PN ABY-810
91027

DESFIL
Development Strategies for Fragile Lands

A LITERATURE REVIEW ON THE POTENTIAL FOR AN INCREASE IN AGRICULTURAL PRODUCTIVITY IN NIGER, WEST AFRICA

Submitted to:

AID/AFR/SD/PSGE/NRM
USAID/Niger

Submitted by:

William Fiebig, Ph.D.
Rodale Institute

September 8, 1995

2000 M Street N.W., Suite 200, Washington, D.C. 20036
Tel: (202) 331-1860 • Fax: (202) 331-1871

-1

PN-ABY-811

A Literature Review on the Potential for an Increase in Agricultural Productivity in Niger, West Africa

William Fiebig, Ph.D.
Rodale Institute

1. Introduction

The Sahelian countries of West Africa may be described as a region of limited rainfall and frequent drought. Although diverse in many ways, the countries of Niger, Chad, Senegal, Mauritania, Burkina Faso, and Mali have in common the problem of fragile agricultural sectors and demographic pressures. Niger is the largest country in West Africa and is the geographic center of the Sahelian region. Niger provides an excellent example of the demographic, economic, and agricultural problems confronting the region.

There is little hard data on the extent, rate or seriousness of soil degradation in the Sahel. However, from a theoretical approach and from direct field observations and discussions with farmers and officials, one can conclude that the majority of the arable land in Sahelian West Africa is very seriously affected. One starts with a marginal climate and a fragile soil, where fertility is almost entirely tied up in the soil organic matter and recycled through the plant system. Under cultivation, some form of equilibrium is maintained through a fallow system. A drier climate, more people, and mechanization have removed the remains of the vegetative cover and eliminated, or greatly reduced, the fallow. Biomass is almost entirely exported, for food, construction, animal fodder and by erosion. Erosion also removes the few fine and better structured top soil. Erosion, loss of organic matter and tillage have destroyed the soil's structure, CEC, infiltration and water holding capacity.

The Republic of Niger has a landlocked area of 1,186,408 km^2 (458,075 mi^2). with a population that exceeds 7 million; it is the tenth largest country in Africa and is sparsely populated. Although estimates vary, between 3% and 8% of the land is considered suitable for agricultural production.

The purpose of this literature review is to evaluate whether the biophysical endowment of the natural resources base will support agricultural production increases in Niger. In other words, what is the potential for an increase in agricultural productivity through the use of natural resources management (NRM) practices. To maximize the production potential of the agricultural sector, the productive capacity of the soil must be rebuilt. This requires a combination of soil stabilization (soil and water conservation) and soil rebuilding (soil fertility enhancement).

2. Soil and Water Conservation Practices

Africa's lands are under pressure to provide increased production to feed the continent's growing population. To meet this demand, farmers have shortened fallow periods on lands already in use and they have expanded cultivation onto lands of marginal productivity. The result is that many agricultural lands are now showing signs of widespread environmental degradation (Lal, 1987; Swindale, 1988).

Soil and water conservation systems may be defined as all measures designed to improve or preserve the productivity of the land (Reij, 1988). Techniques of erosion control usually also contribute to water retention, and some measures for improving soil fertility can, through their effect on soil structure, also increase both the resistance to soil erosion and the water-holding capacity of the soil.

Studies conducted at the CARE neem (*Azadiracta indica*) windbreak project in the Majjia Valley, Niger, showed a 20% increase in pearl millet grain yield in crops grown between young (ca. 5 years) windbreaks spaced about 100 m apart (Bognetteau-Verlinden, 1980). Competition between windbreaks and crops might be reduced by silviculturally managing the trees. At the CARE project, partial pollarding of windbreaks still showed a 30% reduction in windspeed and yielded useful wood products (Persaud et al., 1986). Also, pollarded windbreaks lead to significantly higher grain yield in the adjacent zone of competition (Rorison and Dennison, 1986).

Minimum tillage, mulching, and other soil-conserving practices--all of which achieve their benefits through the presence of an organic cover on the soil--are among the most effective methods of conserving water and reducing soil erosion (Lal, 1987). Minimum tillage, sometimes called conservation tillage, involves seeding through crop residue or sod without plowing. Plowing and other forms of cultivation break up the soil and temporarily increases water infiltration while lowering run-off. However, soon after being tilled, soil structure generally breaks down, decomposition of organic matter accelerates, and erosion potential increases (Constantinesco, 1976). Minimum tillage is an effective tool against this erosion. By leaving a cover of vegetative material, the soil is less susceptible to wind and water. This technique also allows farming on steep slopes that are severely erosion-prone. For example, minimum tillage maize can be grown on a slope of 15 percent while allowing erosion of substantially less than 1 mt/ha (Table 1).

In minimum tillage systems, crop residues left behind from the previous season's harvest act as a mulch and can reduce water runoff and soil erosion dramatically (Table 2). However, crop residues in Africa, such as cereal stalks, often are needed for fodder, cooking fuel, or building materials. The amount of mulch can be increased by managing the crop sequences and combinations or growing a cover crop specifically for this purpose. Mulch material also can be brought in from elsewhere and added to the field. Alley farming, for example, may serve as a source

of tree prunings that can be used for mulch and other purposes (Lal, 1987). Animal manure is another source of mulch. Although obtaining and transporting large amounts of manure can be a serious obstacle, the benefits can be a key factor supporting a farmers decision to incorporate animals into the farming system.

Table 1. The effects of plowing and no tillage on soil and water loss.

	Water runoff (mm)		Soil erosion (ton/ha)		Maize grain yield (ton/ha)	
Slope	No tillage	Plowed	No tillage	Plowed	No tillage	Plowed
1%.....	11	55	0.0	1	4.5	3.6
5%.....	12	159	0.2	8	4.5	3.8
10%....	20	52	0.1	4	4.0	3.6
15%....	21	90	0.1	24	3.6	3.0

Source: Lal. 1987.

Table 2. The effects of mulching with crop residues on water runoff and soil erosion.

	Water runoff (mm)		Soil erosion (ton/ha)	
Slope	No Mulch	Mulch	No Mulch	Mulch
1%.....	412	0	9	0.0
5%.....	483	11	134	0.2
10%.....	303	21	137	0.2
15%.....	375	20	96	0.7

Source: Lal. 1987.

Yields on fields in Burkina Faso reclaimed with stone bunds and receiving substantial runoff from a catchment area, can be as high as 1000 to 1200 kg/ha (Reij, 1988). Treatment of fields already cultivated also leads to yield increases, but usually less spectacular, which in most cases can be explained by the fact that these fields usually receive less runoff. In 1986, yields on 33 fields treated with stone bunds averaged 972 kg/ha whereas yields on 33 non-treated fields averaged 612 kg/ha (Ouedraogo, 1987). Although yield data should be regarded with utmost caution, they show that average yield increases are much higher than the 155 kg/ha needed to make the treatment profitable (Matlon, 1986).

