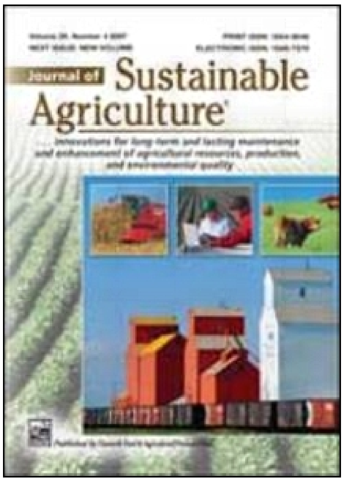

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Agriculture Intensification and Ecologically Sustainable Land Use in Niger: A Case Study of Evolution of Intensive Systems with Supplementary Irrigation

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Agriculture Intensification and Ecologically Sustainable Land Use in Niger: A Case Study of Evolution of Intensive Systems with Supplementary Irrigation

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ABSTRACT. In Niger, a breakdown of the bush-fallow system, low crop yields and reduced availability of communal land have resulted from increasing population pressure. Agricultural intensification is criti-

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cal to the future development of the region. Intensification of agricultural production in Niger must include adoption of sustainable yield increasing technologies, fertilizer use, supplementary irrigation and/or water conservation, high yielding cultivars and improved crop management practices. On-farm constraints analysis of crop productivity and technologies assessment was carried out in two irrigated perimeters: the Konni surface irrigation and the Djirataoua deep well system where supplemental irrigation is provided to rainy season crops in the event of long dry spells, and full irrigation is supplied to dry season crops. Konni is located in southern Niger, approximately 13°48'0"N, 5°15'0"E at approximately 257 m altitude; Djirataoua is located further east, approximately 13°20'0"N, 7°7'60"E at approximately 368 m altitude, near Maradi, which is located at approximately 13°28'60"N, 7°5'60"E, approximately 376 m altitude. In both the Konni and Djirataoua irrigation systems, use of supplementary irrigation has enhanced cropping intensity and crop productivity per unit area (yield) while generating greater employment opportunity. Analysis of long-term crop productivity trends during 1980-1997 revealed that sustainability of gained productivity is possible through agricultural intensification over years without any sign of productivity decline. These results show that the use of agriculture intensification technologies plays a crucial role in sustainable, increased crop production in the Sahel. The results of our diagnostic survey in these two perimeters showed that the major constraints to increased productivity are low fertilizer use, poor nutrient use efficiency, the lack of well adapted, high yielding varieties or hybrids, poor crop establishment and plant protection in farmers fields, and inappropriate input and output pricing. On-farm evaluation of the improved technologies, namely improved varieties or hybrids and optimal fertilizer use with optimal supplementary irrigation, resulted in a 35% increase in grain yields at the farm level. The lesson learned from this study is that developing sustainable agricultural production systems in Niger with higher yields, or production per unit area, than present-day yields depends upon supplementary irrigation if or where potential exists, and upon promotion of fertilizer use, high yielding cultivars and other innovative production technologies. This strategy will help reduce frequency and intensity of food shortages and will ultimately help reduce the incidence of poverty and starvation in Niger.

KEYWORDS. Agricultural intensification, land use systems, supplementary irrigation, sustainable agricultural production systems, water conservation, HIV/AIDS, Sahelian zone, Sudano-Sahelian zone

INTRODUCTION

Agricultural intensification is based on a combination of inputs such as fertilizers, irrigation or water conservation technology, improved varieties, and improved agricultural practices such as multiple cropping. The highly successful "green revolution" was built in Asia on agricultural intensification, which dramatically raised crop yields and production. For instance, yields of rice (Oryza sativa L.), wheat (Triticum aestivum L.) and maize (Zea mays L.) more than doubled in developing countries from 1961 to 1990 (Braun and Pauilo, 1990; Anderson, 1992). Ninety-two percent of the increased production from the "green revolution" resulted from increased yields and only 8 percent from area expansion (Crosson and Anderson, 1994). Only in Sub-Saharan Africa has area expansion contributed about as much as increased yield to cereal production. Between 1960 and 1999 in Niger, expansion of the area where sorghum [Sorghum bicolor (L.) Moench] and pearl millet [Pennisetum glaucom (L.) R. Br.] are cultivated increased five-fold and three-fold, respectively (FAOSTAT database, 2001). During the same period, Niger sorghum production increased from 0.27 to 0.48 million MT, but sorghum yield decreased from 607 kg ha^{-1} to 229 kg ha^{-1}. Also from 1960 to 1999, Niger millet production increased from 0.7 million MT to more than 2.2 million MT, while yield decreased from 473 kg ha^{-1} to 417 kg ha^{-1} (FAOSTAT database, 2001). However, the option of area expansion is rapidly disappearing, and even in Africa, particularly in west Africa, farmers will have to rely on increased yield-increased production per unit area, or intensification of agriculture-to increase food production.

The three pillars of agricultural intensification considered in this paper are supplementary irrigation, fertilizer use and improved varieties in an agro-ecological setting. Furthermore, to optimize natural resource use, such as land, rainfall and stored water on surface or underground, and solar radiation, farmers must mobilize labor and capital in order to achieve the full benefit.

About 60% of the Niger population is below the poverty line of $245 annual per capita GNP (FAO,1997). The relationship between poverty and environmental degradation is close and complicated, with a built-in potential for escalation. Poor people often lack sufficient incomes or access to credit to purchase appropriate tools and materials or inputs such as fertilizer in order to practice environmentally sustainable techniques which protect natural resources against degradation or rehabilitate degraded resources. The poor tend to lose their capacity to sustainably support themselves when their access to resources is diminished or available resources are reduced (Pinstrup-Anderson et al., 1999). Population growth is a key catalyst of environmental degradation, especially in marginal lands (McCalla, 1999). Rapid population growth diminishes farm size and ultimately pushes people off the land to search for employment opportunities elsewhere.

