WORKING PAPER 126

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International Water Management Institute

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Summary

In West Africa, especially in the Sahelian countries of Burkina Faso, Niger, Mali, and Mauritania, erratic rainfall sequences within and between years has often led to a high uncertainty in rainfed crop production. Over the past three decades, severe food shortages attributed to drought have been frequently reported in several Sahelian countries, most of which are amongst the least developed of the world. The long dry periods affecting the majority of the arid and semi-arid countries in West Africa are associated with famine, displacement of populations, and loss of previously fertile land. One of the challenges of the Millennium Development Goals (MDGs) is to reduce poverty and hunger and ensure successful interventions are reported in rainfed agriculture in West Africa, which are transforming the livelihoods of many resource poor smallholder farmers. Innovative and indigenous ways to achieve improved crop yields through integrated land and water management such as rainwater harvesting and soil water conservation have been successfully tested and, in some cases, adopted in West Africa. This paper highlights the successful interventions of improved indigenous rainwater harvesting/soil water conservation technologies such as *Zaï* or tassa, stone rows and half-moon in the Sahelian zones of West Africa over the past 10 years, and their contributions to enhancing food security and alleviating poverty. The potential for adoption of these technologies at the farm level and their outscaling to areas with similar agroecological zones are also discussed.

INTRODUCTION

Agriculture dominates the economies of most West African countries and impacts considerably on the incomes of the poor, 70% of whom live and work in rural areas. Most of these rural people are smallholder farmers who depend on agriculture for their livelihoods. Agricultural development is, therefore, an important factor in meeting the Millennium Development Goal of halving poverty in these countries by 2015. In economic terms, the sector contributes almost half (40-48%) of the total Gross Domestic Product (GDP), employs over 80% of the labor force, and provides the majority (75-90%) of the export earnings of these countries (OECD 2005). It is also the primary source of raw materials (over 70%) required to drive their mainly agro-based industrialization efforts. In West Africa, especially in the Sahelian zones, erratic rainfall sequences within and between years coupled with the desert locust invasion of 2004, the worst of its kind in the past 15 years (OECD 2005), has led to high uncertainties in rainfed crop production. The consequences of erratic and reduced rainfall and locust invasion have resulted in food insecurity for a total of 9,366,804 Sahelian people (an equivalent to 1,461,632 households) as well as 60% of the households in Mauritania (OECD 2005; Traoré et al. 2004). In addition to these gloomy pictures, a 26% reduction in food production has been predicted for Niger, Mali and Burkina Faso in the coming years (CILSS 2005). The Sahel region has five different agro-climatic zones, with different levels of vulnerability. The most fragile zone is situated in the northern Sahel, where the average annual rainfall is less than 400 millimeters (mm)/annum: large parts of Niger, Mali, Mauritania, Burkina Faso and Senegal are affected.

One of the major Millennium Development Goals (MDGs) is to reduce poverty and hunger. Integrated land and water management could play a key role in achieving this goal, especially in increasing food production. Appropriate technologies have been developed and are effective for increasing crop production in dry areas, but in view of severe land degradation in the Sahelian zone of West Africa, integrated rainwater harvesting and soil water conservation (RWH/SWC) can also enhance the effectiveness of these technologies further. They can also be used to rehabilitate degraded land, retain moisture, and re-establish vegetation cover to improve crop growth in order to alleviate poverty and enhance food security. Successful interventions in rainfed agriculture in West Africa have transformed the livelihoods of many poor farmers in the Sahelian zone of West Africa. These technologies have been successfully tested and, in some cases, more widely adopted within the West African subregion; details of these have been documented elsewhere (FAO 2001).

This paper reviews results of successful interventions of improved indigenous technologies (rainwater harvesting/soil water conservation) in the Sahelian zones of West Africa over the past 10 years. It also highlights the contribution of these technologies to enhancing food security and alleviating poverty as well as the potential for successful adoption of these technologies at the farm level. In addition, the paper reports on experiments conducted on RWH/SWC in Burkina Faso and Niger, two drought prone countries in the Sahelian zone of West Africa, which are among the poorest in the world.

POPULATION GROWTH AND FOOD SITUATION IN SELECTED SAHELIAN COUNTRIES OF WEST AFRICA

The population of the Sahelian region of West Africa is estimated to be growing at an annual rate of 2.8%. According to the Food and Agriculture Organization of the United Nations (FAO), the West African population was estimated at about 189.70 million in 1986, 215.20 million in 1990, and would increase to 648.10 million by the year 2025. The region is characterized by a wide diversity of climate, soils, geology, hydrology, topography, ethnic groups and cultural heritage. The Sahel region is characterized by low, erratic and highly variable rainfall. It is undergoing agrarian stagnation, becoming world famous as a region where natural resources are stressed to the limit and food relief efforts have become routine. Concerns of accelerated erosion, desertification, deforestation and other human-driven destruction activities have placed these zones under recurrent threat of drastically reduced food production, starvation and malnutrition.

According to OECD (2005), in March 2005, overall cereal production in the Sahel was estimated to be 11.5 million tonnes (t), which is close to the normal average calculated over five years. Members of the CILSS and officials from the World Food Programme (WFP), FAO and other agencies record that the Sahel region had recorded an overall grain surplus of 85,000 tonnes (OECD 2005). However, from different sources of information, it is evident that there is food insecurity in some pastoral and agro-pastoral zones of Niger, Chad, Mauritania, Mali, and probably Burkina Faso and Senegal. As shown in Figure 1, a CILSS press release of June 2005 indicated that Mali and Burkina Faso had a cereal surplus of 423,000 and 435,000 t, respectively. Countries with cereal deficits are Niger (223,000 t), Chad (220,000 t), Mauritania (166,000 t) and Senegal (160,000 t). However, these figures fail to highlight the wide variability within each country and hence caution must be exercised in their interpretation.

