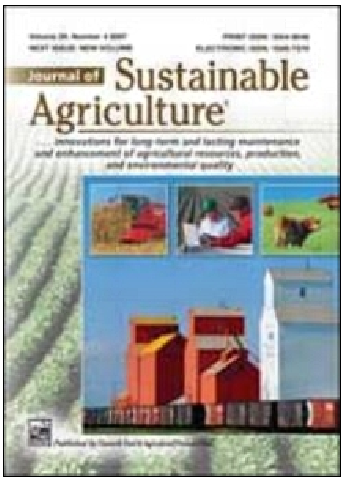

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Agriculture Intensification and Ecologically Sustainable Land Use Systems in Niger: Transition from Traditional to Technologically Sound Practices

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RESEARCH, REVIEWS, PRACTICES, POLICY AND TECHNOLOGY

Agriculture Intensification and Ecologically Sustainable Land Use Systems in Niger: Transition from Traditional to Technologically Sound Practices

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ABSTRACT. Increasing population pressure in Niger has increased demand for arable land leading to expansion of cropping into marginal land

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resulting in soil erosion and diminishing pasture, woodland and forest area which threatens ecosystem sustainability. Highly variable rainfall adds risk to crop production. Intensification of agriculture with adoption of sustainable, yield enhancing technologies is critical to the future development of all agroecological regions in Niger. Farm constraints analysis of crop productivity conducted in rainfed areas of the Niger by farmer surveys and on-farm experiments revealed that the major limitations to increased productivity were (1) low soil fertility and lack of fertilizer use, (2) limited organic manure availability, (3) low mineral nutrient use efficiency of crops when fertilizers were applied during soil moisture stress, (4) lack of high yielding varieties resistant to biotic and abiotic stresses, (5) practice of using low plant densities, (6) limited access to farm inputs, (7) lack of a marketing strategy, and (8) lack of adequate extension service to farmers. The use of improved technologies, such as fertilizer, improved varieties or hybrids, optimum plant density and water conservation technologies were shown to increase yields more than two-fold at the farm level. Key elements in a strategy to increase total crop production in Niger must include support from both the private and public sectors to promote more rapid acceptance of improved production technologies. This will require institutional modifications that enhance technology transfer, development of input delivery systems, improved policies of land tenure, availability of fertilizer, and improved policies that affect the input and output pricing structure.

KEYWORDS. Sustainable management, new agriculture technologies, high risk environment, poverty reduction, production strategies

INTRODUCTION

Population growth over several decades in the semiarid region of the Sahel, particularly in Niger, has resulted in reduced availability of communal land for cultivation, a breakdown of the fallow system, land degradation, depletion of soil fertility, and reduced crop yield (Bationo and Mokwunye, 1991; Shapiro and Sanders, 1998). Increased demand for food in Niger must be met with greater agricultural intensification based on a combination of inputs such as fertilizers, high yielding cultivars resistant/tolerant to both biotic and abiotic stresses, irrigation and rain water harvesting technology, and other improved practices such as intercropping and rotational cropping. The highly successful Green Revolution was built on agricultural intensification that dramatically raised crop yields and production. For instance, yields of maize (*Zea mays* L.), rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) have more than doubled in developing countries. Between 1961 and 1991, world cereal production doubled (FAO, 1991). Ninety-two percent of the increased production resulted from increased yields and only 8 percent from area expansion. Only in sub-Saharan Africa has expansion of cultivated land area contributed as much as yield improvement to cereal production. However, the option of area expansion is limited in Niger where 52% of the country receives 0-100 mm rainfall. Enhancing land productivity in different regions of Niger depends on sustainable use of more highly productive agricultural practices (Braun and Paulino, 1990; Matson et al., 1997). Other countries in Africa will also have to rely on increased yields rather than large increases in cultivated land area to expand food production. Our purpose is to examine pearl millet [*Pennisetum americanum* (L.) Leeke] and sorghum [*Sorghum bicolor* (L.) Moench] production systems and crop productivity trends in Niger, and evaluate the consequences of these trends on natural resource use. We also examined potential gains from newly evolved intensive production systems and agricultural technologies over traditional monocropping systems, and recommend changes in policy for sustainable agricultural development in Niger.

AGROECOLOGICAL REGIONS OF NIGER

Variable and low rainfall below 400-450 mm results in high risk to crop production and is a major reason for subsistence farming and limited use of modern crop production inputs. The Sudano-Sahelian zone with rainfall of 550-850 mm is ecologically suitable for crop production. This higher rainfall zone with considerably less spatial and temporal variability of rainfall is the zone of reduced risk. It is in this zone that modern crop production inputs are most profitable.

The Republic of Niger covers 1,267,000 km^2 and lies within the northern tropics between 11° 33′N and 23° 33′N. Over large areas of Niger, the crucial problem is lack of water. Also, uneven temporal and spatial distributions of rainfall are major factors that restrict agricultural production and the country's economy. Agriculture is concentrated in the southern and southwestern border areas. Areas receiving less than 300 mm of annual rainfall are generally unproductive for agriculture. The land mass of Niger is formed of a low lateritic plateau and broad interior sandy basin rimmed by hills and limestone or sandstone bluffs. Most of the soils are poor sandy to sandy loam. The desert soils produced by wind erosion are low in plant nutrients. Brown soils are prevalent in Ader-doutchi river valleys. In the Niger River Valley, the black soils of alluvial basins have good structure and are fertile.