Agricultural intensification, if managed properly, need not degrade the environment. 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 fertility (Vlek,1990; Larson and Frisvoid, 1996). Alternative technologies and farming practices already exist that involve elements such as appropriate crop rotations, mixed farming systems with crops and livestock, agro-forestry, biological pest control, disease and pest-resistant varieties, balanced application and correct timing and placement of fertilizer, and minimum or zero tillage. Mismanagement of the intensification process and reliance on inappropriate techniques and technology for intensification can be wasteful and a cause of degradation. For example, while fertilizer use can replace soil nutrients and inhibit environmental degradation, application of unneeded mineral nutrients is wasteful, and application of excessive concentrations of some mineral nutrients can be toxic to plants.

FOOD SECURITY

In Niger, declining cereal productivity is linked to declining food security, and this decline in productivity per unit area demands more attention to improve agricultural development and to enhance Niger's food security (FAO, 1999). The prime focus of on-farm adaptive research and technology transfer should be in high rainfall zones (500 mm and above) and in the region along the Niger River where investment in fertilizers, seed and labor by farmers is likely to have assured economic return with lower risk of crop failure. This should increase the likelihood of faster economic impact in areas of the country where the water supply, or rainfall, is less predictable. The cereal crops, millet and sorghum, traditionally grown in these areas have had low productivity due to very low input use and a lack of adoption of production technology. During the period 1992-1997, on average, Niger annually produced 1,716,000 tons of millet and imported no millet, while during the same period Niger annually produced 339,000 MT of sorghum and imported

11,000 MT of sorghum per year (FAO, 1999). Niger did not import sorghum or millet from 1992 to 1997, yet during the same period Niger imported annually, on average, 45,000 MT of wheat and 43,000 MT of rice. Niger's average annual, domestic production of wheat and rice during the period 1992-1997 were 5,000 and 39,000 MT, respectively. Clearly, Niger's domestic production of sorghum and millet generates a major source of income for the farmers of Niger as well as conserving foreign exchange. The annual importation of cereals to Niger decreased from 135,394 MT in 1992 to 67,107 MT in 1997, and the foreign exchange used to pay for those cereal imports decreased from $32.9 million in 1992 to $21.7 million in 1997 (FAO, 1999).

The Sudano-Sahelian zones of Niger are ecologically more suitable for crop production than areas with variable and low annual rainfall (below 400-450 mm) which have high-risk crop production. This is the most likely reason for subsistence farming with little or no use of modern crop production inputs. On the other hand, in the high rainfall zones (500-850 mm), the risk of crop production is less, and the returns for use of modern crop production inputs are usually profitable. Use of rain water harvesting methods would lead to greater returns from the use of external inputs (improved varieties and fertilizer) and would be expected to increase economic viability. Another strategy to augment agricultural production is development of supplementary irrigation through exploitation of surface water by construction of small reservoirs, and use of underground water from deep or traditional wells.

IRRIGATION POTENTIAL IN NIGER

Niger has an area of 270,000 ha which are potentially irrigable. Of this area, as of 1989, about 78,000 ha, or about 2.1% of the cultivated surface area of Niger, had been developed, of which 66,480 ha were under irrigation and 12,000 ha were cultivated in recessional agriculture (FAO, 1995). Out of the irrigated land, as of 1990, 29,000 ha of rice, 2,500 ha of cotton, and 1,000 ha of wheat were cultivated (FAO, 1995). Niger has four predominant types of irrigated systems: (1) joint managed reservoir surface irrigation, (2) ground water pumping, (3) individually managed micro and small irrigation, and (4) river pumping. Water use efficiency differs widely among these four systems of irrigation.

SOIL FERTILITY MANAGEMENT STRATEGY AND FERTILIZER USE

Low soil fertility and very little use of chemical fertilizers have been cited as factors limiting productivity growth of agriculture in most of Sub-Sahara Africa (Bationo and Mokwunye, 1991; Vlek, 1990). Studies of soil nutrient balance across countries in Sub-Saharan Africa show evidence of widespread nutrient "mining" leading to severe nutrient deficiencies across agro-ecological zones (Stoorvogel et al., 1993; Smailing et al., 1993). Fertilizer use in the agricultural areas of sub-Saharan Africa remains very low, averaging, in 1995, about 1.071 million MT of total fertilizers used per 891 million ha, or about 1.2 kg ha^{-1}; in 1995 in Niger, total fertilizers used were 9,979 MT per 16.5 million ha of agricultural area, or about 0.62 kg ha^{-1} (FAO, 2001). 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 infrastructures and physical distribution facilities (Daramola, 1989; Vlek, 1990), and the recent drastic elimination of fertilizer subsidies that is worsened by a lack of adequate credit facilities for farmers (Vlek, 1990; Thompson and Baanante, 1989). Fertilizer use is most common in irrigated areas throughout Niger and the use of fertilizers differs widely in different production systems and regional areas. We estimate that in Niger, ninety percent of the fertilizer is used in irrigated areas. There is very limited documentation on agricultural intensification technology including supplemental irrigation in the Sahel, particularly in Niger. The impact of agricultural intensification on developing intensive production systems which can lead to enhanced economic benefits to farmers and lead to evolution of sustainable agriculture in the region is largely undocumented.

The purpose of this paper is to provide results of a case study which (1) examines current production systems and productivity trends in traditional systems in Niger, (2) evaluates alternate agricultural intensification technologies including supplementary irrigation for intensive production systems, and (3) examines the consequences of newly evolved intensive production systems and their benefits to sustainable production compared to traditional systems.

