329	5159	3880
10. Crop residue (CR)	1830	2610	1482	1648	2426	1999
11. 1/2 treatment 7+CR	3042	3547	1997	3348	4162	3139
12. Manure (10 t ha $^{-1}$) every 3 years	2375	3497	1475	2493	2645	2497
13. Treatment 9+lime	NA	4377	2513	4651	4483	4006
14. Treatment 9+CR	3491	4544	2735	4582	5061	4083
15. Treatment 14+manure+lime	4090	4550	3085	4697	5025	4289

Source: Bationo et al. (1996).

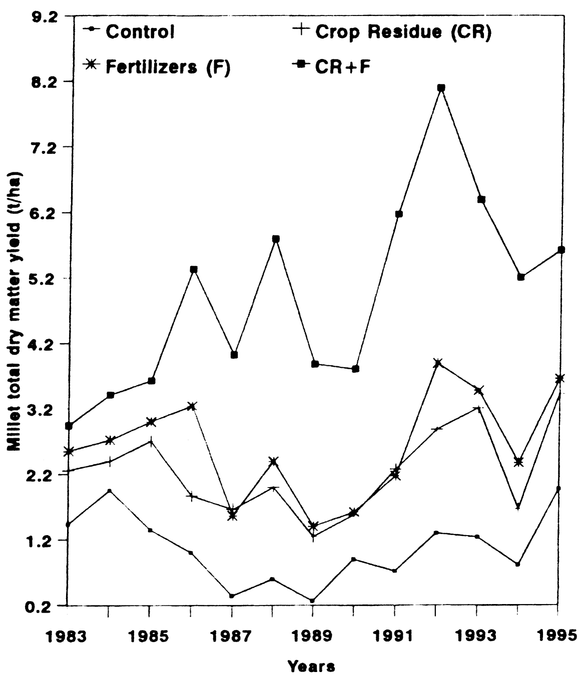

Fig. 7. Pearl millet total dry matter yield as affected by different management practices over years, Sadore, Niger.

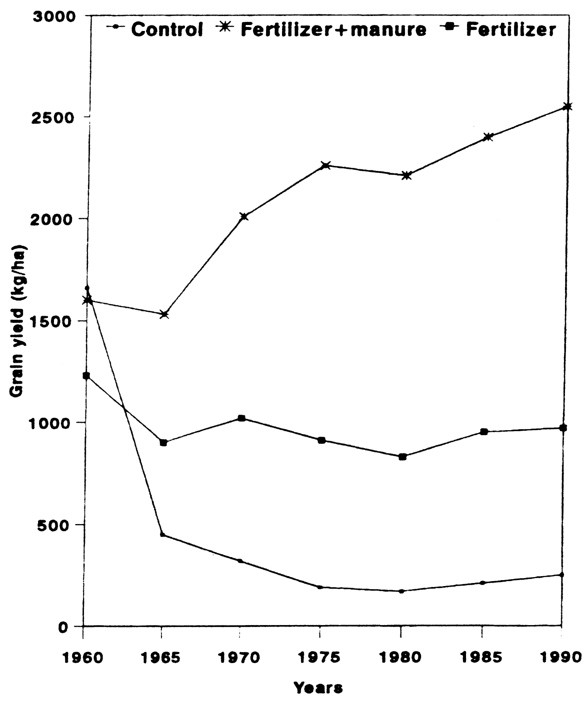

Fig. 8. Sorghum grain yield as affected by mineral and organic fertilizers over time. (Source: Sedogo, 1993).

Equatorial Forest zone of southern Nigeria (Juo and Kang, 1989). All examples show that although application of mineral fertilizers is an effective means of increasing yields in arable farming systems, mineral fertilizers alone cannot sustain yields in the long run. When mineral fertilizers are combined with other

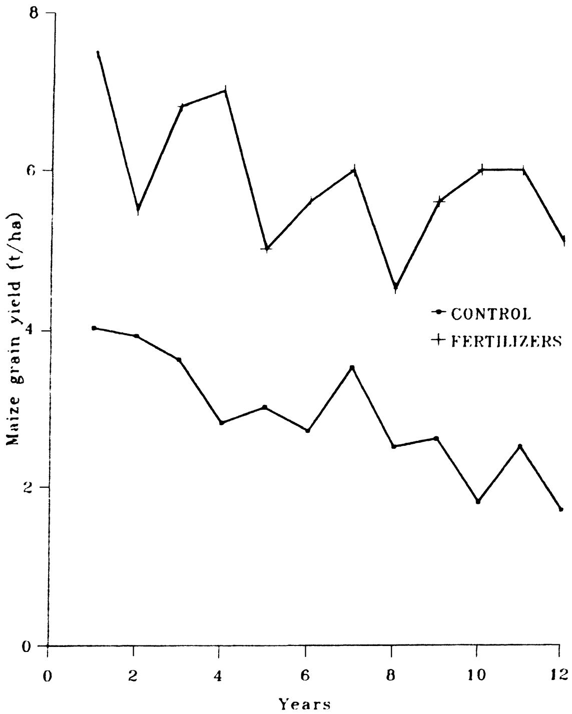

Fig. 9. Effect of long term fertilizers management on maize grain yield in western part of Nigeria (Juo and Kang, 1989).

technologies such as crop residue or manure, productive and sustainable production systems can be obtained.

4. Conclusions

The arable land of all west African countries have, on average, a negative nutrient budget and the present food shortage should be linked with the inherent soil infertility and the low level of plant nutrient use to replace the nutrients removed in the soil system.

Over the past years a considerable amount of technologies to improve the productive capacity of African soils has been generated. These technologies have not been transferred to or implemented by the intended beneficiaries. Future research needs to focus more on reasons for adoption and non-adoption of presently available technologies to combat nutrient depletion. Future research should use more of the participatory approach to technology generation and validation and take more into account the farmer's view, indigenous knowledge, social and economic realities and enabling policy environment.

In addition to a greater on-farm research involving partnership between the researchers, farmers, extension agents and non-governmental agencies (NGOs) at the technology design, development and evaluation stages, there is need for interventions at supranational and national level. At national level there is need for the creation of an enabling environment with action on credit schemes, post harvest operations that add value to farm output, output marketing schemes, clear-cut land tenure arrangements. At supranational level there is need to revisit the impact of structural adjustment programs (SAP) and the general agreement on tariffs and trade (GATT). It is mandatory to provide the farmers with positive incentives on fertilizer use such as the use of phosphate rock as a capital investment and the IFDC-supported Soil Fertility Initiative if west Africa wants to keep feeding itself.

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