In the desert margin area of Niger (100-350 mm annual rainfall), migratory livestock farming with pastural grazing and minor emphasis on crops is a common system, while in areas with annual rainfall of 350-550 mm (Sahelian low rainfall region), there is more reliance on integrated crop and animal farming. The current land use and production constraints and potential use in each agroecological zone are described in Table 1. Pearl millet is the most important staple crop wherever rainfall exceeds 250 to 300 mm during the wet season. Pearl millet is commonly intercropped with cowpea [*Vigna unguiculata* (L.) Walp], sorghum or peanut (*Arachis hypogaea* L.). Sorghum is grown widely in the south, even in some of the driest areas. Other subsistence rainfed crops are maize and cassava (*Manihot esculenta* Crantz).

TABLE 1. Land use patterns and potential alternative land uses for different agroecological zones.

			Agriculture intensification		
Zones	Description and rainfall (mm)	Land area (km^2) and % of total	Current land use	Constraints	Alternative land use for intensive systems
1	Desert 0-100	667,000 52.6%	Nomadic livestock production	Lack of rainfall and soil water	Livestock farming
2	Sahelian Desert margin[1] 100-350	300,000 23.7%	Limited millet cropping, livestock production	Lack of rainfall, low soil water and nutrients	Livestock and farming systems
3	Sahelian low rainfall[1] 350-550	200,000 15.8%	Millet and sorghum cropping; livestock production	Lack of rainfall, soil water and soil nutrients	Ag intensification with improved technology in intercropping and livestock production
4	Sudano-Sahelian[2] 550 and above	100,000 7.9%	Millet and sorghum cropping; limited livestock production	Lack of soil nutrients	Crop intensification/ animal integration; millet/sorghum based intercropping

[1] Zones 2 and 3 have low external inputs but reasonable economic return from livestock farming. Agro-forestry/soil-water conservation technology is underemphasized.
[2] Zone 4 has the greater pressure for economic efficiency and external inputs. This zone supports approximately 60% of the population.

Niger's total population is 95% rural; 79% is sedentary rural and 16% is nomadic or semi-nomadic (Sivakumar et al., 1993). In the south, farming and herding are the way of life for 95% of the people in the Sahel. Agroecological regions shown in Figure 1 are differentiated and characterized by rainfall distribution. Niger has 53% true desert with rainfall of 0-100 mm, 24% Sahelian desert with rainfall 100-350 mm, 16% Sahelian low rainfall with rainfall of 350-550, and 8% Sudano Sahelian with rainfall of 550-850 mm. The extent of annual variability in rainfall at Niamey, Niger, the capital, is indicative of annual rainfall variability throughout the country (Figure 2).

Population growth in Niger (Figure 3) is a fundamental cause of poverty and environmental degradation, especially in marginal lands. The subsequent division of farm ownership and resulting diminished farm sizes has ultimately reduced production thus availability of cereals per capita, forcing rural people to leave the land in search of employment opportunities. Agricultural intensification, if managed properly, need not degrade the environment (Matson et al., 1997). In fact, components of agricultural intensification such as fertilizer use have an important role to play in conserving the soil by replenishing nutrients and improving soil productivity diminished through harvesting crops and grazing animals.

FIGURE 1. Map of Niger showing rainfall isohyets (mm) and sites•) of experimentation and diagnostic survey.

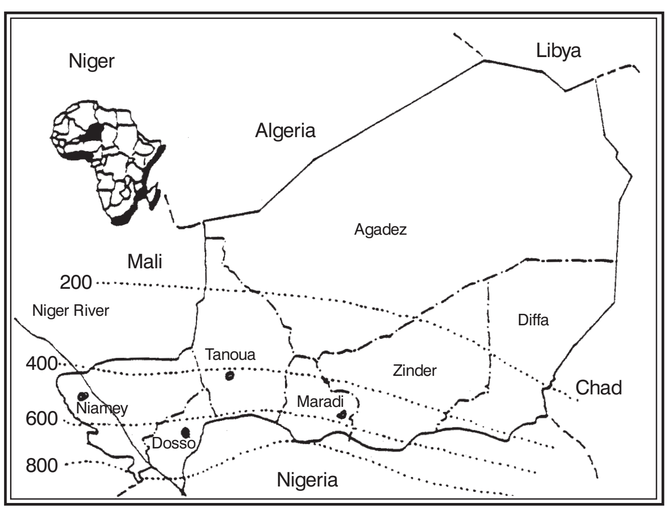


FIGURE 2. Rainfall variability at Niamey, Niger during July-September from 1960 to 1996.