METHODOLOGY

Agro-Ecological Region in Niger

Fifty-three percent of Niger is desert with rainfall of 0-100 mm; 24% is Sahelian desert with rainfall of 100-350 mm; 16% is Sahelian with rainfall of 350-550 mm; and 8% is Sudano-Sahelian with rainfall of 550-850 mm (Table 1).

Supplementary irrigation perimeters have been developed in some areas of Niger and two such perimeters, the Konni surface irrigation system and the Djirateoua deep well irrigation system, have been chosen to examine the effect of supplementary irrigation on yield stabilization in the rainy season and develop sustainable intensive production all year to generate higher returns to farmer from their land, labor, and capital (Table 2).

TABLE 1. Current land use and potential alternative for sustainable agriculture intensification.

Agro-ecological zone–rainfall (mm)	Area in 1000 ha (% of total)	Current land use	Constraints	Alternative land use (intensive system)
1. Desert (0-100)	667,000 (53)	Primarily rangeland, migrant livestock farming	Very low rainfall, highly permeable soils and lack of mineral nutrients	Migratory livestock farming
2. Sahelian desert (100-350)	300,000 (24)	Rangeland, limited millet cropping in lower soil/depression	Low rainfall, soil quality and lack of mineral nutrients	Livestock farming and afforestation-reduced range land, degradation
3. Sahelian (350-550)	200,000 (16)	Predominantly millet-based cropping and cowpeas	Erratic rainfall, soil quality and lack of mineral nutrients	Intensification–agro-forestry, new technologies and inputs, mono/double cropping with supplementary irrigation
4. Sudano-Sahelian (550-850)	100,000 (8)	Millet- and sorghum-based cropping including legume, cassava (cowpea peanut)	Soil quality, lack of mineral nutrients, erratic rainfall	Intensification–input use, livestock, integrated farming with irrigation

TABLE 2. Perimeter cropped area (CA) in ha, irrigated area (IA) in ha, irrigation intensity (II) and cropping intensity (CI) at Konni and Djirataoua, Niger, 1992-97.

Year	Konni				Djirataoua			
	Rainy season		Dry season		Rainy season		Dry season	
	CA	II	IA	CI	CA	II	CA	CI
1992	1984	88	713	136	350	78	202	145
1993	1912	85	687	133	445	99	197	147
1994	1805	80	653	126	346	77	205	122
1995	1954	87	743	138	395	88	206	134
1996	1926	86	601	129	426	95	216	147
1997	1834	82	686	129	446	99	231	150

1. The command area of Konni surface irrigation system was 2250 ha and 450 ha at Djirataoua.
2. Irrigation intensity (II) = area irrigated divided by total irrigable area × 100.
3. Cropping intensity (CI) = Cropped area in rainy season + dry season divided by total irrigable area × 100.
4. Labor employment potential/hectare: sorghum 94, cotton 250, millet and maize, 115, wheat 164, compared to rainfed millet/sorghum 30.

Site Description and Soil Characteristics

The Konni irrigation perimeter is located about 450 km SE of Niamey. The perimeter is gravity-fed surface irrigation and has an area of about 2,050 ha under cultivation. The main and secondary canals are concrete-lined, and farmlands were precision-leveled before the land was subdivided for settlement. Annual rainfall is around 450-500 mm with mean temperature on the order of 25-30°C. Annual potential evapotranspiration is around 2,250 mm. The watershed is sparsely vegetated and is surrounded by lateritic hills which drain into a broad, sandy valley floor of farmland. Most of the actual storage behind the barrage lies in the remnants of a steep side and deep bottom. The reservoir is divided into two storage reservoirs; however, siltation has been observed recently. Each farm family has a parcel of 0.37 ha. Soil types of the perimeter range from sandy loam to silty loam with a moderately low level of soil fertility. The prominent crops in the rainy season are cotton (Gosypium hirsutum L.) and sorghum, with a small area under maize and millet. In the dry season, wheat is the prominent crop and vegetables are cultivated in a small area.

The Djirataoua crop production area, which is a subject of the present research, includes 450 ha irrigated by 44 deep wells powered by electricity. Data from nearby Maradi indicate that long-term annual rainfall varies between 450 and 550 mm with most received in the months of June to September. Mean temperature ranges from 22 to 32°C. Potential evapotranspiration demand per annum is about 2,450 mm. Each deep well serves about 10 ha, and approximately 1,312 parcel holders are served by the system with an area of 0.32 ha per farmer. Water is discharged from tube wells into fabricated rectangular concrete channels (30 cm × 45 cm). For individual parcels, water is removed from the lined channel into field channels with the use of aluminum siphons. The soil type in the perimeter ranges from sandy loam to clay loam with moderately low soil fertility. The dryland farming in the vicinity includes millet and sorghum intercropped with cowpea [Vigna unguiculata (L.) Walp] or peanut (Arachis glabrata Benth). In the perimeter area, sorghum and cotton are the predominant crops in the rainy season with a small area under vegetable, maize and millet. In the dry season, wheat as a cash crop is usually followed by onion (Allium cepa), and a small area is under vegetables such as tomato (Lycopersicon esculentum Mill.) and pepper (Capsicum annuum L.). A composite sample analysis at the beginning of the study showed that the clay loam soil had 0.65% organic carbon and 506 mg N kg^{-1} while the sandy loam soil had 0.48% organic carbon and 396 mg N kg^{-1}. The available phosphorus and exchangeable potassium were 12.4 mg P kg^{-1} and 0.18 mg K kg^{-1}, respectively, and the soil pH was 6.5.

Institutional and Social Structure in Irrigation Management

Both the Konni and Djirataoua perimeters are jointly managed by the office of National Agricultural Irrigation (ONAHA), the Department of Rural Development Project (DRDP), and a local cooperative of farmers. Under this system, ONAHA is responsible for technical services, training and monitoring, while DRDP provides financial support at the level of infrastructure maintenance. The perimeters are operated by a management committee represented by these agencies and farmer representatives. The management committee is composed of a president elected by farmers, treasurer, secretary and director of the perimeter appointed by ONAHA. The committee, in consultation with farmers, harmonizes the cropping operation and irrigation schedule, provision of input supplies, and collection of irrigation fees.