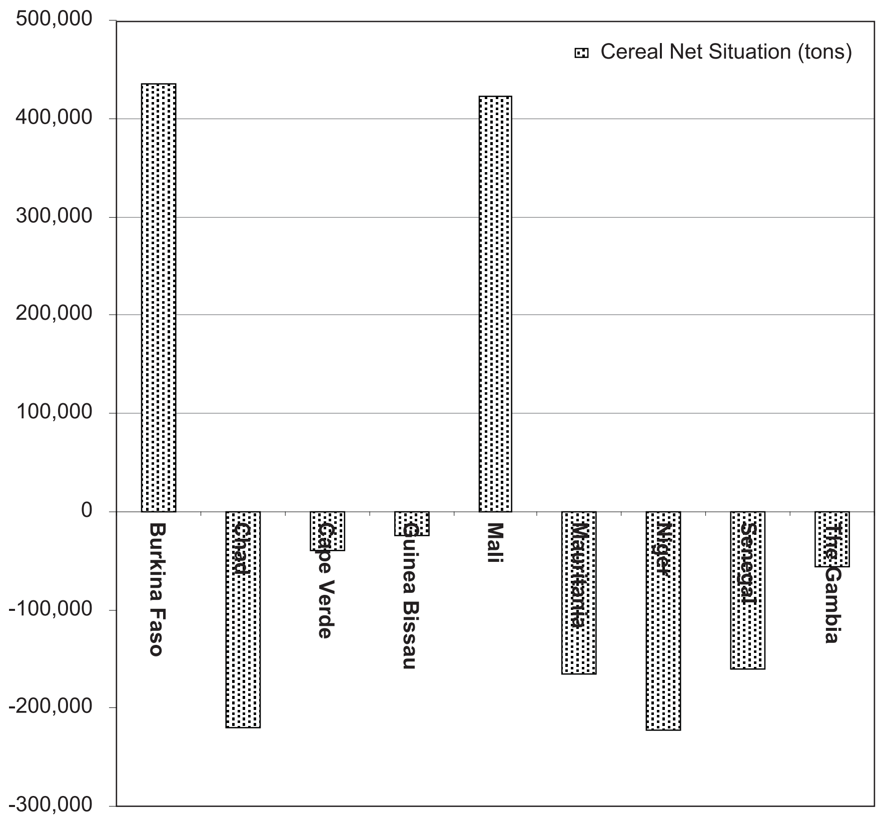

FIGURE 1. Cereal food situation in the CILSS member countries (2004-2005) (*Source:* OECD 2005).

THE NEED FOR RESOURCE CONSERVATION TECHNOLOGIES

Two major factors characterizing agriculture in the Sahel are: (i) erratic climatic conditions with frequent periods of water shortages (Sivakumar and Wallace 1991; Stroosnijder and Van Rheenen 2001), and (ii) the presence of large areas of inherently low fertility and crust prone soils (Morin 1993; Breman et al. 2001). This picture is worsened further by slash and burn practices, continuous cultivation with low inputs, and overgrazing and trampling by cattle (Sanchez et al. 1997; Mando et al. 2001). These have resulted in severe human-induced land degradation in the Sahel (IFAD 1992; Roose 1994). Indeed, Oldeman et al. (1991) indicated 15 years ago that in Africa, 40% of agricultural lands were affected by human-induced land degradation. A recent report (Henao and Baanante 2006) provides even more alarming figures: 85% of African farmland, some 185 million hectares (ha), had nutrient mining of more than 30 kilograms (kg)/ha during 2002-2004, and about 95 million ha are so degraded that it would require huge investments to restore it to productive use.

In the Sudano-Sahelian regions, eight-nine months of the year are dry and rainfall is intermittent and confined to a short season and averages less than 400 mm (Figure 2) mostly from June to August. Drought is the most serious physical hazard to agriculture in this region.