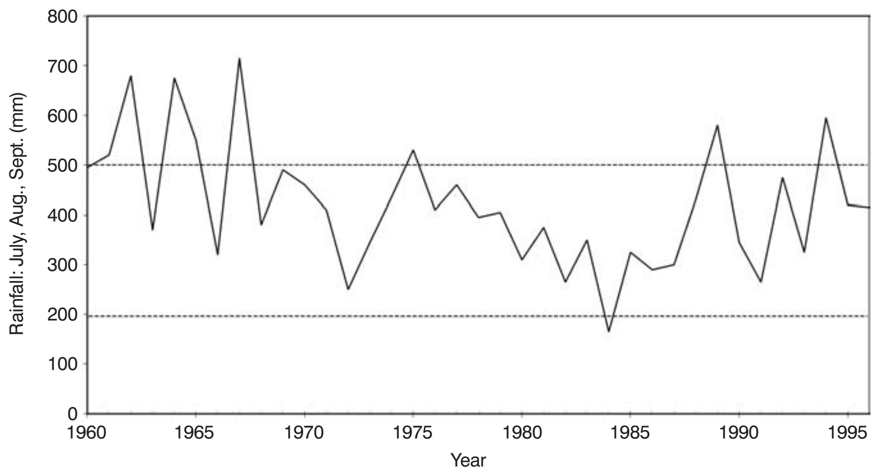
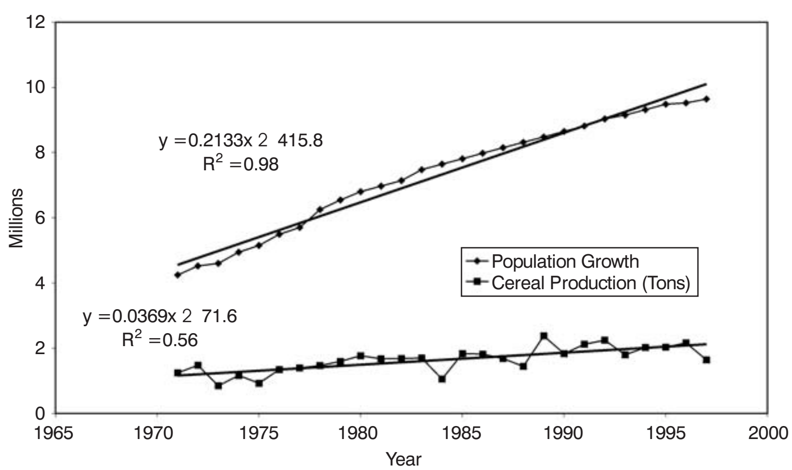


FIGURE 3. Population and cereal production in Niger, west Africa, from 1970-1997.



Increasing soil fertility through the use of essential mineral nutrients from both mineral fertilizer and organic sources promotes the growth of soil stabilizing vegetation that decreases soil erosion. Alternative technologies and farming practices already exist that involve appropriate crop rotations and mixed farming systems with crops and livestock, agroforestry, biological pest control, disease and pest-resistant varieties, balanced application and correct timing and placement of fertilizer, and minimum or zero tillage.

Trends in Land Area, Production and Shifting to Intensive Management

The area of Niger planted to millet and sorghum has increased rapidly over the past two decades due to increased population growth (Figure 4), while yield per unit area declined due to cultivation of marginal land and also use of traditional crop management practices on fertilized land (Figure 5). Traditionally, farmers grow pearl millet and sorghum with few external inputs. Variable rainfall, poor soil water conservation and continuous cropping without either long-term fallowing or fertilizer use has resulted in declining total grain yield per unit of land. The transformation of agriculture in Niger, combining farm productivity, agricultural growth and sustainability of natural resources is essential to achieve the goals of alleviating food shortages and poverty, and achieving a better life for people. Efficient resource management as well as adoption of appropriate farm technology and favorable government policies can achieve the goals of reducing rural poverty, assuring food security, conserving natural

FIGURE 4. Increase in cultivated area of pearl millet and sorghum in Niger from 1980-1987.

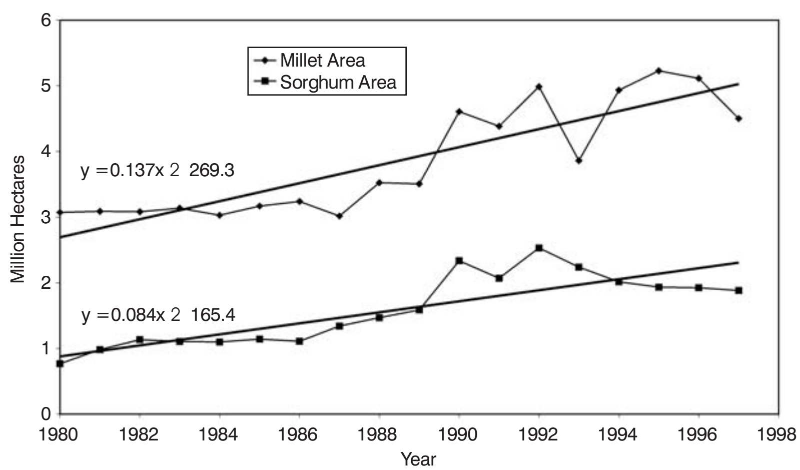
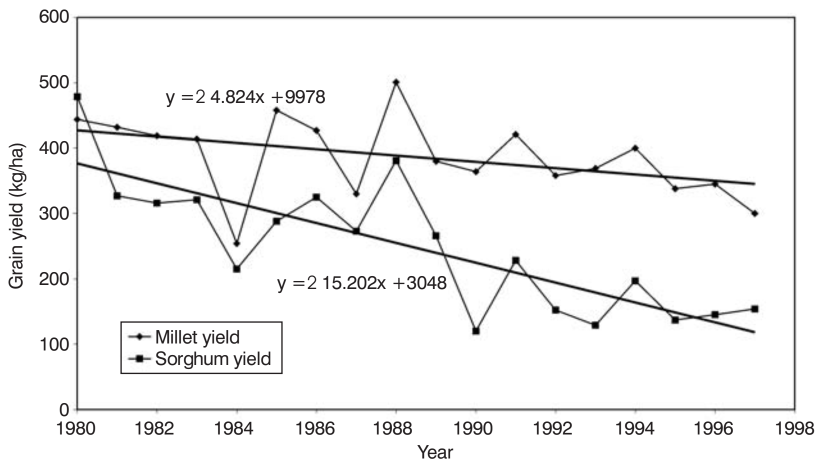