Farmer-Managed Cultivation of Crops

Crops are cultivated in two distinct cropping seasons which are the rainy season (July-October) and the dry season (November-March). The cereal crops are generally planted the last week of June to mid July, when at least 30 mm rainfall has been received. Cotton is planted in early May with supplemental irrigation. Normally, most farmers plow the field by country plow, and the soil is tilled by country harrow. Generally, a row spacing of 60-80 cm and hill-to-hill spacing of 25-30 cm is used for sorghum, maize, millet and cotton. Four to six seeds per hill, depending on seed quality are used at planting. Crops are normally weeded manually twice during the season. As a general rule, supplementary irrigation is applied when rainfall has stopped for 10 to 15 days. Normally, the perimeter provides a maximum of two to three supplemental irrigations for rainy season crops. Cotton receives frequent irrigation at intervals of 7-10 days before the normal rainy season begins, and the cotton crop may get an additional irrigation after the rainy season. The amount of water applied per irrigation may vary from 30 to 45 mm. Wheat is usually irrigated each week in the Konni perimeter; however, in the Djirataoua perimeter during the crop's reproductive phase, irrigation frequency is increased to an interval of 5-6 days. Often, water is not limited for wheat production in this perimeter. Normal cropping duration is 90-100 days for sorghum, maize and millet, 150-160 days for cotton, and 95-105 days for wheat.

Crop Water Requirement and Water Supply

Water requirements of crops were estimated in terms of the consumptive use of the crop, its special water needs and the effective rainfall. Relevant values of the crop coefficient (κ) as outlined by Doorknobs and Pruit (1977) were used. The effective rainfall was determined by using the method by the US Department of Agriculture, Soil Conservation Service (Dastane, 1975). The water requirements for cotton and wheat establishment were included, while sorghum, millet and maize were sown when adequate amount of rainfall was received to allow for planting. Water supply was calculated by water delivered at the barrage gate at Konni divided by the cropped area plus effective rainfall during the growing season. The conveyance losses were minimal, because primary, secondary and tertiary channels are concrete.

On-Farm-Evaluation of Intensive Production Systems and Technologies

On-farm technology evaluation trials were conducted in farmer fields during 1997 and 1998 in both the rainy season for sorghum and the dry season for wheat in both the irrigated perimeters. The purpose of this exercise was to determine the productivity gap due to lack of adoption of technology by the farmer. Two major constraints identified during the diagnostic survey were inadequate fertilizer and non-availability of seed of high yielding varieties (Table 3). Two cultivars of sorghum, Sepon82 (an open pollinated variety) and hybrid NAD-1 were evaluated under five nitrogen (N) rates (0, 45, 90, 135 and 180 kg N ha^{-1}). Nine farmers participated in this study. The management practices of the farmers were used in this study except for seed and fertilizer which were supplied.

RESULTS

Weather and Production Constraints

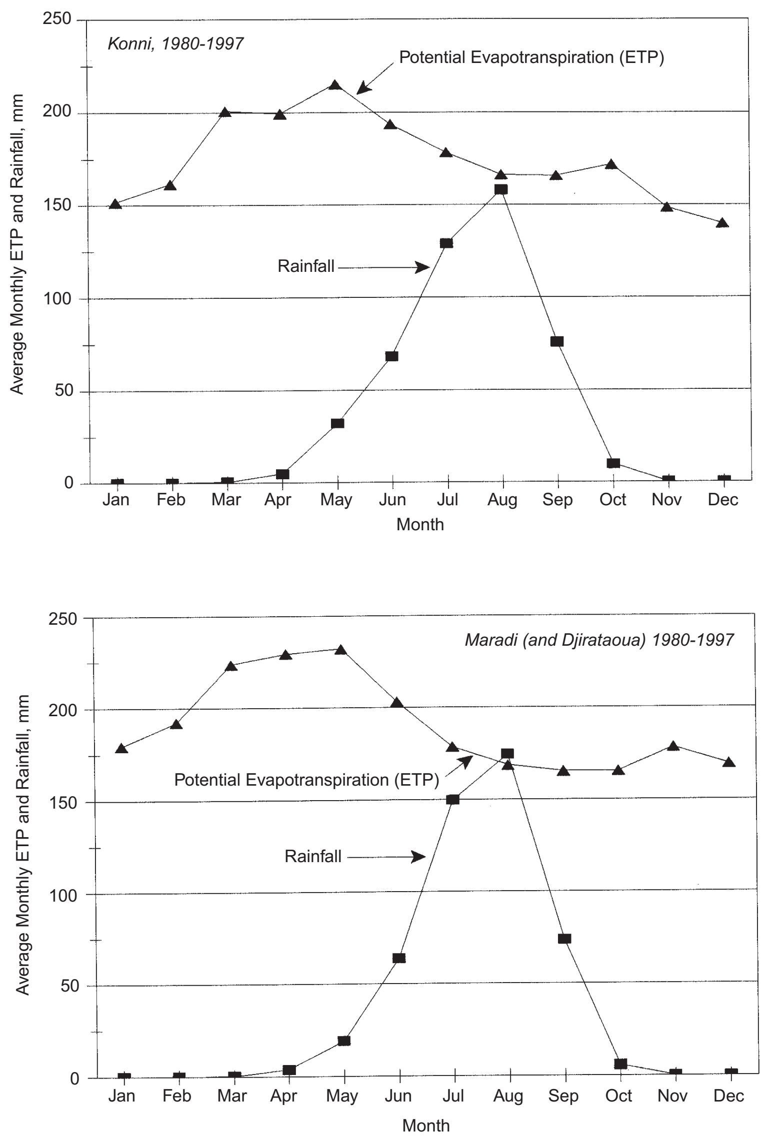
The potential evapotranspiration and rainfall for two sites is presented in Figure 1.