An example of a traditional water harvesting technique, "zay", is a technique which consists of digging holes with a depth of 5-15 cm and a diameter of 10-30 cm. The spacing is about 50-100 cm (Wright, 1985). Some manure and grasses are mixed with the seed added to each zay. Sorghum and/or millet yields obtained are often in the order of 1000 kg/ha or even more, which is spectacular in a region where the average cereal yields on cultivated lands are 400-500 kg/ha (Reij et al., 1988).

Grain and dry matter yields of sorghum grown in Niger on soil (300 g/kg sand and 700 g/kg clay mixed with limestone) tilled by different methods are reported on by van der Ploeg and Reddy (1988). These data indicate that there was a grain yield increase of 24% due to ridging and 60% due to tied-ridging in 1985. This grain yield increase was realized through a 35% increase in dry matter production in the tied-ridging treatment and with almost no extra dry matter production in the case of the ridging treatment (Table 3). Similar grain yield increases occurred due to ridging (+30%) and tied-ridging (+48%) compared with flat tillage in 1986. This grain yield increase was realized through a 35% and 58% dry matter yield increase in ridged and tied-ridge plots, respectively, compared with flat tillage.

Table 3. Effect of tillage method on sorghum grain and dry matter yield at Kolo, Niger, 1985 and 1986.

	Grain yield (kg/ha)		Dry matter yield (kg/ha)	
Tillage method	1985	1986	1985	1986
Flat tillage	1000	520	5250	2060
Ridges	1240	680	5230	2780
Tied ridges	1600	770	7090	3270
SE	180	90	630	320

Source: van der Ploeg and Reddy. 1988.

Contour Strip Rainfall Harvesting (CSRH) is a potential management technique to conserve soil and make more efficient use of rainfall (Zaongo et al., 1988). The effects of the different factors on millet grain yield are given in Table 4. At all sites, CSRH and fertilizer significantly increased grain yields, but plant density had no effect on millet yield. The interactions between CSRH and fertilizer resulted in significant increases in millet yield at all locations.

Sorghum grain yield response patterns were similar to those of millet (Table 5). However, unlike millet, plant density had a significant effect on sorghum grain yield at N'Dounga and Chikal. Grain yield increased from 1035 to 1920 kg/ha at N'Dounga and from 257 to 346 kg/ha at Chikal with the higher plant density. The largest yield increases were due to fertilization and rainfall management.

The mean sorghum grain yield was higher than millet at N'Dounga (1477 versus 1280 kg/ha). This indicates that under more favorable soil and rainfall conditions, sorghum has a higher grain production potential than millet. At other locations, millet yielded more than sorghum, indicating that millet is better adapted under low soil pH (Kala Pate) or low rainfall conditions (Chikal). The CSRH technique increased rooting depth and soil water storage.

Table 4. Millet grain yield as affected by rainfall management, fertility, and plant density at three locations in Niger, West Africa (1987).

Treatment	Site		
	Kala Pate	N'Dounga	Chikal
	kg/ha		
Rain management:			
Traditional	464 a*	923 a	401 a
CSRH	1019 b	1667 b	644 b
Fertilization:			
No fert.	641 a	1135 a	476 a
Fertilization	841 b	1455 b	569 b
Plant density:			
Low	786 a	1216 a	518 a
High	697 a	1374 a	527 a
Mean	792	1280	523

*Means within location and treatment followed by different letters are significantly different (P<0.05). Source: Zaongo et al. 1988.

Table 5. Grain sorghum grain yield as affected by rainfall management, fertility, and plant density at three locations in Niger, West Africa (1987).

Treatment	Site		
	Kala Pate	N'Dounga	Chikal
	kg/ha		
Rain management:			
Traditional	321 a*	1140 a	288 a
CSRH	501 a	1814 b	312 b
Fertilization:			
No fert.	274 a	1204 a	255 a
Fertilization	547 b	1751 b	345 b
Plant density:			
Low	334 a	1035 a	257 a
High	486 a	1920 b	346 b
Mean	411	1477	300

*Means within location and treatment followed by different letters are significantly different (P<0.05). Source: Zaongo et al. 1988.

Two experiments addressing poor soil environment and the effects of tillage were conducted at the ICRISAT Sahelian Center (ISC) in Niger from 1985 to 1987 (Klaij and Serafini, 1988). In the first, the effects of plowing to a depth of 15 cm, ridging (75 cm between ridges, ridge height 15 cm) without other primary tillage, "sandfighting" (increasing the surface roughness by creating depressions and clods), and a zero tillage treatment were compared for millet production over a 2-year period. In the second, concurrent experiment, that was repeated over three years, the "sandfighting" treatment was dropped and the other tillage treatments maintained. In this case, crop residues were either maintained or removed. In both cases, these treatments were compared with and without the addition of chemical fertilizers; 17 kg P/ha pre-sowing and a split application of 40 kg N/ha at 3 and 6 weeks after sowing.

Fertilizer use was the most important factor contributing to better stands and yields. In the first experiment, plowing and ridging improved plant stands and yields more when they were combined with fertilizer use. The response to fertilizer was moderate in the abscence of primary tillage and on "sandfought" plots (Table 6). Ridging without other primary tillage requires considerably less time and energy than plowing. Ridging also helps to reduce wind erosion by increasing the surface roughness, which lowers wind speeds and traps sand in the furrows, thereby minimizing seedling abrasion and burial.

Table 6. Effect of pre-sowing cultivation and fertilization on plant population (in percent of number of hills survived at harvest) and millet grain yield, ISC, rainy seasons of 1985 and 1986.

	Stand at harvest			Grain yield		
Treatment[a]	F0	F1	Mean	F0	F1	Mean
	--------- % ---------			-------- kg/ha -------		
Plowing	68	87	78	254	681	467
Ridging	44	80	62	180	649	414
Sandfighting	31	63	47	89	352	220
Zero-till	42	63	53	139	402	271
SE		3.3	2.5		40	34
Mean	46	73		165	521	
SE		1.5			15	

[a] F0 = control; F1 = fertilizer added. Average across 2 years and 3 cultivars.
Source: Klaij and Serafini. 1988.

For the second experiment, stand establishment data were not presented because the millet was grown in a protected area where wind erosion was not a problem. However, due to insect damage to the panicles, only biomass (total dry matter) data were presented (Table 7). Biomass was increased by 89% with fertilizer use. Mulching, either millet haulms (stalks) (2-4 t/ha) left on the soil surface, or

partially incorporated in ridges, or plowed under, increased yields by 54% on unfertilized plots and 12% on fertilized plts. Without fertilizer or crop residues, the effect of primary tillage was moderate, resulting in yield increases of only 11 to 16%. There was a significant tillage x fertilization x crop residue interaction. When ridging was practiced, residues were concentrated in the ridge. Ridging with crop residues and without added fertilizer depressed yields. When fertilizer was applied, ridging with crop residues enhanced crop yields. Between 1985 and 1986, mulching increased OM from 2.6 to 2.9 g/kg (SE = 0.006) while the pH (KCl) increased from 4.98 to 5.16 (SE = 0.06). It is unlikely that the beneficial effect of crop residues stem from changes in the soil biophysical and chemical processes rather than the physical ones. Maximum soil temperatures were decreased by only 1 to 2°C with the low levels of mulch in this experiment. The water use increased in 1986 from 287 mm on the lowest-input plots to 320 mm when the highest levels of inputs were applied. Water use efficiencies were higher in all years with higher levels of inputs, especially fertilizer.