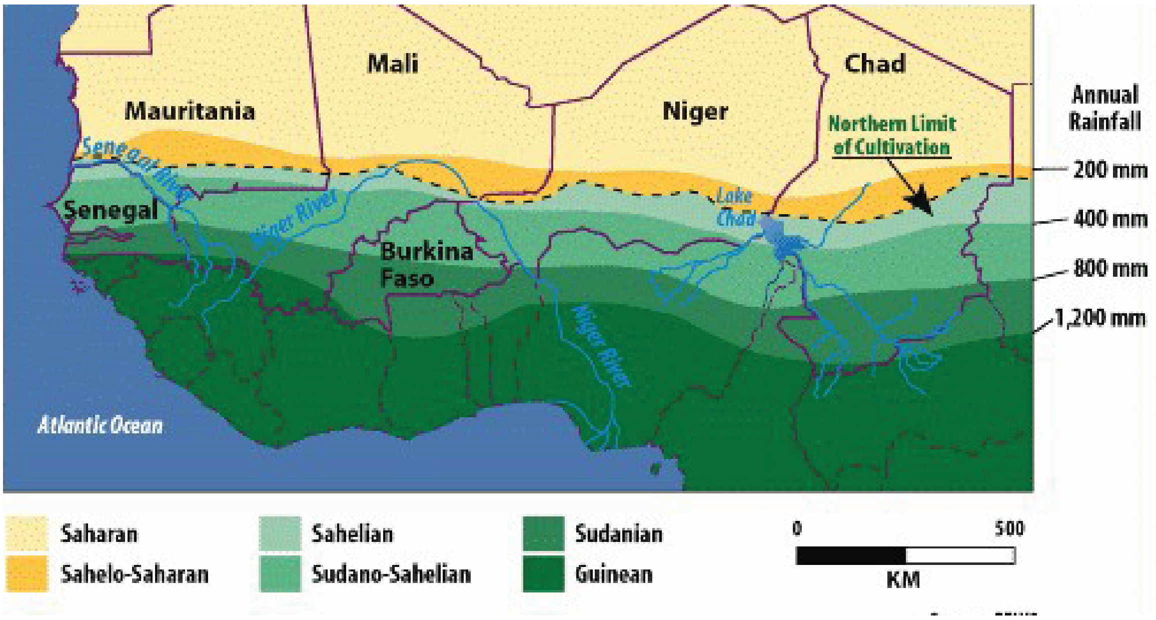

Figure 2. Rainfall limits (mm/year) of sustainable rainfed crops in the Sahel (*Source:* OECD 2005).

The consequence of these recurrent droughts over the past decades is severe food shortages, frequently reported in several of these countries (e.g., Burkina Faso, Senegal, Niger, Mali and Mauritania). The long dry period, which affects the majority of the Sahelian countries in West Africa, results in conditions such as famine, displacement of populations and loss of previously fertile land, which have also created considerable awareness at the national and international levels and are usually described as a calamity.

Land degradation and soil erosion are major causes for concern among farmers in this zone (Roose 1994). In Burkina Faso and Niger, farmers have developed their own soil and water conservation techniques to reduce the ongoing processes of soil erosion and land degradation. Most of these methods are multi-functional and consist of rainwater harvesting and soil water conservation technologies. These technologies reduce soil erosion and at the same time maintain the soil organic matter status as well as the physical properties of the soil. The choice of an appropriate method depends on the average rainfall, soil type and geographical location of the land. In West Africa, rainwater harvesting technologies can be classified into three major categories as shown in Table 1; detailed descriptions of these and many other technologies in Africa have been published (Ngigi 2003; FAO 2001; Drechsel et al. 2005; Barry and Sonou 2003).

Table 1. Classification of Rainwater Harvesting Technologies in West Africa.

A. Non-indigenous rainwater harvesting technologies	**B. Traditional micro-catchment (runoff harvesting technologies)[†]**	**C. Macro-catchment runoff farming technologies**
1. Plowing	1. Rock-bunds/stone rows	1. Bouli[1]
2. Ridge tillage	2. Contour earthen bunds	2. Farmers' micro-reservoir
3. Hilling	3. *Zai/tassa*	3. Micro-sand dams
4. Soil scarifying	4. Straw mulching	
	5. Half-moon[2]	

[†] Zai/tassa (water pocket) is a traditional practice developed by Sahelian farmers and consists of creating holes about 0.2-0.40 meters (m) wide and 0.10-0.25 m deep. Two handfuls of organic amendment such as cropresidues, manure or their composted form are then placed in the pits.

[1] Bouli, the *"bouli"* reservoir is an artificial pool dug at the foot or midway up a slope at a point where there is convergence of runoff and water collected lasts for 2-3 months after the rains and is mainly used for livestock and to irrigate market garden crops.

[2] Half-moon, the technique consists of making a hole in the form of a half-moon, and placing the removed earth on the downhill side.

Four main groups of water harvesting techniques can be generally distinguished: micro- and macro-catchments, floodwater harvesting and storage reservoirs (FAO 2001). Typical micro-catchment techniques found in West Africa involve the delineation of natural depressions, the construction of contour and stone bunds, systems for inter-row water harvesting, straw mulching, *Zai/tassa*, and construction of semicircular half-moons. Macro-catchments include large semicircular and trapezoidal bunds and hillside conduits. Floodwater can be harvested within the stream bed or diverted to the cropping fields. Storage media include underground storage reservoirs such as soil and sediment, and cisterns, and surface storage media like tanks, jars, ponds and reservoirs. Generally, the majority of technologies used in the Sahelian zone of West Africa fall into category B (Table 1). In late 2005, some countries in the Sahel region faced a situation of food insecurity due to structural and circumstantial factors. Recurrent droughts and dry spells led to food shortages and famine and continuous degradation of natural resources due to widespread slash and burn practices; this in turn reduced resilience and increased vulnerability to the next dry spell, in a vicious circle. Therefore, promotion and adoption of these RWH/SWC technologies have the potential to reverse the current trend of increasing food insecurity in the region. The specific objectives of this paper are, therefore, to:

- present research findings on biophysical and socioeconomic benefits of proven indigenous RWH/SWC technologies, and
- discuss the potential for outscaling and adoption of these technologies within the Sahelian region of West Africa.

METHODOLOGY

Two case studies from Burkina Faso and Niger are presented to highlight some successes/"bright spots" in the adoption of these technologies. Three sites were selected in each country, namely, Kirsi, Saria and Pougyanou in Burkina Faso and Sadore, Damari and Kakassi in Niger. All the sites are located in the Sudan-Sahelian zone and are characterized by low soil fertility and erratic and variable rainfall (400–800 mm), as well as limited possibility of increasing cultivable area. These areas are also characterized by a high population growth rate.