TABLE 3. Farmers' responses to question regarding their agronomic practices and constraints in millet and sorghum cultivation in irrigated perimeters (N = 69).

Feature	Percent of farmer's response	
Cultural practices		
1. Crop culture	cereal/legume intercrop (19)	pure (81)
2. Crop establishment		
a. Land preparation	no tillage (8)	tillage (92)
b. Source of power	hand (8)	animal (92)
3. Sowing methods plant spacings	60-80 × 25-30 cm (71)	80-100 × 20-25 cm (21)
4. Varieties	local (68)	improved (32)
Soil class and soil fertility management strategy		
1. Soil type	sandy/sandy loam	silt loam/clay loam
2. Soil fertility	manure and fertilizer none (16)	use of FYM/fertilizer (84)
3. Sources of nutrients	organic (18) fertilizer (24) both (39) none (19)	
4. Quantity of fertilizer	0-25 (34), 26-50 (36), 50-75 (24), >75 (6)	
Response of farmers in ranking the major constraints in sorghum production		
1. Fertilizer (44), 2. Improved variety (18), 3. Low price of sorghum (38)		

1. Diagnostic survey conducted around Konni and Maradi perimeters where farmers have land for rainfed as well as supplementary irrigation.
2. Each farmer has 0.37 ha of land in perimeter and 3-4 hectare rainfed.
3. The average perimeter yield from 1980-1997 has been 3 to 6 times compared national average of rainfed crops.
4. The traditional system of cultivation includes low input system with tall variety local Motta Maradi in sorghum, while improved system constituted moderate input, nutrient and improved variety/hybrid, higher density and supplementary irrigation.
5. Quantity of farm yard manure used by farmers varies from 3 to 8 t/ha.

FIGURE 1. Average monthly potential evapotranspiration (ETP) and rainfall at Konni and Maradi from 1980-1997.



The large increase in difference between potential evapo-transpiration and rainfall during the latter part of the rainy season (August-October) normally results in increased water stress for rainfed crops. This is the primary cause of low productivity and high variation in crop yield. Moreover, the pattern of rainfall determines single cropping in all regions of the country unless irrigation facilities exist. Supplementary irrigation during the rainy season can reduce the variability in crop yield. Development of the surface irrigation system in Konni has enhanced crop production, income and employment potential in the area. The irrigation system has increased almost four to six times the productivity of the land compared to rainfed farming. Full utilization of rainfall in the Sahel is a prerequisite to realize the full potential of the region in terms of crop productivity, labor employment and reducing poverty. Based on the diagnostic survey (Table 3), the production constraints in supplementary irrigated perimeters include lack of fertilizer use, improved varieties and low market prices for sorghum. The optimization of production inputs in these perimeters is key to maximize crop productivity and economic return.

Long-Term Productivity Trends of Crops

Analysis of long-term productivity trend of millet grown in the irrigated perimeter and outside the perimeter at Konni shows that grain yield in rainfed production declined by approximately 4.8 kg ha^{-1} annually, while it remained sustainable in the irrigated perimeter over this period (Figure 2).

Similarly, grain yield of sorghum remained high under irrigation and increased 1.7 kg ha-1 annually. The mean yields of sorghum and millet were 1,900 kg and 1,545 kg ha^{-1}, respectively, in the irrigated perimeter compared to 432 and 392 kg $^{-1}$ of millet and sorghum in the rainfed area. This was primarily due to both better water management practices and also application of both organic and inorganic fertilizer in the irrigated perimeter compared to virtually no use of fertilizer in rainfed culture. The farmers' strategy of managing mineral nutrients and water has led to sustained production in these irrigated perimeters.

Water Supply (S) and Requirement(R) for Cropping System

At Konni and Djirataoua from 1992-1997, the amount of water supplied by irrigation and rainfall correlated well with grain yield of sorghum and wheat, as well as lint yield of cotton (Figure 3).

FIGURE 2. Trends in grain yields of pearl millet and sorghum under conditions of rainfall and rainfall plus supplementary irrigation at Konni, 1980-1997.