Table 7. Effect of pre-sowing cultivation and fertilization on plant population (in percent of number of hills survived at harvest) and grain yield, ISC, rainy seasons 1985 and 1986.

	F0			F1		
Treatment[a]	R0	R1	Mean	R0	R1	Mean
	kg/ha					
Plowing	246	416	331	548	568	558
Ridging	197	280	238	469	586	528
Zero-till	222	327	274	472	543	507
Mean[b]	221	341	281	496	556	531

[a] F0 = no fertilizers added; F1 = 17 kg/ha of P fertilizer added and 40 kg/ha of N ; R0 = crop residue removed; R1 = crop residue left. Average across 3 years and 2 cultivars.

[b] SE for comparing means are for: fertilization - 223, tillage - 108, residue - 88, and their interaction - 298.

Source: Klaij and Serafini. 1988.

3. Soil Fertility Enhancement Practices

Low soil fertility is a major constraint to improving African agricultural productivity. Fertility levels vary throughout the continent, but they are generally low because of extensive weathering of the soils (Davies, 1973). Traditional farming systems relied heavily on fallow periods to restore soil fertility (Lal, 1987; Nye and Greenland, 1960). But this practice is less viable now in much of Africa because of human population increases. Consequently, more intensive management is necessary to replenish soil fertility.

Soil fertility can be maintained or improved through a variety of practices that optimize the benefit of internal farm resources. For example, soil and water management practices can conserve nutrients by reducing soil erosion and by reducing leaching of nutrients below crops' root zones. Organic fertilizers also can improve or help maintain soil fertility. For example, legumes and other biological nitrogen fixers can typically add some 100 kg of nitrogen per hectare per year in the tropics (Halliday, 1985).

Trials with millet during one year in Niger, at two locations with below average rainfall, showed that application of NPK fertilizers increased total shoot dry matter production (important for animal fodder and construction materials), grain yield, and water-use efficiency (Table 8). The larger plant canopy of the crops where fertilizer was applied, apparently helped to reduce water loss by evaporation from the soil.

Table 8. Effects of N, P, and K fertilizer on total shoot dry matter (SDM) and grain yield (GY) for crops of pearl millet grown at two sites in Niger during the 1984 rainy season (ICRISAT, 1985).

Site	Rainfall (mm)	Treatment	Water use (mm)	SDM	GY
				(kg ha^{-1})	
Sadoré	260	Fertilizer	165	4750	410
		No fertilizer	163	2417	290
Dosso	380	Fertilizer	247	5000	1120
		No fertilizer	270	3100	480

Source: Gregory. 1989.

Organic fertilizers can play an important role in ensuring that soil fertility is adequate for producing stable yields of African crops. Manures can increase yields substantially, but economic analyses have rarely been conducted taking all factors into account. These analyses are complicated because of the indirect effects of

manuring on improving soil quality (Jahnke, 1982). Manuring can be expected to become more widespread in the future as animals become more fully integrated into farming systems.

Nutrients from fallow and shrubland can be transferred onto arable lands by cattle through manure. Cattle in dryland West Africa produce 1.1 kg of manure dry matter per head each day during the dry season and twice that amount during the wet season (Omaliko, 1981). Manure can be deposited on arable fields during crop residue grazing, by "night paddocking" on the fields, and by spreading manure from kraals. In Mali, cultivators dig wells on their farm lands and offer water to pastoral cattle owners in exchange for the soil enrichment that results from the presence of cattle in the dry season (Wilson, 1986).

On-going studies of manuring practices show that cultivated and manured area are three times larger in drier than in more "humid" areas of western Niger (Powell and Williams, 1993). The amounts of manure dry matter and N and P applied to crop land are greatest, however, in the higher rainfall areas where manure is more important than sheep and goat manure (Table 9). The risk of excessive manure application and a consequent reduction in yields increases in drier areas.

Table 9. Cultivated and manured areas, manure dry matter (DM), nitrogen (N), and phosphorous (P) on farmers' fields in Niger, 1990.

	Zones		
	Wet	Mid	Dry
Rainfall (mm)	600	425	350
Households studied	15	10	15
Cultivated area			
ha/household	3.2	6.3	9.2
% manured	29	52	30
Manure DM (kg/ha)	3800	1700	1300
% cattle	52	55	19
% small ruminant	48	45	81
Manure N (kg/ha)	45	23	22
Manure P (kg/ha)	5.7	3.0	2.7

Source: Powell and Williams. 1993.

The decomposition of plant and animal wastes in soil has other important benefits: gradual release of nutrients and increased water retention. Furthermore, soil with adequate organic matter can take full advantage of phosphate rock and more highly processed chemical fertilizers, increasing yields beyond those obtained

by adding organic matter or commercial fertilizer alone (Table 10).

Table 10. Effect of manure and commercial fertilizer on sorghum yield at Saria, Burkina Faso.

Treatment	Sorghum yield	
	Without nitrogen	With 60 kg ha^{-1} nitrogen
	---------- kg/ha ----------	
Without manure	1831	2796
With 10 tons ha^{-1} of manure	2409	3591

Source: Pieri. 1985.

Studies carried out in Burkina Faso indicate that composting of sorghum residues surpress the "nitrogen deficiency" effect (Table 11).

Table 11. Effect of different organic residues on sorghum yield at Saria, Burkina Faso.

Treatment	Sorghum yield	
	Without nitrogen	With 60 kg ha^{-1} nitrogen
	---------- kg/ha ----------	
Without organic treatment	1831	2796
10 t/ha of sorghum straw	1652	3427
10 t/ha of manure	2409	3591
10 t/ha of aerobic compost	2505	3688
10 t/ha of anaerobic compost	2304	3601

Source: Sedogo. 1981.

In 1983, an on-farm trial was initiated at Sadoré, Niger, with the following treatments: (1) crop residues (pearl millet straw) left on the field after harvest; (2) crop residues removed after harvest and recommended rates of NPK fertilizer applied; (3) crop residues removed and no fertilizer applied, and; (4) crop residues left on the field and fertilizer applied. From the first year, the presence of crop residues in treatment (1) resulted in a 25% increase in pearl millet yield over the control treatment (3). Addition of crop residues has continued to improve yields but the highest yields were obtained when crop residues were supplemented with mineral fertilizers (Table 12). After 4 years of continuous cropping, pearl millet production in the control plots where crop residues were completely removed was practically nil. Although production was reasonably high initially with fertilizers alone (816 kg ha^{-1}), yields steadily declined since 1983 (Bationo et al., 1989).