FIGURE 5. Trends of declining yields per unit area of pearl millet and sorghum in Niger from 1980-1987.



resources and protecting the environment. There is close relationship between poverty and environmental degradation. Often environmental degradation is driven by poverty, by the loss of entitlement, and by the loss of capacity of the poor to support themselves. Many people often lack sufficient income and access to credit to purchase appropriate tools and inputs such as fertilizer and other technologies to protect natural resources against degradation or to rehabilitate degraded soils. Poverty leads to a condition where people are forced to use their limited resources in a way that degrades rather than maintains or enhances the natural resource base. When survival is at stake, it may be perfectly rational to mine the resource base that may be critical to future productive capacity.

Low soil fertility and low use of chemical fertilizers have been cited as two factors limiting agricultural productivity in most of sub-Saharan Africa (Bationo and Mokwunye, 1991; Vlek, 1990). Studies of soil nutrient balance across countries in sub-Saharan Africa show evidence of widespread "nutrient mining." This term refers to a rate of removal of mineral nutrients exceeding the rate of replenishment by natural processes and/or fertilizer applications which results in severe nutrient deficiencies (Stoorvogel et al., 1993; Smaling et al., 1993). Fertilizer use in sub-Saharan Africa remains very low, averaging about 10 kg of fertilizer nutrients per ha (FAO, 1998), and Niger is one of the Sahelian countries that uses the least fertilizer at 4 kg per ha (Mokwunye et al., 1996). Macro-level constraints to fertilizer use in sub-Saharan Africa include fertilizer markets that preclude socially profitable domestic investment in fertilizer production (Vlek, 1990), high import prices, extremely high marketing costs, and irregularity of supply due to very poor road infrastructure and physical distribution facilities (Daramola, 1989; Vlek, 1990). The elimination of fertilizer subsidies, accentuated by a lack of adequate credit facilities for farmers, is also a major problem (Vlek, 1990; Thompson and Bannante, 1989). The government of Niger spent US$17.05 million to import cereals each year (1994-96 data) while the cost of import of fertilizer would be about US$ 4.5 million to produce a similar amount of cereals even at low rate of nutrient response in a drought-prone environment. Import costs for cereals of over US$30 million a year were common in the early 90s. Thus, moderate fertilizer use by farmers is necessary if crop production level is to be improved in arid and sub-arid environments. The government of Niger, or preferably the private sector, must develop a long term plan to make fertilizer available to farmers either through regular imports or indigenous production in collaboration with foreign companies.

The responses of millet and sorghum to fertilizer are largely determined by availability of water for growth. In the low rainfall zone, response of crops to fertilizer is low and variable and not always economically profitable. This is the reason that resource-poor farmers often hesitate to apply fertilizer and are not sure if they would get suitable return from their investment. In moderate to high rainfall zones with water conservation practices and also supplementary irrigated condition, farmers apply fertilizer and their quantity of application is often determined by availability of cash, credit, and available fertilizer. In these areas, many farmer use improved high yielding varieties and hybrids. Thus, it is clear that water harvesting technology must be used for rainfed agriculture in low rainfall zones in order to get full benefit of fertilizer and high yielding varieties. The availability and utilization of technologies to intensify agriculture in Niger are not well documented. The potential of agricultural intensification in different agroecosystems of Niger has not been fully explored in light of sustainable land use systems and agricultural practices that meet demands for food at socially acceptable economical and environmental costs (Crosson and Anderson, 1993).

METHODOLOGY AND RESULTS

Diagnostic Survey

The studies reported here consisted of a diagnostic survey to determine production constraints, and field experiments to evaluate potential technologies. For the diagnostic study, 69 randomly selected farmers from Konni, in the Tahaou region, and 69 farmers from Djeritaoua village near Maradi (shown in Figure 1), were surveyed for agronomic practices and constraints in crop production (Table 2). The survey was conducted by

TABLE 2. Survey of farmers' agronomic practices and constraints in sorghum and millet production in rainfed areas within the Konni and Djeritaoua regions. Numbers in parentheses are percent of total responses (N = 138).