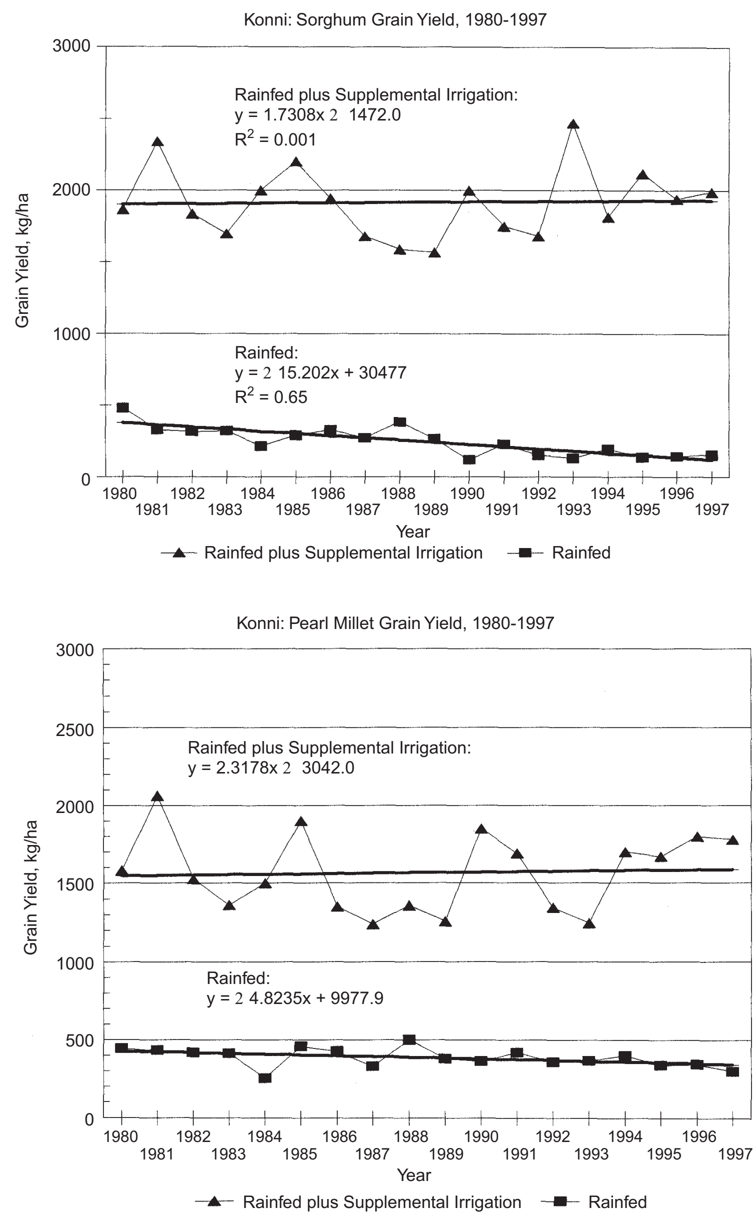
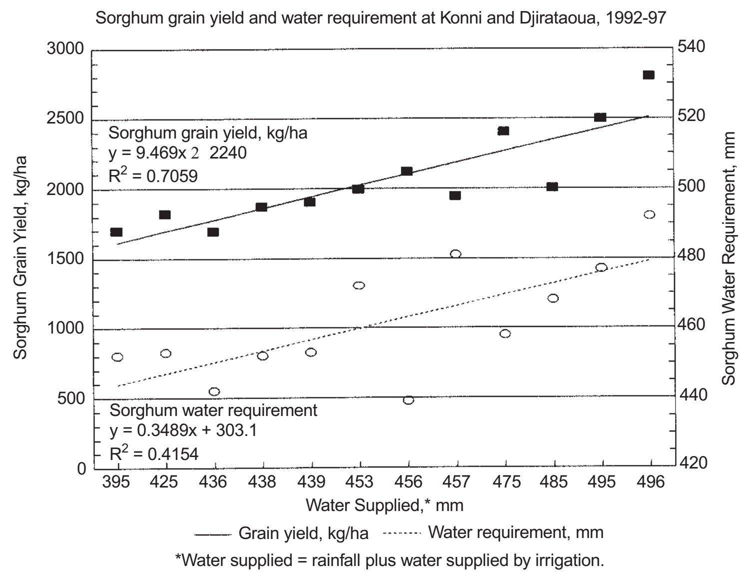


FIGURE 3. Relationships between water supplied, water required and grain yield of sorghum and wheat and lint yield of cotton, Konni and Djirataoua from 1992-1997.



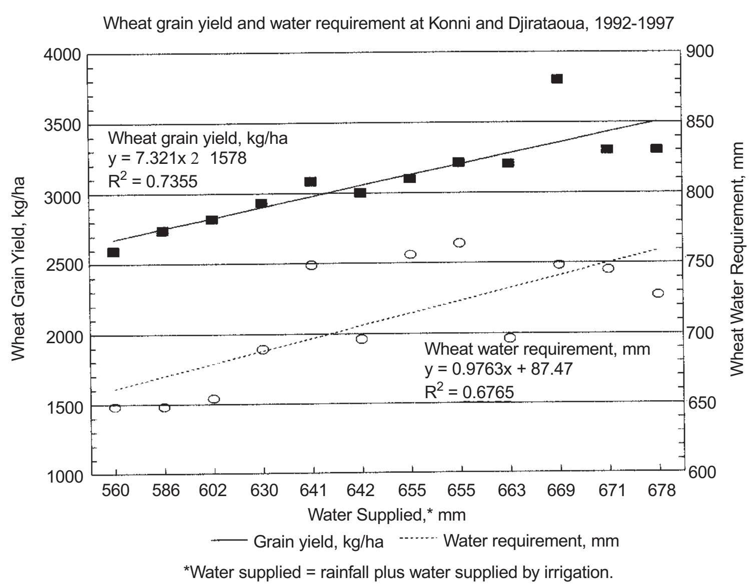
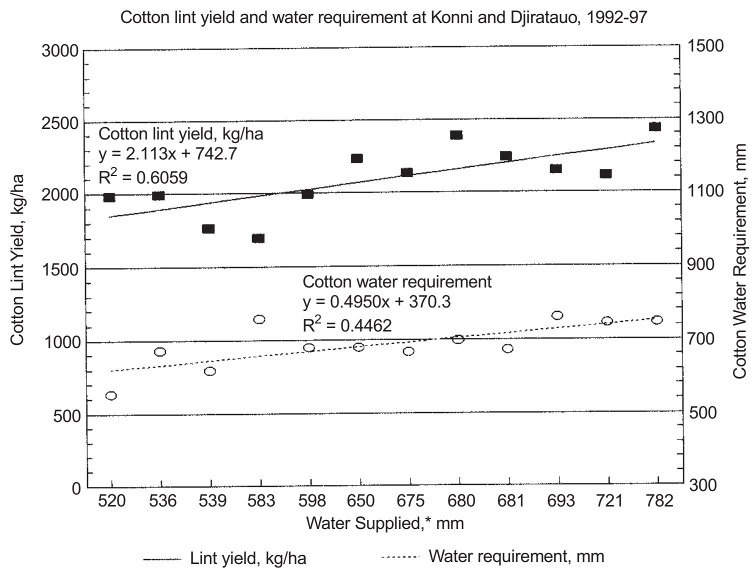


FIGURE 3 (continued)



*Water supplied = rainfall plus water supplied by irrigation.