Table 12. Effect of pearl millet residues on yield of pearl millet and total organic matter (Sadoré, 1986)

Treatment	Grain yield (kg ha^{-1})	Total Organic Matter (%)
Control	56	0.24
Crop residue	743	0.29
Fertilizers	816	0.25
Crop residues and fertilizers	1532	0.33

Source: Bationo et al. 1989.

Chabalier (1985) studied the effects of fertilizer nitrogen (N) and composted maize straw on crop yield after 11 years. The effect of 40 tons of fresh compost per hectare was roughly 51 kilograms of grain per ton of composted dry matter. The interaction between N and compost was small in the first five years of the trial and then significantly positive in the following six years. With compost, 40 kilograms of N per hectare gave the same result as 200 kilograms of N per hectare without compost.

For over 50 years, investigators have observed that lack of phosphorous is a major constraint to crop growth in semi-arid West Africa (Hauck, 1966; Pichot and Roche, 1972; Jones and Wild, 1975). In the pearl-millet growing region of Niger, available P as measured by the Bray 1 extraction hardly exceeds 3 mg kg^{-1} soil (Bationo et al., 1989). These sandy soils also have a low capacity to absorb phosphates. Results from several trials have shown that as little as 20 kg P_2O_5 ha^{-1} can more than double the yield of pearl millet as compared with yield from unfertilized land. An IFDC/ICRISAT collaborative project in Niger assessed the ability of indigenous phosphate rock (PR) to satisfy the phosphorous needs of crops such as pearl millet (IFDC, 1986). Three phosphate rock deposits (Tahoua, Parc W, and Aschia Tinamou) are currently known in Niger. The IFDC/ICRISAT study found that the direct application of indigenous ground PR can be an economical alternative to imported commercial P fertilizers.

4. Intercropping Systems

Nigerian agriculture is mainly rainfed; 4 million ha out of a total of 4.08 million ha are rainfed. Intercropping of cereal crops with legumes is quite prevalent in these areas (Reddy and Gonda, 1985). Pearl millet (*Pennisetum americanum*), the widely grown cereal crop is intercropped in about 70% of its total cultivated area primarily with cowpea (*Vigna unguiculata*) and secondarily with peanuts (*Arachis hypogaea*) and sorghum (*Sorghum bicolor* [L.] Moench) (MDR, 1984). Farmers' objectives in intercropping are (i) satisfying basic food needs, (ii) risk reduction, (iii) earning cash, and (iv) higher rate of crop production (Reddy and Gonda, 1985).

The performance of intercropping systems were evaluated at two high rainfall sites at Tarna in 1984 and 1985 and at Kolo in 1986 and 1987 (Reddy et al., 1988). The two sites are situated at 13° N in Niger. On an average, these sites receive about 500 mm rainfall and have a 90-day rainy season during the summer months, June to September. In these four experiments, millet grain yield in intercrop systems was similar to its sole crop yield. Cowpea intercrop yields were significantly lower than its respective sole crop yields in all four years (Tables 13 and 14). However, intercrop systems Land Equivalent Ratios (LERs) were always higher than the sole crop LERs, indicating better land use efficiency by millet/cowpea intercrop systems.

Table 13. Millet and cowpea grain yield and Land Equivalent Ratio (LER) in sole and intercrop systems at Tarna, 1984 and 1985.

	1984			1985		
	Grain yield			Grain yield		
Treatment	Millet	Cowpea	LER	Millet	Cowpea	LER
	kg/ha			kg/ha		
Millet sole crop	670 a[a]	---	1.00	960 a	---	1.00
Cowpea sole crop	---	260 a	1.00	---	580 a	1.00
Millet/Cowpea Intercrop	580 a	90 b	1.20	880 a	170 b	1.31

[a] Means within column followed by the same letter are not significantly different at the 5% confidence level, based on Duncan's Multiple Range Test (DMRT).
Source: Reddy et al., 1988.

Table 14. Millet and cowpea grain yield and Land Equivalent Ratio (LER) in sole and intercrop systems at Kolo, 1986 and 1987.

	1986			1987		
	Grain yield			Grain yield		
Treatment	Millet	Cowpea	LER	Millet	Cowpea	LER
	kg/ha			kg/ha		
Millet sole crop	1160 a[a]	---	1.00	600 a	---	1.00
Cowpea sole crop	---	1450 a	1.00	---	750 a	1.00
Millet/Cowpea Intercrop	1200 a	560 b	1.41	640 a	340 b	1.51

[a] Means within column followed by the same letter are not significantly different at the 5% confidence level, based on Duncan's Multiple Range Test (DMRT).
Source: Reddy et al., 1988.

Ouallam and Chikal are sites situated about 14° N and are relatively dry sites within Niger. The Ouallam site on average receives about 460 mm rainfall and has a 70-day crop growing season. The Chikal site on average receives about 450 mm rainfall and has an 80-day crop growing season (Reddy, 1988). At these two sites, the crop season commences in July instead of June. In an experiment involving three millet sole crop treatments (range of densities), one cowpea sole crop treatment, and three millet/cowpea intercrop systems (range of densities), grain yields were compared at Ouallam and Chikal during the 1985, 1986, and 1987 crop seasons (Reddy et al., 1988.). Due to severe droughts, data from 1986 and 1987 at Ouallam and from 1987 at Chikal were not presented.

These data indicated that at Ouallam, intercropped millet and cowpea yields were significantly lower compared with their sole crop yields. This led to lower LER for intercrop systems compared with the two sole crop systems (Table 15). At Chikal in 1985, millet grain yield in the intercrop system was significantly lower than its respective sole crop yield. The case was similar with cowpea grain yield, which led to lower LER values for intercrop systems compared with their respective sole crop systems (Table 16). At Chikal in 1986, millet grain yield did not differ significantly between sole and intercrop systems. However, cowpea grain yield in the intercrop system was significantly lower compared with its sole crop yield. LERs of intercrop systems were significantly lower than their respective sole crop system.

These results indicate that it would be beneficial to practice sole crop systems of millet and cowpea in the low rainfall regions of Niger with a 70-day crop growing season and millet/cowpea intercrop systems in the high rainfall zones with a 90-day crop growing season (Reddy, 1988). Similarly, in high rainfall sites, such as Tarna and Kolo, when there is an early season drought and it becomes necessary to plant millet in July rather than June, it would be better to plant sole crop systems.

Table 15. Millet and cowpea grain yield and Land Equivalent Ratio (LER)[a] in sole and intercrop systems at Ouallam, 1986.

Treatment	1986 Grain yield Millet	Cowpea	LER
	kg/ha		
Millet sole crop (high density)	1200 a[b]	---	1.00
Millet sole crop (medium density)	1080 a	---	0.90
Millet sole crop (low density)	1060 a	---	0.88
Intercrop system (high density)	730 b	320 b	1.08
Intercrop system (medium density)	420 bc	310 b	0.81
Intercrop system (low density)	350 c	340 b	0.79
Cowpea sole crop	---	680 a	1.00

[a] LER is calculated by using the highest sole crop treatments yield as standard sole crop yield for that season.
[b] Means within column followed by the same letter are not significantly different at the 5% confidence level, based on Duncan's Multiple Range Test (DMRT).
Source: Reddy et al., 1988.