Cultural Practices	
Crop Culture	
Monocrop	28
Intercropping legumes and cereals	72
Land Preparation and Crop Establishment	
No tillage	92
Tillage	8
Hand labor	89
Animal traction	11
Sowing Methods and Varieties	
Hill spacing 80 cm × 80 cm	41
Hill spacing 100 cm × 100 cm	59
Local variety 'Motta Maradi'	96
Improved variety	4
Soil Classification and Fertility Management	
Sandy/sandy loam	87
Silty/clay loam	13
No manure or fertilizer	88
Farm yard manure/fertilizer	12
Quantities of Amendments Used	
Farm yard manure only at 2-3 T ha^{-1}	78
Fertilizer at 8-15 kg ha	22
*Farmer Rank of Major Constraints**	
Lack of fertilizer	54
Lack of improved varieties	24
Low prices for commodities	22

*Each farmer had an average of 0.37 ha irrigated land to supplement rainfed area.

providing each farmer with simple questions related to their agronomic practices and constraints. Each farmer had three to four ha under rainfed production, and a majority also had 0.37 ha irrigated land. Results revealed that 88% of farmers do not use fertilizer and grow local cultivars using their traditional crop establishment in rainfed systems. Out of the total, 72% planted legume and cereal intercropping while 28% used traditional monocropping. Only 8% of the farmers in the survey used tillage, and planting density was equally split between 80 cm × 80 cm and 100 cm × 100 cm hill spacing. Farmyard manure was the amendment of choice due to inavailability or high cost of fertilizer. The major constraints identified were high cost of fertilizer, lack of improved seed and low price during the harvest season. The diagnostic analysis clearly indicated the need for input availability and an output pricing policy for rapid adoption of new agriculture technology in this high risk environment.

ON-FARM EVALUATION OF SORGHUM TECHNOLOGIES

Several on-farm farmer-participatory trials were conducted at three locations to evaluate the effect of yield-enhancing production technologies. Locations differed in 20-year rainfall regimes at Lossa (393 mm), Konni (477 mm), and Bengou (797 mm). Precipitation received during the 1996 to 1998 trials was near the long term average (Table 3). Potential evapotranspiration was slightly higher at the Bengou location compared to Konni. Stepwise production factors including fertilizer, improved variety, tied-ridge system for harvesting rainwater, and higher plant density (60,000 vs. 40,000 plant ha^{-1}) were evaluated in the three different zones. Stepwise addition of technologies included (i) farmer's traditional system (farmer variety and practices), (ii) 45 kg ha^{-1} N fertilizer, (iii) fertilizer + improved variety 'Sepon 82', (iv) fertilizer + 'Sepon 82' + tied ridges, (v) fertilizer + 'Sepon 82' + tied ridges + 50% increased plant density. In each on-farm trial, at least five farmers participated in technology evaluation. The farmer managed trials had a plot size of 10 m × 10 m.

The evaluation of different combinations of agricultural technology to produce sorghum indicated that a package of technology that included variety, fertilizer, rainwater conservation and optimum plant density can increase grain yield more than two-fold depending on site and year (Table 3). In the high rainfall zone, the grain yield increase was greater than in the low rainfall zone; similarly, grain yield was greater in the year of high and

TABLE 3. Evolution of improved production through stepwise technology introduction. Data are averages of three years at Lossa, Konni and Bengou, from 1996-1998. Actual precipitation received at locations averaged over the three year period was Lossa–382 mm, Konni–524 mm, and Bengou–784 mm.

Treatments[1]	Yield			Gross Revenue[3]		
	kg ha^{-1}			\$ ha^{-1}		
	Lossa	Konni	Bengou	Lossa	Konni	Bengou
1. Traditional system	467 c+	578 d	689 d	70	87	103
2. Traditional system + fertilizer[2]	643 b	855 c	1067 c	96	128	160
3. Traditional system + fertilizer + improved variety	781 b	973 c	1165 c	117	146	175
4. Improved system + fertilizer + improved variety + tied ridges	976 b	1226 b	1476 b	146	184	221
5. Improved system + fertilizer + variety + density	1198 a	1529 a	1860 a	180	229	279

1 Treatments 1 and 2 used variety 'Motta-Maradi', while variety 'Sepon 82' was used in treatments 3, 4 and 5; plant density was 40,000 plants ha^{-1} in treatments 1 through 4 and 60,000 plants ha^{-1} in treatment 5.
2 Fertilizer 45 kg N ha^{-1} was side dressed after the first weeding, 30 days after planting.
3 Price of grain kg^{-1} (\$0.15); price of N kg^{-1} (\$0.67).
+ Means within a column follow by the same letter are not significantly different at 5% probability level.

well distributed rainfall, but overall benefits were observed in all sites in all years. The results showed increased benefit from fertilizer use, while change of variety did not significantly bring additional gain in yield. The use of tied ridge significantly improved yield at Konni and Bengou. Increased plant density consistently increased grain yield at all three locations.The results revealed that under enhanced availability of soil moisture, use of fertilizer and higher plant density produced higher grain yield.

Evaluation of Yield Potential of Improved Sorghum Varieties and Hybrids

Yield potential of newly released sorghum varieties was compared at four locations to that of the farmers' local variety, Motta Maradi, under on-farm conditions in 1997 in order to examine their performances compared to the local variety in major sorghum growing areas. Three open-pollinated varieties, the local Motta Maradi, IRAT-204, the *Striga* tolerant variety SNR-39 and hybrid NAD-1 were included. A randomized complete block design with four replications was used. The plot size was 8 m × 4 m. The crop was grown in 80-cm row spacing in hills spaced 40 cm apart with 3-4 seeds sown per hill, and fertilizer application of 54-27-27 kg combined N-P-K per hectare.