Applied water accounted for 60% of the difference in yield averaged from 1992-1997 in both perimeters. There is a low degree of correlation between water requirement and water supplied, indicating that lack of adherence to irrigation schedule and quantity applied resulted in water stress. The ratio of water supply (S) to water requirement (R), or the S/R ratio, ranged from 0.70 to 0.94 for the whole crop season averaged over 1992-1997 with the lowest being for cotton and highest for wheat. Water shortage defined as 100% − [(S/R)(100%)] ranged from 6 to 30%. Water shortage was observed in both perimeters due to low rainfall in Konni and to failure to repair electric pumps at Djirataoua in a timely manner. In spite of these diff\iculties, water supply, by using irrigation to supplement rainfall, matched fairly well with the amount of water needed to meet the need of crops.

On-Farm Technology Evaluation

Low fertilizer use is a major constraint in realizing the full benefit of supplementary or full irrigation in Niger. Results of research conducted on sorghum showed that there is a large yield differential between farm-applied nutrients and the optimal amount needed to obtain full benefit of the resource in terms of yield. A similar trend was seen in wheat (Figure 4).

Sorghum and wheat had a near linear response to N for grain yield up to 135 kg N ha^{-1}. Sorghum response to N was 28.9 and 27.5 kg grain/kg N at Konni and Djirataoua, respectively, while wheat response was 15 and 23.4 kg grain/kg N at these respective locations (Table 4).

Appropriate fertilizer policy affecting availability and pricing will be needed if full benefits are to be realized from other production factors such as high-yielding varieties/hybrids, water, and improved cultural practices.

DISCUSSION

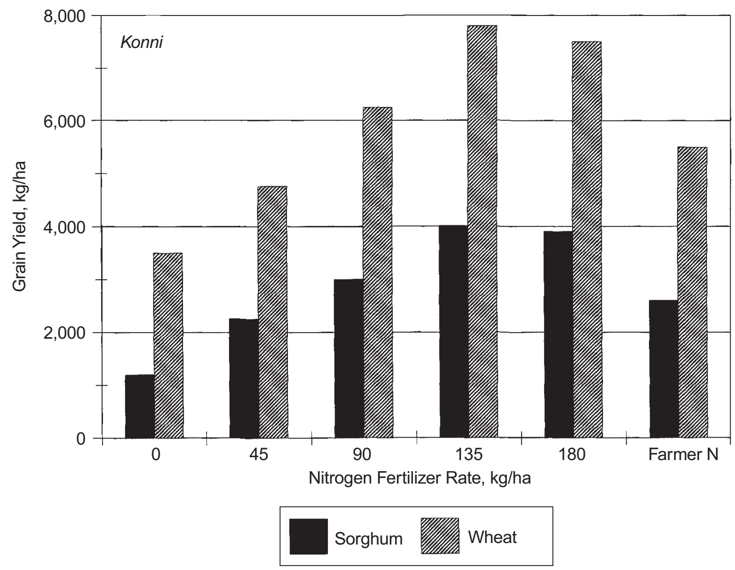
Changes in Cropping Systems, Productivity of Sorghum and Wheat

The introduction of supplementary irrigation has dramatically changed the cropping systems of the area around Konni and Djirataoua. Traditional systems of millet- and sorghum-fallow have been changed to sorghum-wheat, cotton-fallow, and maize/millet-vegetable. Intensification and diversification of crop production systems in these irrigated areas have increased farmers' income and labor employment. Introduction of cash crops like cotton, vegetables and wheat has increased farm income significantly (data not presented here). The introduction of supplementary irrigation increased crop productivity nearly three-fold in both perimeters, compared to the rainfed system. The most remarkable characteristic is long-term sustainability of crop productivity, despite year-to-year variability in yield (Figure 2). The productivity of the sorghum-wheat cropping system remained at a very high level during the period from 1980-1997. The increase in productivity was almost 10 times, compared to rainfed cropping (Figure 2).

Water Management Related Issues: Irrigation Intensity and Deficit Irrigation Potential

Supplementary irrigation enhances productivity of land, but efficient use of limited water must be made by optimizing other production factors such as fertilizer, improved varieties, optimum crop cultivation and plant protection measures. During our survey, we observed that farmers tend to apply more water with each irrigation due to the uncertainty of

FIGURE 4. Sorghum-wheat cropping system productivity using best available cultivar as influenced by nitrogen rate at Konni and Djirataoua, averaged over two years.



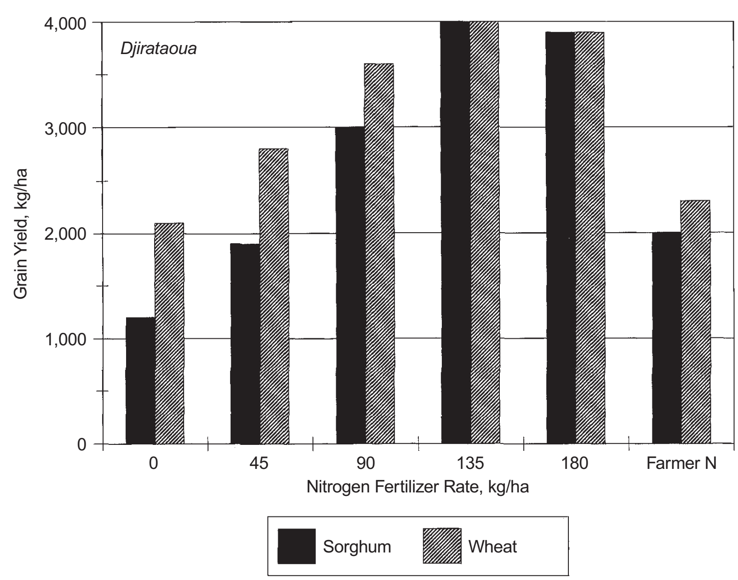


TABLE 4. Regression equations showing the yield response to nitrogen in sorghum-wheat cropping systems at two irrigated locations.