Burkina Faso

Burkina Faso is a landlocked country in the West African Sahel. The latitudinal (between 9° N and 15° N) and continental position influences the country's climatic features, making it an intertropical country with a clearly marked Sudano-Sahelian climate. Agriculture is the main driving force of the economy with over 80% of the population engaged in farming, and accounting for 37.1% of the GDP (World Bank 2003). The annual rainfall ranges from 300 mm in the northern part of the country to less than 1,100 mm in the south, and is very erratic and unreliable (Figure 3). According to FAO, rainfall has decreased significantly from the long-term average of 720 mm $annum^{-1}$ to 440 mm^{-1} within the last 20 years. The major soil types in Burkina Faso are Lixisol, Cambisol, Vertisol and Lithosol (FAO 1976). These soils have a strong tendency to seal and crust (Casenave and Valentin 1992).

Experiments were conducted in three stations (see Figure 3):

Saria Agricultural Research Station (12° 16'N, 2° 9'W, 300 m altitude). The soil type is Ferric Lixisol (leached ferruginous tropical soil) with an average slope of 1.5% and with a hardpan at 70 cm depth. According to the United States Department of Agriculture (USDA) system, the textural class is sandy loam in the 0-30 cm layer (62% sand, 28% silt, 10% clay) with a gravel content decreasing from 36% at the 0-5 cm layer to 30% from the 10 cm depth.

Kirsi village, which is about 150 km northwest of Ouagadougou (13° 3'N and 1° 54'W). The soils are characterized by low natural soil fertility, low water holding capacity and soil surface crusting that does not permit water to infiltrate easily. Low soil fertility as well as low and highly variable rainfall with high intensities (130 mm/hr), make these soils highly sensitive to erosion despite the gentle slope (<3%).

The third site was located at **Pougyanou village** (12° 59'N and 2° 9'W) on sealed and crusted bare soils locally called ***Zipellé*** with a slope of 1%. The soil type is Ferric Lixisol with a rooting depth of 30 cm, due to the presence of a lateritic iron pan below the 30 cm depth. The dominant surface crust (more than 60%) is very compact and impermeable. In some places the soil has a gravelly texture with more than 60% of ferruginous gravels encrusted in a thin layer of fine sand. The soil texture in the 0-30 cm layer is sandy loam. The soils are very acidic, poor in organic C, N, and available P, and low in CEC.

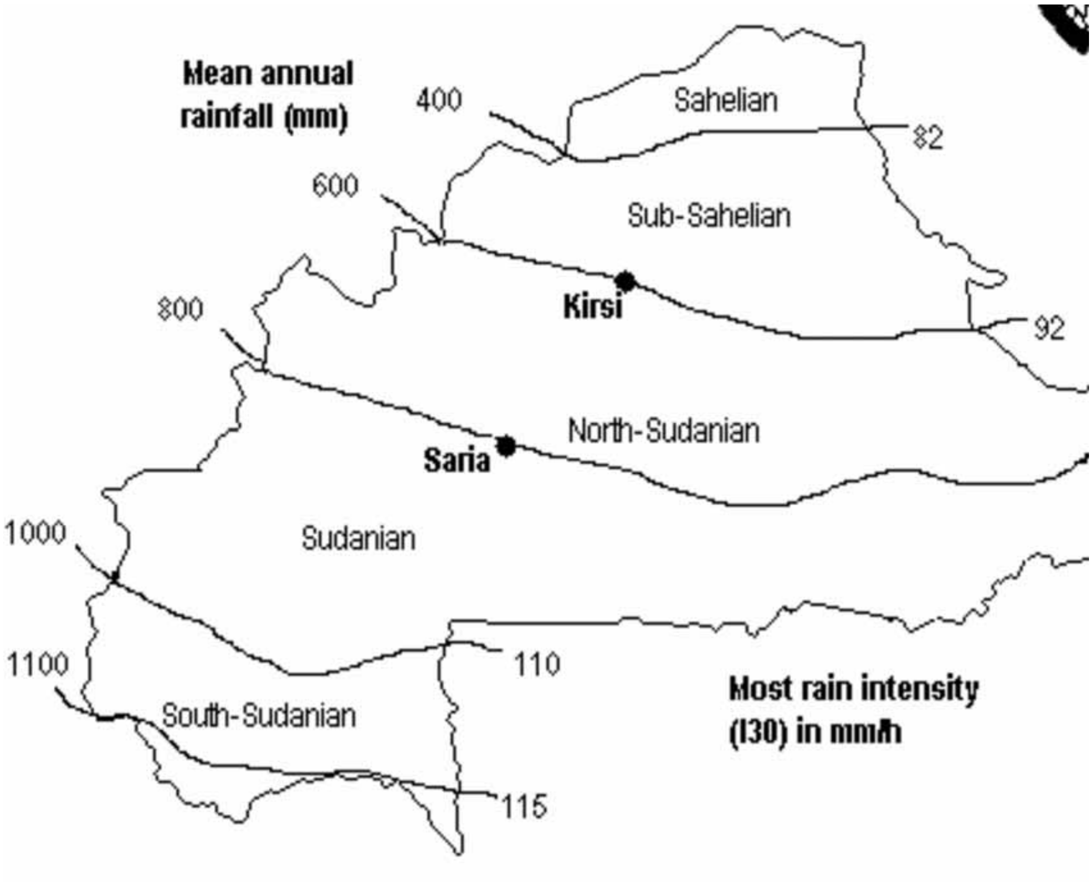

FIGURE 3. Rainfall distribution in Burkina Faso (*Source:* After Guillobez 1996).