The highest yielding genotype was the newly released hybrid NAD-1 at all locations followed by IRAT-204 and the local Motta Maradi (Table 4). Variety SNR-39 had significantly lower yield than the other genotypes except at Bengou where it was equal to the local. There was no serious *Striga* infestation this season which may have given a slight advantage to other genotypes in the test. The high yield of NAD-1 in response to improved management has been observed frequently since its release (Maranville, 1998). A significant increase of the hybrid over the local cultivars emphasizes the importance of new production technology to be promoted at the farm level to enhance cereal production.

Evaluation of Potential of Millet and Sorghum Intercropping

Potential intercropping of pearl millet-cowpea, pearl millet-peanut, sorghum-cowpea, and sorghum-peanut was examined in 1997 and 1998 with farmers from villages near Bengou, Tara (higher rainfall regions) and two areas near Sakoira (lower rainfall near Niamey) to investigate their potential to improve soil fertility improvement. Pearl millet and sorghum were planted in 1-m row spacing with 25 cm between hills, and cowpea and peanut were planted in 25 cm × 25 cm spacing. Each field was manually weeded. An improved technology package included pearl millet/cowpea or sorghum/cowpea intercrop combined with 90 kg ha^{-1} of a 30-30-30 N-P-K fertilizer side banded 3 weeks after planting. This package also included spraying an insecticide on cowpea at flowering to control insect damage. Monocropped pearl millet and sorghum were used as comparative checks, and gross revenue (\$ ha^{-1}) was calculated.

Results in Table 5 show that intercropping of millet or sorghum with cowpea or peanut resulted in consistently higher productivity compared to

TABLE 4. On-farm yield potential of released varieties and one hybrid of sorghum from trials for the 1997 cropping season at four locations.

Variety	Bengou	Tara	Sakoira 1	Sakoira 2
	kg ha^{-1}			
SNR-39	686 c[1]	604 c	894 c	1196 c
NAD-1	1401 a	1441 a	1817 a	2050 a
IRAT-204	1014 b	834 b	1389 b	1670 b
Local	755 c	836 b	1284 b	1688 b

[1]Treatment means within column with same letter are not significantly different ($P \geq 0.05$).

TABLE 5. Productivity of millet and sorghum based intercropping, Konni 1997 and 1998.

Cropping System	Grain Yield (kg ha^{-1})				Gross Revenue ($ ha^{-1})	
	1997		1998		1997	1998
	Millet	Cowpea/Peanut	Millet	Cowpea/Peanut	Total	Total
Pearl Millet	695 b[1]	-	706 b	-	111	113
Millet Cowpea	699 b	205 b	715 b	265 b	214	247
Millet Peanut	804 b	406 a	726 b	486 a	413	556
Millet Cowpea + Fertilizer[3]	1084 a	308 a	1025 a	325 b	327	326
Sorghum						
Sorghum	527 b		625 b		79	92
Sorghum Cowpea	634 b	208 b	612 b	286 b	200	203
Sorghum Peanut	761 b	412 a	698 b	453 b	403	310
Sorghum Cowpea + Fertilizer[3]	996 a	356 a	982 a	342 b	327	341

[1] Mean yields within a crop column with same letter are not significantly different ($P \geq 0.05$).
[2] Millet price = \$0.16 kg^{-1}; Sorghum price = \$0.15 kg^{-1}; Cowpea price = \$0.50 kg^{-1}; Peanut price = \$0.60 kg^{-1}.
[3] Rate = 90 kg ha^{-1} of 30-30-30 N-P-K at cost of \$0.65 kg^{-1}.

monoculture and doubled the gross revenue. This is consistent with the finding of other investigators (Shapiro et al., 1993; Reddy et al., 1994). Addition of 45 kg N fertilizer further increased productivity and doubled gross revenue. Pearl millet grain yield over two years increased by 51% when grown with fertilizer in association with cowpea. Similarly, mean grain yield increase of sorghum over two years with ferilizer was 73% when grown in association with cowpea. Gross revenue increased by use of fertilizer by 42% and 62% millet-cowpea and sorghum-cowpea intercropping (Table 5). Much of the reason for the high gross income when peanut was included is due to the relatively high yield of peanut and its favorable price per kg.

In another experiment, pearl millet-cassava intercropping at different fertilizer rates was evaluated at Bengou in 1997 to determine the effect on land resource use efficiency. This location received 797 mm annual precipitation on average over a 20-year period. Pearl millet was planted in 1-m row spacing with 25 cm between hills and cassava was planted at 1×1 m^2 spacing. Three rates of fertilizer treatments, 27-13-13, 54-26-26, and 81-39-39 kg ha^{-1} N-P-K, were side banded 3 weeks after planting. The experimental design was randomized complete block with four replications. The plot size was 8×6 m^2. The field was manually weeded. At harvest, grain yields were recorded from the center rows after discarding border plants.