Table 16. Millet and cowpea grain yield and Land Equivalent Ratio (LER)[a] in sole and intercrop systems at Chikal, 1985 and 1986.

Treatment	1985 Grain yield Millet	Cowpea	LER	1986 Grain yield Millet	Cowpea	LER
	kg/ha			kg/ha		
Millet sole crop (high density)	280 b	---	0.55	920 a	---	1.00
Millet sole crop (medium density)	480 a	---	0.94	580 a	---	0.63
Millet sole crop (low density)	510 a	---	1.00	750 a	---	0.81
Intercrop system (high density)	160 bc	210 c	0.65	580 a	500 b	0.89
Intercrop system (medium density)	110 bc	320 b	0.74	580 a	700 b	0.99
Intercrop system (low density)	160 bc	300 b	0.80	500 a	880 b	0.99
Cowpea sole crop	---	680 a	1.00	---	1960 a	1.00

[a] LER is calculated by using the highest sole crop treatments yield as standard sole crop yield for that season. [b] Means within column followed by the same letter are not significantly different at the 5% confidence level, based on Duncan's Multiple Range Test (DMRT). Source: Reddy et al., 1988.

5. Integration of Crop and Animal Production Systems

In the Sahel, the adoption of animal traction (AT) for farming operations has been limited. Its use has been recommended as a labor saving practice and as a means to increase productivity by expanding the area under cultivation. Pingali et al. (1987) have examined the conditions that are present when animal traction has been successfully introduced in Sub-Saharan Africa. These include an intensification of the farming system, an appropriate soil type, an ability to make use of AT, available land, and good access to markets.

N'Dounga is a region that borders the Niger River and is within 30 km of Niamey and Kolo, both major market centers. The area receives 450 to 550 mm rainfall during the cropping season that lasts less than 120 days. This places N'Dounga in the semiarid zone that is marginal for cropping (Sivakumar et al., 1979). Rice paddies occupy the heavy soils along the river and traditional crops, millet and cowpea, predominate on the sandy upland soils. There has been some adoption of AT in the irrigated paddies for land preparation. It is used more widely for transport related to both irrigated and rainfed agricultural activities. The use of AT for rainfed cropping operations is almost nonexistant. Equipment is available for purchase if the farmers are shown that their use will be profitable (Panin, 1987). The operations for which AT might be used include land preparation, planting, and weeding. For AT to be used profitably for rainfed crops grown on sandy soils in this region, it would have to result in labor savings and/or improved yields.

During the 1986 and 1987 rainy season, an experiment using millet was planted with three collaborating farmers (O'Neill et al., 1988). Two animal traction tillage treatments, ridging and field cultivation using oxen (paired oxen in 1986; single ox and paired oxen in 1987), and traditional hand cultivation were compared. The tillage treatments were used for both primary tillage and weeding. Appropriate applications of single superphosphate and urea were also applied to all treatments.

AT improved millet grain yields in both years (Table 17). Yield differences were much smaller between the tillage treatments. Nonetheless, with the paired oxen system, field cultivation significantly outyielded ridging in 1986. This was also the case in 1987, but the differences were not significant due to generally greater variability in the results. Using the single ox system, ridging yielded slightly more than field cultivation. While statistical comparisons were not possible, yields with paired oxen were higher than those with single oxen.

The use of the paired oxen system for field cultivation resulted in an increase in net revenue of 74% while ridging increased net returns 43% (Table 18). These results are particularily noteworthy because planting was late due to a late onset of the rainy season. Although there was no net revenue increase using the single ox system for field cultivation, there was a 30% increase when used for ridging.

Table 17. Millet grain yield for single ox and paired oxen traction systems, 1986 and 1987, N'Douga, Niger.

	Grain yield (kg/ha)		
	1986	1987	
Treatment	Paired	Single	Paired
Manual	312	395	387
Field Cultivation	703	512	747
Ridging	688	582	672
SE	13.0	59.2	111.1

Source: O'Neill et al. 1988.

Table 18. Economic returns of millet yields for single ox and paired oxen traction systems, 1987, N'Douga, Niger.

Revenues and costs	Manual	Single Ox		Paired Oxen	
		Cult.	Ridging	Cult.	Ridging
	FCFA[a] /ha				
Gross revenue[b]	31,280	40,960	46,560	59,680	53,760
Input costs					
SS phosphate	5,000	5,000	5,000	5,000	5,000
Urea	6,500	6,500	6,500	6,500	6,500
Seed	650	650	650	650	650
Capital costs[c]					
Animals		1,310	1,310	2,460	2,460
Materials		3,675	3,675	3,540	3,540
Recurrent costs					
Feed[d]		2,500	2,500	5,000	5,000
Veterinarian		300	300	600	600
Animal loss (5%)		1,000	1,000	1,875	1,875
Equipment repair		855	855	820	820
Net revenue	19,130	19,170	27,770	33,235	27,315
% increase		0	30	74	43

[a] $1.00 (US) = 280 FCFA (December, 1987) [b] Millet price in Kolo = 80 FCFA [c] Capital costs discounted at 20%, equipment life 10 years, and resale of animals after 5 years at twice the purchase price. [d] Average dryland farm size in region = 4 ha. Source: O'Neill et al. 1988.

Labor times were similar for the two AT systems in 1987 (Table 19). Both AT systems reduced weeding time compared to manual methods Labor input with AT was reduced by 56% and 68% for the first and secon weeding, respectively.

Table 18. Mean work times for single ox and paired oxen traction systems, 1987, N'Douga, Niger.

Operation	Manual	Single Ox		Paired Oxen	
		Cult.	Ridging	Cult.	Ridging
	man-hours/ha[a]				
Cultivation[b]		15.9	21.1	15.8	16.6
Fertilizer	2.2	2.0	2.0	2.0	2.0
Planting[c]	38.3	32.0	32.0	36.5	36.5
Replanting[c]	2.5	1.9	1.9	1.8	1.8
First weeding	27.6	11.5	12.3	12.4	12.2
Second weeding	30.4	11.2	9.9	8.0	9.0
Harvest[c]	9.5	15.0	15.0	13.1	13.1
Total man-hours per ha	110.5	89.5	94.2	89.6	91.2

[a] Man-hour calculations: 1 male-adult-hour = 2 male-child-hour (for children under 16 years). Females did not participate in the trials. [b] Cultivation not performed on traditional manual plots.
[c] Not time difference between plowing and ridging because these operations were done by hand.
Source: O'Neill et al. 1988.