The trial at **Saria** was conducted over three seasons (2000-2002) and consisted of two treatments of linear soil water conservation (SWC) measures with three types of nitrogen input. The treatments are: TSR: stone rows, no nitrogen supply, TGS: grass strips, no nitrogen supply, TSRC: stone rows + compost, TGSC: grass strips + compost, TSRM: stone rows + manure, TGSM: grass strips + manure, TSRU: stone rows + fertilizer N, TGSU: grass strips + fertilizer N, T0: no SWC measures, no nitrogen supply (control plot).

At **Kirsi village** the treatments involved stone rows and different levels of spacing as shown below:

Plots	Number of stone rows	Spacing (m)
P1	1	100 (conventional)
P2	2	50
P3	3	33
P4	4	25

At **Pougyanou village**, the experiment evaluated half-moon techniques combined with organic and/or mineral sources of nutrients. The treatments are T_o: control (neither half-moon nor amendments), HM: half-moon without amendment, HM_{an}: half-moon + animal manure, HM_c: half-moon + compost, HM_{cp}: half-moon + compost + BP (rock phosphate), and HM_f, half-moon + BP + NPK + urea.

Niger

Niger is also a landlocked country located between 11°37'N and 23°33'N, and between 0° and 15° E. It covers an area of 1,267,000 square kilometres (km^2), of which 62% is desert or semi-desert. The climate is predominantly Sahelian and dependent on the movements of the intertropical convergence zone (ITCZ). Rainfall distribution is unimodal with large spatial and temporal variability. The rainy seasons fall between the months of May/June and September/October. Annual rainfall varies from 800-900 mm in the southwest to less than 100 mm in the north, with an average rainfall decrease of 1 mm km^{-1} latitude (See Figure 4). The temporal coefficient of variation for annual rainfall (1931-1990) increases from south to north: 17% in Gaya, 22% in Niamey, 27% in Tahoua and 35% in Agadez.

The country has limited surface water resources and, therefore, agriculture relies predominantly on rainfall. The need for efficient water use is becoming even more pressing with the observed decline in rainfall over the last 30 years. As exploiting groundwater resources is expensive, rational use of rainwater for food production is a priority and the sole practical means of achieving food security for the rural population.

The experimental sites were located at (i) **Damari** (13° 12'N and 2° 14'E); (ii) **Kakassi** (13° 50' N and 1° 29' E); and (iii) **Sadore** *(*13° 15'N, 2° 17') (Figure 4). On-farm field experiments were conducted between 1999 and 2000. The experiments were designed to assess the utility of *Zaï* cultivation with regard to resource-use efficiency and to ameliorate crusted soils called "*Zippelle*". The experiment at Damari and Kakassi consisted of *Zaï* and traditional flat planting. The treatments within each planting technique were no amendment (control), crop residues (CR) and animal manure (M). Test crops were either sorghum or millet sown at the beginning of the rainy season.

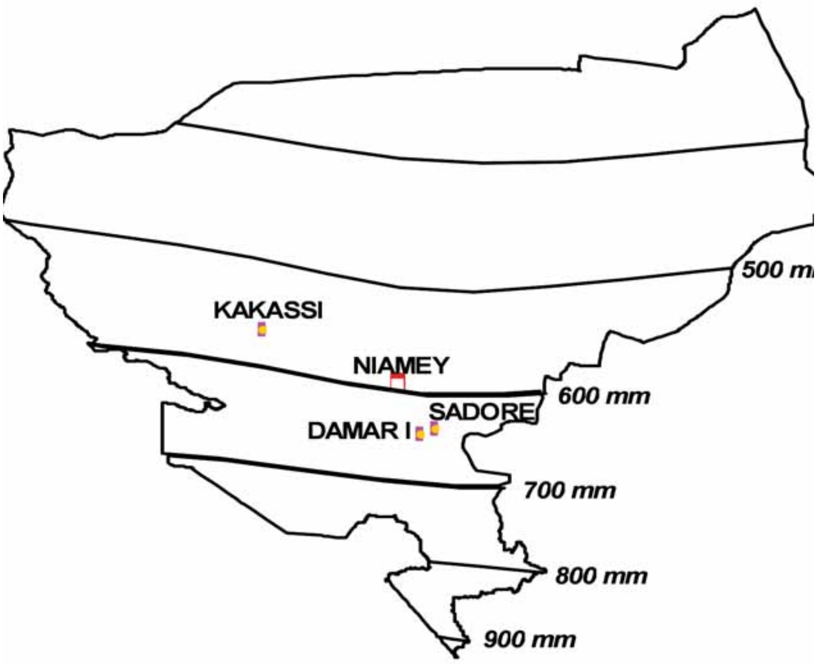

FIGURE 4. Location of experimental sites in Niger.

Ferruginous tropical soils represent the major soil type in all three sites. Ferruginous tropical soils have a sandy texture (on average 87% sand) (ICRISAT 1999) and are easy to till. They have a low water holding capacity and low soil fertility but higher permeability. The long-term average annual rainfall recorded varied between 450-550 mm. These soils have low effective cation exchange capacity (ECEC=2.8 $cmol_+ kg^{-1}$) and a relatively high aluminum saturation (29%) and 61% base saturation. The sand and clay content of the soils is 84 and 13%, respectively; extractable P is 2 mg kg^{-1} and the total N is 116 mg kg^{-1}.

RESULTS AND DISCUSSION

Research findings in Burkina Faso and Niger on improved-indigenous RWH/SWC technologies (biophysical and socioeconomic) as well as the potential for dissemination are presented below.