Inclusion of cassava with millet production was promising in increasing total yield and revenue of the system, thus bringing greater food security as well as income to the farmers (Table 6). Application of fertilizer increased pearl millet grain yield by 2.5 fold in both monoculture and intercropping. Significant increase in cassava yield was observed by fertilizer use up to 54-26-26 N-P-K rate applied in this experiment. Fertilizer application increased net income to farmers. Another factor in this rainfed system is that the increase in yield per unit fertilizer is not as high as with irrigation. When intensification is practiced by adding cassava as an intercrop, all levels of added fertilizer increased net return. Adding 27-13-13 N-P-K formulation resulted in a 28% greater net return when zero fertilizer was applied.

On-farm trials conducted by INRAN in collaboration with FAO from 1981-91 examined fertilizer response by pearl millet in the 200 to 800 mm precipitation zones across the country. These trials, jointly managed by researchers and farmers, consisted of N and P applications to 100 m^2 applied

TABLE 6. Performance of monocropped pearl millet versus intercropped pearl millet/cassava at Bengou, Niger in 1997.

	Yield			
	Millet Grain Yield	Cassava	Gross Return[2]	Net Return[2]
Millet Monocropping	kg ha^{-1}	kg ha^{-1}	($) ha^{-1}	($) ha^{-1}
N-P-K (kg ha^{-1})				
0-0-0	756 c[1]	-	121	121
27-13-13	1135 bc	-	182	163
54-26-26	1559 b	-	249	214
81-39-39	1986 a	-	318	265
Intercropping				
Millet + Cassava				
N-P-K (kg ha^{-1})				
0-0-0	725 c	4200 bc	284	284
27-13-13	1035 bc	5400 b	382	364
54-26-26	1458 b	6853 b	507	3472
81-39-39	1887 a	8124 a	627	574

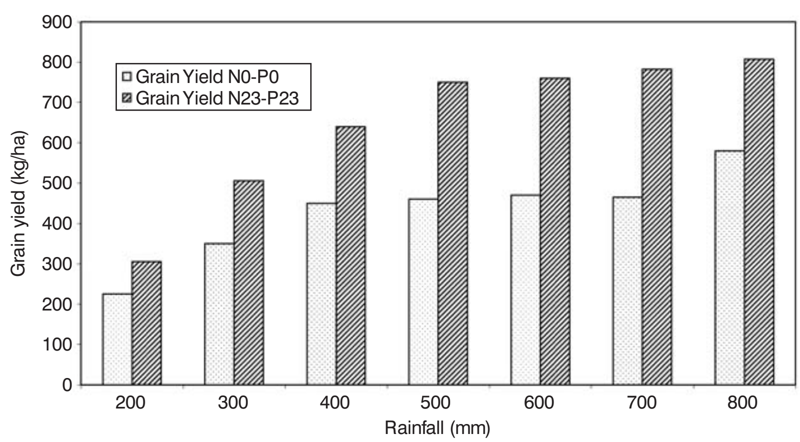
[1] Mean yields with same letter are not significantly different ($P \leq 0.05$).
[2] Millet price = \$0.16 kg^{-1}; Cassava = \$0.04 kg^{-1}; Fertilizer = \$0.65 kg^{-1}.

three weeks after planting. Two replications per farm were used and 23 kg ha^{-1} of N and P was compared to no fertilizer under farm managed conditions.

Results of these combined tests from more than 500 sites over much of Niger (Figure 6) showed that fertilizer was effective in increasing yield within any rainfall zone, but the yield increase per unit N and P applied tended to increase with increasing precipitation. If rainwater harvesting technique or supplementary irrigation is available in these low rainfall zones, yield enhancement and profitability can be increased. This suggests a need for water harvesting/conserving technology when irrigation is not available in order to maximize the yield increase per unit fertilizer.

In 1998, on-farm trials were conducted at three locations comparing four different fertility treatments to a zero application. The experiment also contained three different moisture regimes as (1) Lossa; 350 mm rainfall; (2) Lossa; 350 m rainfall + 100 mm supplemental irrigation; (3) Bengou; 585 mm precipitation in rainy season of 1998. A randomized complete block with four replications was used. The pearl millet crop was planted on an area 5 m × 10 m in 50 cm row spacing and 25 cm between hills with 3-4 seeds $hill^{-1}$. Treatments consisted of fertilizer at rates of 27-13-13, 54-26-26, and 81-39-39 kg ha^{-1} N-P-K and 81-39-39 kg ha^{-1} N-P-K + one Mg residue applied three weeks after planting. Supplemental

FIGURE 6. Pearl millet grain yield response to nitrogen and phosphorus in different rainfall zones in Niger as an average of more than 500 site years.



irrigation was applied in two 50 mm increments at 30 and 50 days after seeding, and the experiment was hand weeded.