6. Conclusion

Intensifying agricultural production systems to increase agricultural productivity can be achieved through the integration of various NRM practices, some of which are discussed in this paper. Appropriate trees can provide fuelwood, fodder, conserve soil, and improve soil fertility. If sources of fodder are available, animal traction may become an acceptable option for limited resource farmers to adopt. The manure can be used for direct application or for compost production to improve soil fertility, it also improves soil structure and soil organic matter content.

Natural resources management practices are needed to improve crop productivity in the fragile and nutrient-poor sandy soils of Niger. The data presented in this paper show the agronomic value of a number of practices which can contribute to increased agricultural productivity. Fertilizers are essential but expensive inputs, and must therefore be properly managed to maximize efficiency. Finally, the addition of farmyard manure and crop residues can improve the chemical properties of these chemically fragile soils as organic matter to complement inorganic fertilizers and help sustain productivity.

7. References Cited

Bationo, A., C. B. Christianson, and U. Mokwunye. 1989. *Soil fertility management of the pearl millet-producing sandy soils of Sahelian West Africa: The Niger Experience.* Soil, Crop, and Water Management Systems for Rainfed Agriculture in the Sudano-Sahelian Zone: Proceedings of an International Workshop. ICRISAT Sahelian Center. Niamey, Niger. January 11-16, 1987.

Bognetteau-Verlinden, E. 1980. *Study on impact of windbreaks in Majjia Valley,* Niger. MSc thesis, Wageningen University, Wageningen, The Netherlands. 88 pp.

Chabalier, P. F. 1985. *Bilans de fumures sous cultures de mais.* Agronomie Tropicale 40(3):253-260.

Constantinesco, I. 1976. *Soil conservation for developing countries.* FAO Soils Bulletin 30, U.N. Food and Agricultural Organization, Rome, Italy.

Davies, H. R. J. 1973. *Tropical Africa: An atlas for rural development.* Cardiff: University of Wales.

Gregory, P. J. 1989. *Water-Use Efficiency of Crops in the Semi-Arid Tropics.* Soil, Crop, and Water Management Systems for Rainfed Agriculture in the Sudano-Sahelian Zone: Proceedings of an International Workshop. ICRISAT Sahelian Center. Niamey, Niger. January 11-16, 1987.

Halliday, J. 1985. *Agrotechnologies based on symbiotic systems that fix nitrogen.* U. S. Congress, Office of Technology Assessment.

Hauck, F. W. 1966. *Fertilizer needs and effectiveness with tropical crops in West Africa.* FFHC/FAO Bulletin, Rome, Italy.

IFDC. 1986. *Sulfuric acid-based partially acidulated phosphate rock: its production, cost, and use.* Technical Bulletin no. T-31. Muscle Shoals, Alabama, USA.

Jahnke, H. E. 1982. *Livestock production systems and livestock development in tropical Africa.* Kiel, FRG: Kieler Wissenschaftsverlag Vauk.

Jones, M. J., and A. Wild. 1975. *Soils of the West African savannah.* Technical Communication no. 55. Harpende, UK: Commonwealth Agricultural Bureau.

Lal, R. 1987. *Managing the soils of Sub-Saharan Africa.* Science Vol. 236:1069-1076.

MDR (Ministrere de Development Rurale). 1984. Presented at the annual meetings of Officers of the Ministry of Agriculture, Government of Niger, Niger. 13-24 February 1984.

Matlon, P. 1986. *Annual report of ICRISAT/Burkina Faso Economics Program*, 1985.

Nye, P. H., and D. J. Greenland. 1960. *The soil under shifting cultivation.* Technical communication No. 51. Harpenden: Commonwealth Bureau of Soils.

Omaliko, C. P. E. 1981. *Dung deposition breakdown and grazing behavior of beef cattle at two seasons in a tropical grassland ecosystem.* J. of Range Management 34:360-362.

O'Neill, M. K., B. Shapiro, R. Imboden, and I. Batoure. 1988. *Single ox and paired oxen animal traction on Sahelian sandy soils.* In: Proceedings of the International Conference on Dryland Farming, Amarillo, Texas, August 15-19, 1988.

Ouedraogo, M. 1987. *Projet Agro-Forestier: Rapport d'activites de la campagne* 1987.

Panin, A. 1987. *The use of bullock traction technology for crop cultivation in northern Ghana: An empirical economic analysis.* ILCA Bull.No 29. ILCA Center, P.O. Box 5689, Addis Ababa, Ethiopia.

Persaud, N., S. Long, M. Gandah, and M. Ouattara. !986. *Influence of wood harvesting method on wind protection between rows of a neem (Azadiracta indica) plantation in Niger, West Africa.* In: Proceedings of the International Symposium on Windbreak Technology, 23-27 June, 1986, Lincoln, Nebraska, USA.

Pichot, J., and P. Roche. 1972. *Le phosphore dans les sols tropicaux.* Agronomie Tropicale 27:939-965.

Pingali, P., Y. Bigot, and H. P. Binswanger. 1987. *Agricultural mechanization and the evolutiion of farming systemsin Sub-Saharan Africa.* Baltimore: John Hopkins University Press.

Powell, J. M., and T. O. Williams. 1993. *Livestock, nutrient cycling and sustainable agriculture in the West African Sahel.* Gatekeeper series no. 37, International Institute for Environment and Development, London, UK.

Reddy, K. C. 1988. *A handbook on alternative production strategies for millet and cowpea in rainfed agriculture in Niger.* Nigerian National Agricultureal Research Institute (INRAN), B.P. 429, Niamey, Niger.

Reddy, K. C., and J. Gonda. 1985. *A review of intercropping research in Niger.* Liaison Sahel 3:109-125.

Reddy, K C., I Mahamadou, and J. van der Ploeg. 1988. *Appropriate cropping systems for the Nigerian semiarid tropics.* In: Proceedings of the International Conference on Dryland Farming, Amarillo, Texas, August 15-19, 1988.

Reij, C. 1988. *The present state of soil and water conservation in the Sahel.* Paper submitted to the Club du Sahel. Working group for resource development in Africa, Free University, Amsterdam.

Reij, C., P. Mulder, and L. Begemann. 1988. *Water harvesting for plant production.* Volume I. World Bank Technical Paper No.91, The World Bank, Washington D.C.

Rorison, K., and S. Dennison. 1986. *Windbreak harvesting influences on crop production.* Niamey, Niger: CARE International.

Sivakumar, M. V. K., S. M. Virmani, and S. J. Reddy. !979. *Rainfall climatology of West Africa: Niger.* ICRISAT Info. Bull. No. 5. ICRISAT Center, Patancheru, A.P. 502324, India.

Swindale, L. D. 1986. *Increasing food production in semi-arid west Africa.* Paper presented at International Centers Week, CGIAR, Washington, D.C.

van der Ploeg, J., and K. C. Reddy. 1988. *Water conservation techniques for sorghum growing areas of Niger.* In: Proceedings of the International Conference on Dryland Farming, Amarillo, Texas, August 15-19, 1988.