Research Findings in Burkina Faso

Kirsi village

Results at Kirsi village showed that closer stone row spacing significantly reduced runoffs in the following order: P4=25 cm > P3=33 cm > P2=50 cm > control (P1=100 cm) (Figure 5). The differences in water content between plots at 10, 20 and 40 cm depths were also significant ($p<0.05$) within these treatments (Table 2). At all depths, soil water content increased with decreasing stone line spacing and increased with increasing soil depth. Soil water content in the 0±10 cm layer was 121 g kg^{-1} in P1, 127 g kg^{-1} in P2, 148 g kg^{-1} in P3 and 144 g kg^{-1} in P4. Similarly, water content in P1 was 121 g kg^{-1} for 0±10 cm layer, but increased to 133 g kg^{-1} in the 10±20 cm layer and to 150 g kg^{-1} in the

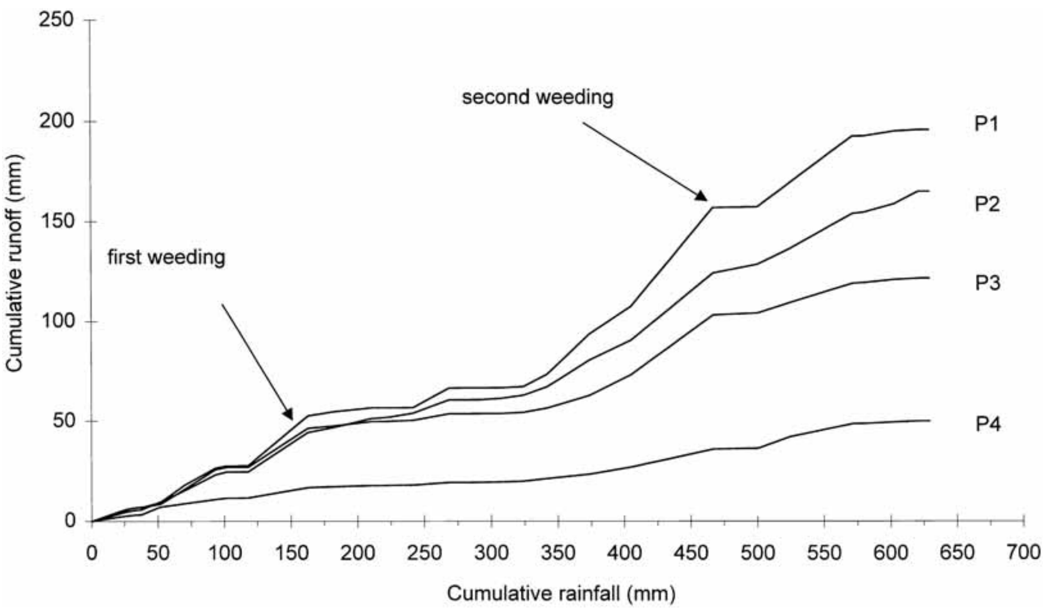

FIGURE 5. Effect of stone lines on surface runoff at Kirsi village (P1, P2, P3 and P4 are stone row spacing treatments defined in the methodology).

20±40 cm layer. Differences were also observed between points at various distances from the stone line. In all plots, the highest water content was observed just behind the stone line (upslope).

TABLE 2. Effect of stone lines spacing on soil water content on September 21, 1993 (g kg-1).

Stone row spacing	Depth		
	0-10 cm	10-20 cm	20-40 cm
P1	121d*	133d	150b
P2	127c	138c	153b
P3	148a	166a	176a
P4	144b	158b	175a
ESE	1.5	2.6	4.0
Significance level	0.003	0.007	0.038
SED	2.1	3.7	5.6
No of samples	24	24	24
CV (%)	1.6	2.5	3.4

Note: *same letter in same column are not significantly different at 5% (DMRT)
DMRT - Duncan Multiple Range Test

The effect of stone row spacing on the grain and straw yields of sorghum is presented in Figure 6. The highest grain and straw yields were recorded in treatments P3 and P4. During the experiment, 470 mm of rainfall was experienced at the experimental site. Furthermore, major dry spells occurred during 1992 for 11 days in the first half of July, 10 days in August and 20 days in September. In 1993, however, 664 mm of rainfall was recorded at the site and the distribution was more even compared with 1992.

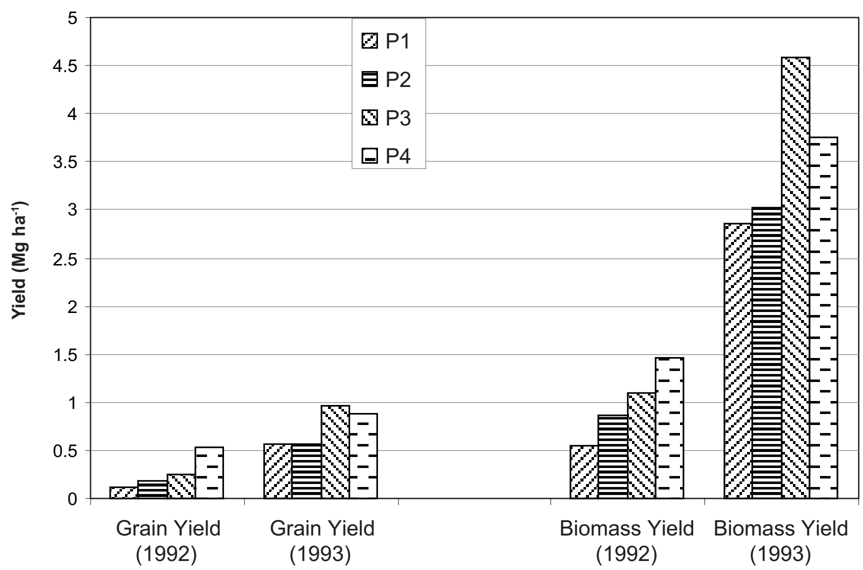

FIGURE 6. Effect of stone row spacing on grain yields of Sorghum at Kirsi village, Burkina Faso.