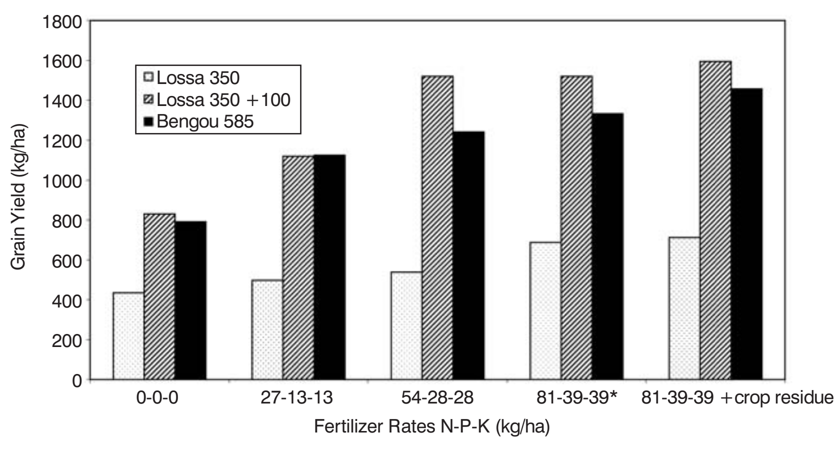
Fertilization increased pearl millet yields markedly, with the greatest increases observed at the higher fertilizer rates (Figure 7). The addition of residue to fertilizer at 81-39-39 kg ha^{-1} N-P-K gave only minimal yield enhancement compared to fertilizer only. Grain yield at Lossa without supplemental irrigation ranged from 450-700 kg ha^{-1} which is normal for this area. Supplemental irrigation of only 100 mm water more than doubled yield at high fertilizer rates, and equaled yields at the Bengou location (585 mm precipitation). This supports the previous 10-year FAO results indicating the value of saving soil moisture and/or using minimal supplemental irrigation if available.

DISCUSSION

Transition from Traditional to Technologically Improved Intensive Management Systems

A shift from the traditional bush-fallow system to a more extensive cultivation of land without fertilizer has occurred in most areas of Niger leading to declining crop yield. Lack of fertilizer or sufficient organic residues

FIGURE 7. Pearl millet grain yield at two rainfall zones in Niger, and effect of supplementary irrigation in the low rainfall zone in 1998.



and other soil conservation technologies have led to soil nutrient depletion and greater soil erosion of arable land, especially where crop production has extended to marginal sloping lands (Smaling et al., 1993). Use of production technology such as fertilizer (N and P) and lime in some areas (Bationo and Mokwunye, 1991), techniques of rainwater capture and conservation (Shapiro and Sanders, 1998) and improved cultivars (Maranville, 1998) must be promoted at the farm level. Alternative production systems should contain soil enhancing techniques such as incorporating grain legumes. More intensive production systems demand greater soil fertility maintenance; therefore, the supply of fertilizer must be made more dependable, available and affordable through correct input and output price policies to allow farmers to plan application of mineral nutrients to their land (Shapiro and Sanders, 1998).

As previously discussed, four pillars of crop intensification in rainfed areas can be identified as rainwater harvesting, fertilizer use, improved cultivars, and intercropping systems. The results of present studies clearly support these primary intensification principles. Results of the diagnostic survey indicate that farmers believe any or all of these are needed to enhance grain yield and economic gain. The historic failure of farmers to adopt these technologies emphasizes the need to strengthen technology transfer and institutional support (Braun and Pauilo, 1990; Shapiro et al., 1993; Darmola, 1989).

Institutional and Policy Related Items

While developing a strategy to achieve the goal of food security, key elements should include the adequate financial resource availability from public and private funds that include infrastructure development and assuring availability of essential inputs such as seed, fertilizer and credit. On-farm analysis of costs and benefits for pearl millet and sorghum indicate favorable economic returns under rainfed conditions with moderate use of fertilizer, although variable precipitation may affect the magnitude of return (Shapiro et al., 1993; Shapiro and Sanders, 1998). Technologies that include seed of improved varieties, fertilizer, and improved soil and water management technology are essential to improve food production. The technology package should also be linked with support services and an adequate supply of credit to derive full benefit. The zones of Niger with higher rainfall are the zones in which technology can be expected to have the greatest financial benefits. A strong delivery system for technology inputs must be developed to intensify agricultural production. There is a need for continuous dialogue on input and output prices. The government should have an effective Agricultural Price Commission between public and private sectors to review prices of inputs and cost of production of different cereals. A minimum support price should exist to provide guidelines for private traders and farmers and to facilitate the market economy based on supply and demand which improves the marketing system of agricultural products.

Risk Sensitive Resource Management

It is important to promote diversified production systems in Niger such as intercropping and cost effective production practices such as rainwater harvesting that mitigate risk of variable rainfall. Diversified cropping and farming systems should be encouraged to diminish price fluctuations and market risk of single crops. Production of more biomass will support more farm animals per unit area and insure greater financial security. Agroforestry can bring greater stability in reducing wind erosion and providing animal feed and fuel to the production system (Matson et al., 1997; Anderson, 1992). Risk of high seasonal price fluctuations can be addressed by developing an efficient marketing system combined with minimum support prices (Pinckney, 1988; Mattas and Katsadonis; 1989; Daromola, 1989). The intensive technologies evaluated here demand substantially more investment and institutional policy reform to enhance farmers' profitability and to help minimize risk of crop failure if improved rainwater harvesting technologies are practiced. Focusing dissemination of improved agricultural technology in high rainfall and irrigated areas would promote avoidance of land degradation in marginal areas. However, a cautious optimism about the potential in agriculture technologies to raise farmers' income and increase sustainability of the farming systems in semi-arid regions can only be considered in view of farmers' experience in high risk environments. A formidable difficulty for Sahelian countries is to introduce multiple inputs simultaneously. If this can be accomplished, then a more profitable environment for agriculture can be created for these regions.

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