Wilson, R. T. 1986. *Livestock production in Central Mali: Long term studies on cattle and small ruminants in the agropastoral system.* ILCA Research Report no. 14. Addis Ababa, Ethiopia.

Wright, P. 1985. *Soil and water conservation by farmers.* OXFAM, Ouagadougou, Burkina Faso.

Zaongo, C. G., C. W. Wendt, and L. R. Hossner. 1988. *Contour strip rainfall harvesting for cereal grains production in the Sahel.* In: Proc. of the International Conference on Dryland Farming, Amarillo, Texas, August 15-19, 1988.

5. Supplemental References

African Biodiversity Advisory Group. 1993. *African Biodiversity : Foundation For The Future.* Biodiversity Support Program.

Aina, P. O., R. Lal, and G. S. Taylor. 1977. *Soil and crop management in relation to soil erosion in the rainforest of western Nigeria.* Proceedings of National Soil Erosion Conference, Purdue University, West Lafayette, IN.

Andrews, D. J. 1987. *Intercropping in low-resource agriculture in Africa.* Contractor report prepared for the Office of Technology Assessment. National Technical Information Service, Springfield, VA.

Bloch, P. C. 1989. *Land issues in the Senegal River Valley: Report on a reconnaissance trip.* Land Tenure Center, Madison, WI.

Booth, G.A. 1993. *Biological Diversity Monitoring Indicators Within A Natural Resources Management Framework For Sub - Saharan Africa.* AFR/ARTS/FARA, USDA/FS/IF.

Bromley, D.W. and Cernea, M.M. 1989. *The Management of Common Property Natural Resources.* World Bank Discussion Papers, No. 57. The World Bank , Washington D.C.

Carr, Stephen, J. 1989. *Technology for small-scale farmers in Sub-Saharan Africa: Experience with food crop production in five major ecological zones.* World Bank Technical Paper 109, The World Bank, Washington D.C.

Club du Sahel. 1991. *Donor Agencies and the Environment : In Pursuit of Sustainable Development in the Sahel.* OCDE/OECD/CILSS

Critchley, W. 1991. *Looking After Our Land: Soil and water conservation in dryland Africa.* ALIN/IIED, Oxford, UK.

Critchley, W., C. Reij, and S. Turner. 1991. *Soil and Water Conservation in Sub-Saharan Africa: Towards sustainable production by the rural poor.* A report prepared for IFAD by the Centre for Development Cooperation Services, Free University, Amsterdam.

Critchley, W., C. Reij, and A. Seznec. 1992. *Water harvesting for plant production.* Volume II. World Bank Technical Paper No. 157, The World Bank, Washington D.C.

Davies, H. R. J. 1973. *Tropical Africa: An atlas for rural development.* Cardiff: University of Wales.

Delenanty, J., M. Hoskins, and J. Thomson. 1985. *Majjia Valley Evaluation Study: A Sociological Report.* Report submitted to CARE International, Niamey, Niger.

Dumanski, J., H. Eswaran, and M. Latham. 1991. *A proposal for an international framework for evaluating sustainable land management.* In: Evaluation for Sustainable Land Management in the Developing World. IBSRAM Proceedings no. 12, volume II.

Erdmann, T, K. 1993. *An Analysis of Ten African Natural Resources Management Practices.* An ARTS/FARA Publication: Technical Paper No. 8. USAID, Washington, D.C.

Falloux, F., and A. Mukendi. 1988. *Desertification control and renewable resource management in the Sahelian and Sudanian zones of west Africa.* World Bank Technical Paper No. 70, The World Bank, Washington D.C.

Faure, A. 1992. *Perception de l'approche gestion des terroirs par les populations rurales au Burkina Faso.* Rapport Final. Caisse Centrale de Cooperation Economique, Ouagadougou, Burkina Faso.

Francis, C. (ed.). 1986. *Multiple Cropping Systems.* MacMillan Publishing Co., New York, NY.

Francis, C. A., and R. R. Hargrove. 1985. "*Enough Food.*" Special publication, Rodale Press and Regenerative Agriculture Association, Emmaus, PA.

Freeman, P. H., and F. Tejeda. 1988. *Cereals Production II Project: Comprehensive Report and Evaluation.* Cereals Production II Project, Project Extension. USAID/Senegal Project # 685-0235, Dakar, Senegal.

Freudenberger, Dr. M. Schoonmaker. 1992. *Land Tenure, Local Institutions and Natural Resources in Senegal.* Volume I. USAID/Senegal, Madison, Wisconsin.

Freudenberger, Dr. M. Schoonmaker. 1992. *Bibliography on Land Tenure in Senegal.* Volume III. USAID/Senegal, Madison, Wisconsin.

Freudenberger, K. and M. Schoonmaker. 1991. *Fields, Fallow, and Flexibility: Natural Resource Management in Ndam Mor Fademba, Senegal.* World Vision, Ndam Mor Fademba, Senegal.

Gorse, J. E., and D. R. Steeds. 1987. *Desertification in the Sahelian and Sudanian zones of west Africa.* World Bank Technical Paper No. 61, The World Bank, Washington, D.C.

Grove, T. L. 1989. *African development through sustained use of natural resources.* Draft Report for the Government of Mali. AID, Washington D.C.

Hagen, R. T. 1987. *Agroforestry in Africa.* Contractor report prepared for the Office of Technology Assessment. National Technical Information Service, Springfield, VA.

Halliday, J. 1985. *Agrotechnologies based on symbiotic systems that fix nitrogen.* U. S. Congress, Office of Technology Assessment.

Harrison, P. 1987. *The Greening of Africa: Breaking Through the Battle for Land and Food.* An International Institute for Environment and Development-Earthscan Study. Toronto: Paladin Grafton Books.

I.I.E.D. Issues Papers Series

Paper No. 29. 1991. Freudenberger, K.S. *Mbegue: The Disingenuous Destruction of a Sahelian Forest.*

Paper No. 34. 1992. Stocking, M. *Land Degradation and Rehabilitation. Research In Africa 1980 - 1990 : Retrospect and Prospect.*

Paper No. 35. 1992. Gueye, I. and Laban, P. *From Woodlots to Village Land Management in the Sahel.*

Paper No. 37. 1992. Gueye, M.B. *Co-operation between Senegalese Non-Governmental Organizations and National Research Structures : Constraints and Perspectives.*

Paper No. 39. 1992. Lindskog, P. and Mando, A. *The Relationship Between Research Institutes and NGOs in the Field of Soil and Water Conservation in Burkina Faso.*

Paper No. 40. 1993. Painter,T.M. *Getting it Right : Linking Concepts and Action for Improving the Use of Natural Resources in Sahelian West Africa.*

Paper No. 45. 1993. Leye, N. *Writing From Experience: Grassroots Work in Senegal.*

Paper No. 49. 1994. Gueye, M.B. *Conflicts and Alliances Between Farmers and Herders: A Case Study of the " Goll " of Fandene Village, Senegal.*

Kang, B. T., G. F. Wilson, and T. L. Lawson. 1984. *Alley Cropping: A stable alternative to shifting cultivation.* IITA, Ibadan, Nigeria.