Assessment of the effect of these stone rows on the soil chemical properties in 1992 and 1996 showed that there were no significant differences in the soil pH (SP), organic carbon (OC), total N (TN), available P (AP) and total exchangeable bases (TEB) in treatments P1, P2, P3 and P4 (Table 3). However, over a long term (four years), across treatments, there were significant differences in the OC, TN and AP contents (Table 4).

TABLE 3. Initial soil chemical properties of the plots at Kirsi village, 1991 cropping season.

Treatments		——— g kg^{-1} ———		—mg kg^{-1}—	—cmol kg^{-1}—
	pH (H_2O)	Organic C	Total N	Available P	TEB
P1	5.88	5.72	0.40	20	4.31
P2	5.64	6.29	0.46	30	4.42
P3	6.17	7.16	0.55	30	4.13
P4	6.28	6.47	0.44	30	4.51
Significance (5%)	NS	NS	NS	NS	NS

Note: TEB - Total exchangeable bases
NS - not significant at 5%

Comparison of results of the 1992 and 1996 cropping seasons showed that after four years of cropping, significant differences in soil chemical properties were observed within the treatments in the following soil attributes: OC, TN, and AP (Table 5).

TABLE 4. Comparison of selected chemical properties at different soil depths**.**

	——Soil depth (cm)——		
	E1*	E2	E3
pH	4.74	4.73	5.09
Organic C (g/kg)	7.1	7.7	7.64
Total N (g/kg)	0.61	0.63	0.63
TEB (cmol/kg)	1	2.06	2
Available P (mg/kg)	6.6	6.7	6.5

Note: *E1=0-10 cm, E2=10-20 cm, and E3=20-40 cm at Kirsi site, Burkina Faso

TABLE 5. Soil chemical properties of the plots at Kirsi village, 1992 cropping season.

Treatments		——— g kg^{-1} ———		—mg kg^{-1}—	—cmol kg^{-1}—
	pH (H_2O)	Organic C	Total N	Available P	TEB
P1	5.42a†	5.1d	0.33c	24d	4.49a
P2	5.15a	5.5c	0.36b	34a	4.86a
P3	5.14a	7.1a	0.45a	27c	5.14a
P4	5.84a	6.4b	0.37b	32b	4.70a

Note: † same letter in same column are not significantly different at $p<0.05$ (DMRT)
DMRT - Duncan Multiple Range Test
TEB - Total exchangeable bases

Furthermore, when the selected soil chemical properties of the initial cropping season (1992) were compared with the final cropping season (1996), significant differences in these properties were observed except in the available P(AP) and the total exchangeable bases (TEB) (Table 6). The smaller the spacing between stone rows, the higher the organic carbon content and higher the water holding capacity. Though chemical composition of soils can vary from year to year or through cropping patterns, the quantities of soil elements may be higher or lower depending on the availability of water in the soil.

TABLE 6. Comparison of selected chemical properties across years, Kirsi village.

Treatments		——— g kg^{-1} ———		—mg kg^{-1}—	—cmol kg^{-1}—
	pH (H_2O)	Organic C	Total N	Available P	TEB
1992	5.99a†	6.41a	0.46a	26a	4.34a
1996	5.39b	6.05b	0.40b	29a	4.79a

Note: † same letter in the same column are not significantly different at p<0.05 (DMRT)
DMRT - Duncan Multiple Range Test

Saria site

Experiments at the Saria station compared the effectiveness of stone-rows and grass strips with and without compost and fertilizer N. During the three years (2000–2003), all treatments significantly ($p<0.05$) reduced runoff compared with the control plots. In the 2000 rainy season, the runoff in treatments with stone rows was always lower than that in the treatments with grass strips (TSR/TGS; TSRC/TGSC; TSRM/TGSM; TSRU/TGSU (Figure 7). This difference in runoff reduction between stone rows and grass strips was 2% in composted plots, 5% in plots with manure and 7% in un-amended plots, but was 19% in plots with fertilizer N. A similar trend was also observed in 2001 and 2002 with greater differences than in year 2000.

Similarly, the effects of these treatments on soil loss in three rainy seasons are presented in Figure 8. Grass strips and stone rows significantly ($p<0.05$) reduced soil loss. The effects of these treatments on the grain yields of sorghum are presented in Figure 9. The results showed that treatments TSRC and TGSC compared with TGS and TSR improved the grain yields of sorghum.