Variable	Equation	R^2
	Konni 1998	
Sorghum	$y = 1147 + 28.90\,N - 0.072\,N^2$	0.98**
Wheat	$y = 2167 + 15.02\,N - 0.035\,N^2$	0.91*
Total	$y = 3314 + 43.92\,N - 0.108\,N^2$	0.96**
	Djirataoua 1998	
Sorghum	$y = 1057 + 27.46\,N - 0.06\,N^2$	0.96**
Wheat	$y = 2034 + 23.36\,N - 0.071\,N^2$	0.98**
Total	$y = 3091 + 50.82\,N - 0.131\,N^2$	0.97**

failure of the system which might curtail the next irrigation. Improved operation and management, proper scheduling of irrigation and appropriate quantity of water to be applied would further increase the efficiency of water use and enhance system production (Norman et al., 1998). Supplementary irrigation in the Konni perimeter in the rainy season varied during the period 1992-1997 from 80 to 88%, while it ranged from 77 to 99% at Djirataoua (Table 2). At Konni, less supplementary irrigation was due to lack of rainfall resulting in less stored water in the reservoir available for irrigation. At Djirataoua, the decrease in supplementary irrigation was due to problems of maintenance of the electric irrigation pump. Overall, however, the production system was satisfactory. Both irrigation systems increased cropping intensity an average of 30%. The high demand for water in the dry season limits the area which can be covered by irrigation. In spite of supplementary irrigation during the rainy season, crops experienced varying degrees of stress from the lack of water due to variability in rainfall and availability of irrigation water at the appropriate crop stages. Although water stress caused by deficit irrigation practiced by farmers often results in reduced yield, yield levels were still very good in terms of economic return to farmers for their investment. In a field study conducted in the perimeter, deficit irrigation in maize produced moderately high yields (Pandey et al., 2000).

Institutional and Organizational Concerns

Although the irrigated perimeters have cooperatives to handle input and disposal of crop harvests, greater attention is needed to managing the irrigation systems. Policy-related issues must be considered, adequate financial resources must be made available for infrastructure development, and input supplies of seed, fertilizer and credit must be commercially available. Optimum use of inputs is restricted by lack of a supportive economic policy. Use of technology packages of better varieties, fertilizer, and improved soil and water management technology in a supportive socio-economic environment is essential to improve crop production in the Sahel (Sanders et al., 1996). Technology packages should be linked with support services and credit supply to derive full benefits from inputs of land, labor and capital. The most favorable rainfall zones where potential for supplementary irrigation exists, the Sahelian and Sudano-Sahelian zones, should be targeted for intensification of agricultural production in Niger (Table 1). A strong delivery system must be developed for the following inputs: seed, fertilizer, pesticide and farm implements. There is also a need for continuous dialogue among government, traders and producers on input and output prices. The government of Niger should have an effective agricultural price commission to review, from time to time, prices of inputs and cost of production of different cereals. Minimum support prices could be established to provide guidelines for private traders and farmers and to facilitate a market economy based on supply and demand to improve the marketing system of agriculture products.

Equity and Sustainability

Over the years, crop rotations have evolved in which cotton, sorghum, millet and maize are grown during the rainy season followed by wheat and certain vegetables in the dry season. The returns from these cropping systems have been very attractive and have enhanced labor employment. Irrigation has also increased return to labor compared to the traditional rainfed system practiced for years. One of the goals of the supplementary irrigation perimeter is to diminish social disparities. Although the average farmer is better off than before, disparity has increased between irrigated perimeter farmers and rainfed farmers outside the perimeter. Traders, rich farmers and consumers in the cities have greatly benefitted from supplementary irrigation. Crop productivity trends during 1980-1997 suggest that supplementary irrigated systems are more sustainable in maintaining yield as farmers apply both organic and inorganic fertilizer.

Government policy on investment for supplementary irrigation and the role of international organizations like the World Bank on investment policies needs clear vision if the goal of food security is to be realized. The argument that surplus production in developed countries should provide for feeding the poor in developing countries is not sound when these developing countries do not have foreign exchange and the poor do not have adequate buying power to purchase imported commodities.

CONCLUSIONS

One of the dilemmas for agricultural development in the Sahel has been the failure of the farmers to adopt agricultural intensification technologies in spite of declining productivity per unit area of continually more extensive agriculture over time. As land becomes limited and expensive, farmers are forced to shift to more intensive agricultural practices or abandon farming, and as morbidity and mortality resulting from HIV/AIDS make labor-intensive cultivation of extensive areas increasingly more difficult, more intensive agriculture will become a necessity rather than a choice (du Guerney, 1999). Use of supplementary irrigation in Niger, either by developing small surface reservoirs or underground water by deep wells, offers genuine potential to stabilize crop production and increase cropping intensity. The case study discussed here unequivocally demonstrates the fact that crop productivity can be sustained at a reasonably high level with the use of inputs, such as water, fertilizer and improved seed, over time in the Sahelian environment. Increased cropping system productivity increases higher economic returns to labor. Although management of a supplementary irrigation system will need attention to match water supply and crop water requirement, both of these systems performed reasonably well in this study. Minimizing the constraints to realizing full system productivity, optimization of nutrients, use of improved cultivars and refinement of cultural technologies is needed so that farmers can take the initiative to get full benefit over a traditional system of low input. As farmers adopt more management-intensive technologies such as irrigation and fertilizer, and as they obtain the advantages of improved agricultural technology, they tend to avoid land degradation of marginal areas (McCall, 1999).

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