Kleene, P., B. Sanogo, and G. Vierstra. 1989. *A Partir de Fonsébougou: Systèmes de production rurale au Mali.* Volume I. KIT/IER, Amsterdam.

Kreike, E. H. 1990. *Local Communities, Renewable Natural Resources Management, and Sustainable Agriculture in Senegal.* A report to the Senegal Agricultural Sector Analysis. USAID/Dakar, Senegal.

Lal, R. 1987. *Managing the soils of Sub-Saharan Africa.* Science Vol. 236:1069-1076.

MacDonald, L. H. (ed). 1981. *Agroforestry in the African humid tropics.* Proceedings of a workshop held in Ibadan, Nigeria.

McGahuey, Michael. 1986. *Impact of forestry initiatives in the Sahel: Effect of Acacia albida on millet production in Chad.* Chemonics International, Washington D.C.

McGahuey, Michael. 1987. *Natural Resources in Sub-Saharan Africa: Review of Problems and Management Needs.* Chemonics International, Washington, D.C.

Ministère de l'Agriculture et de l'Environnement. 1987. *Manuel des activites de restauration et d'amenagement forestier dans le Sahel basé sur les études de cas des forêts classées de Guesselbodi et Gorou-Bassounga, Niger.* Niamey, Niger.

Nair, P. K. R. 1984. *Soil productivity aspects of Agroforestry.* International Council for Research in Agroforestry, Nairobi, Kenya.

Norman, D. W., M. D. Newman, and I. Ouedraogo. 1981. *Farm and village production systems of the semiarid tropics of west Africa: An interpretive review of research.* ICRISAT Research Bulletin No. 4., Pantancheru, India.

Nye, P. H., and D. J. Greenland. 1960. *The soil under shifting cultivation.* Technical communication No. 51. Harpenden: Commonwealth Bureau of Soils.

Osborn, Tom. *Multi - Institutional Approaches to Participatory Technology Development: A Case Study From Senegal.* Agricultural Administration (Research and Extension) Network, Dakar, Senegal.

Reij, C. 1988. *The present state of soil and water conservation in the Sahel.* Paper submitted to the Club du Sahel. Working group for resource development in Africa, Free University, Amsterdam

Reij, C., S. Turner, and T. Kuhlman. 1986. *Soil and Water Conservation in Africa: Issues and Options.* Prepared by the Centre for Development Cooperation Services, The Free University of Amsterdam in cooperation with the Africa Division, IFAD.

Reij, C., P. Mulder, and L. Begemann. 1988. *Water harvesting for plant production.* Volume I. World Bank Technical Paper No.91, The World Bank, Washington D.C.

Roberts, W.C. 1993. *Natural Resources - Based Agricultural Research Project Monitoring and Evaluation Plan.* USAID/Senegal, NRBAR Project, Dakar, Senegal.

Rochette, R. M. 1989. *Le Sahel en Lutte Contre la Desertification: Leçons d'expériences.* CILSS/GTZ.

Rodale Institute. 1989. *Soil Degradation and Prospects for Sustainable Agriculture in the Peanut Basin of Senegal.* USAID/Dakar, Senegal.

Senegal Reforestation Project. 1986. *Project Paper.* USAID/Dakar, Senegal. USAID Project # 685-0283.

Senegal Reforestation Project. 1990. *Baseline study.* SECID/VPI/LBII. USAID/Dakar, Senegal. USAID Project # 685-0283.

Senegal Reforestation Project. 1991. *Project Paper Supplement.* USAID/Dakar, Senegal. USAID Project # 685-0283.

Senegal Reforestation Project. 1992. *1991 Follow Up and Monitoring Study: End of tour report.* SECID/VPI/LBII. USAID/Dakar, Senegal. USAID Project # 685-0283.

Seymour, M., L. McPherson, and D. Harmon. 1985. *Development Management in Africa: The Case of the Bakel Small Irrigated Perimeters Project in Senegal.* AID Evaluation Special Study No. 34. AID, Washington D.C.

Shaihk, A., E. Arnould, K. Christophersen, R. Hagen, J. Tabor, and P. Warshall. 1988. *Opportunities for Sustained Development: Successful Natural Resources Management in the Sahel.* Vol. I: Main Report. Washington D.C.: E/DI.

Shaihk, A., E. Arnould, K. Christophersen, R. Hagen, J. Tabor, and P. Warshall. 1988. *Opportunities for Sustained Development: Successful Natural Resources Management in the Sahel.* Vol. II: Case Descriptions. Washington D.C.: E/DI.

Speirs, M., and O. Olsen. 1992. *Indigenous Integrated Farming Systems in the Sahel.* World Bank Technical Paper No. 179. The World Bank, Washington D.C.

Swindale, L. D. 1986. *Increasing food production in semi-arid west Africa.* Paper presented at International Centers Week, CGIAR, Washington, D.C. United Nations Environment Programme. 1987. *Desertification Control Bulletin.* UNEP, Nairobi, Kenya.

USAID/Senegal. 1991. *Country Program Strategic Plan.* USAID/Dakar, Senegal.

USAID/Senegal. 1993. *Inventaire des technologies basées sur la gestion des ressources naturelles et utilisées dans la production des céréales.* Report prepared for the ISRA/NRBAR Project (USAID Project # 685-0285) by AFID Consultance & ACG Afrique, Dakar, Senegal.

U.S. Congress, Office of Technology Assessment. 1988. *Enhancing Agriculture in Africa: A Role for U.S. Development Assistance*, OTA-F-356 (Washington D.C.: U.S. Government Printing Office).

Warren, D.M. 1991. *Using Indigenous Knowledge in Agricultural Development.* World Bank Discussion Papers, No.127. The World Bank, Washington D.C.

Weber, F. R., and Carol Stoney. 1986. *Reforestation in arid lands.* Volunteers in Technical Assistance, Arlington, VA.

Willey, R. W. 1079. *Intercropping-- Its importance and research needs, 1. Competition and yield advantages, and 2. Agronomy and research approaches.* Field Crop Abstracts, vol 3, pp. 1-10, 73-85.

Winrock International. 1993. *On-Farm Productivity Enhancement Program: First annual report.* USAID Cooperative Agreement No. FAO-0158-A-00-2054-00, USAID/Dakar, Senegal.

Winterbottom, R., and P. T. Hazelwood. 1987. *Agroforestry and Sustainable Development: Making the Connection.* Ambio., vol. 16, No. 2-3, pp. 100-110.

World Bank. 1993. *Les Documents de la Deuxieme Rencontre Des Projets Saheliens De Gestion Des Ressources Naturelles.* Ouagadougou, Burkina Faso.

World Resources Institute. 1993. **In Draft:** *Local-level Natural Resource Management: Lessons from the Ground Up.* WRI Crucial Decade Publication Series. World Resources Institute, Washington D.C.