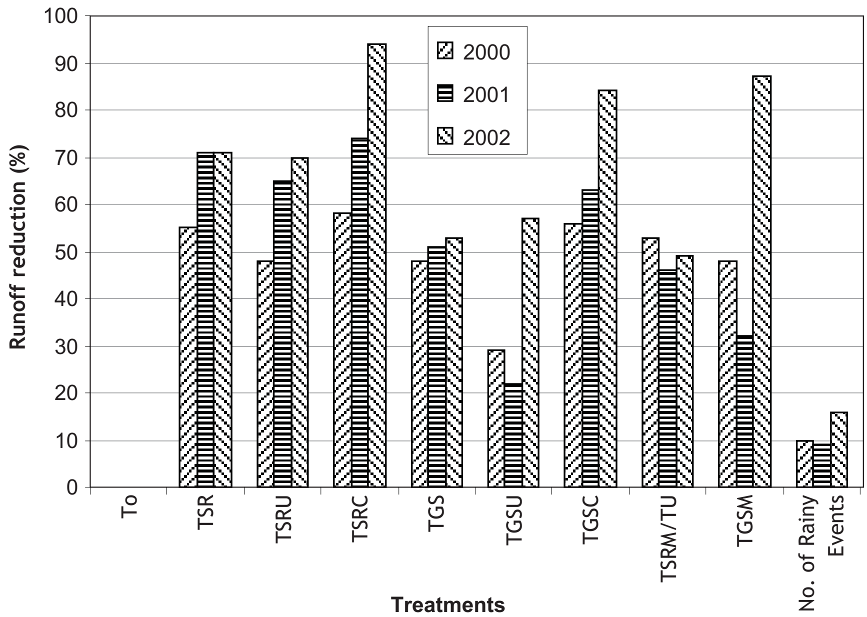

Figure 7. Effect of stone rows and grass strips and treatments on runoff reduction at Saria, Burkina Faso (TSR: stone rows, no nitrogen supply, TGS: grass strips, no nitrogen supply, TSRC: stone rows + compost, TGSC: grass strips + compost, TSRM: stone rows + manure, TGSM: grass strips + manure, TSRU: stone rows + fertilizer N, TGSU: grass strips + fertilizer N, T0: no SWC measures, no nitrogen supply (control plot)).

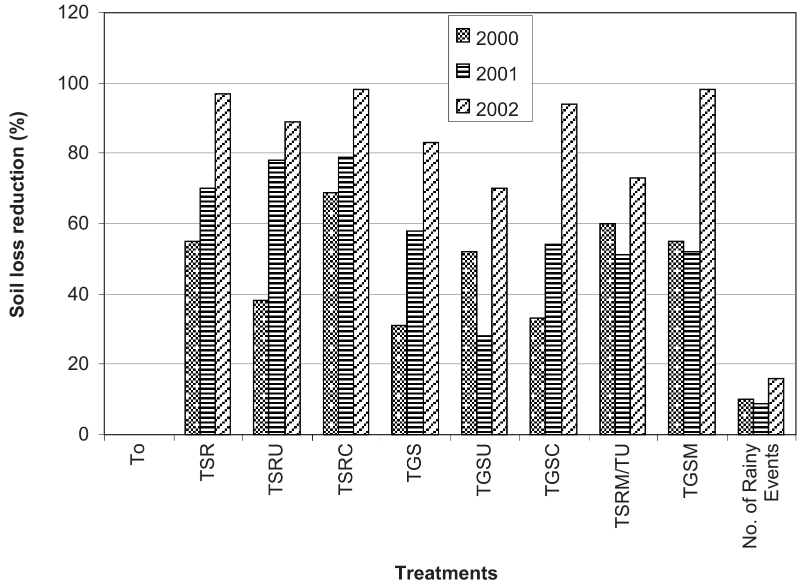

Figure 8. Effect of stone rows and grass strips and treatments on soil loss reduction at Saria, Burkina Faso (TSR: stone rows, no nitrogen supply, TGS: grass strips, no nitrogen supply, TSRC: stone rows + compost, TGSC: grass strips + compost, TSRM: stone rows + manure, TGSM: grass strips + manure, TSRU: stone rows + fertilizer N, TGSU: grass strips + fertilizer N, T0: no SWC measures, no nitrogen supply (control plot)).

These results presented on the utility of stone rows in the Sahel are consistent with those reported by Lamachère and Serpantié (1991) who found that during wet years, the impact of stone rows is not impressive and could even be negative (they measured a 20% loss in production behind stone rows). This suggests that stone row technology would mainly help to mitigate the effect of drought and thereby minimize the risk of crop failure during dry spells. The major process involved in the improvement of crop performance through stone rows is increase of soil water content. Where water is limiting, these results agreed with Reij et al. (1988) that the judicious use of stone row techniques and soil fertility management is a sound means for improving agricultural production in semi-arid zones. Furthermore, the results were consistent with those of Lamachère and Serpantié (1991) and Mietton, (1986), who obtained an increase in crop yield of 30.90% due to the adoption of stone row technology. These studies also showed a relationship between crop yields and the increase in water storage in deep layers (>20 cm) due to stone rows. It was hypothesized that the water stored in the deep layer diffuses upwards during dry periods and is then used by the crop. Furthermore, it is known that water availability increases nutrient uptake and nutrient use efficiency and this could also account for better crop performance on plots with stone rows. Because they slow down runoff, stone rows also cause deposition of organo-mineral particles (sediments), which provide nutrients upslope from the stone rows (Hien 1995; Spaan and Van Dijk 1998).

On the Central Plateau of Burkina Faso, constructing stone rows on the contour is one of the most effective techniques for reducing erosion and increasing water infiltration, while improving yields. About 24% of arable land in Burkina Faso is severely degraded (Kambou et al. 1995). Most of this degraded land is on the Central Plateau, where population pressure has led farmers to cultivate marginal lands and reduce fallow periods. Kaboré et al. (2000) estimated that fields protected by stone rows have an average of 11% higher sorghum (*Sorghum bicolor* (L.) Moench) yields than unprotected fields. Wright (1985) reported a 47% increase in average sorghum and millet (*Pennisetum glaucum* (L.) R.Br.) yields with bund spacing varying from 10 to 50 meters. Vlaar (1992) reports doubling of yields in some cases when stone rows are constructed. Hulugalle et al.

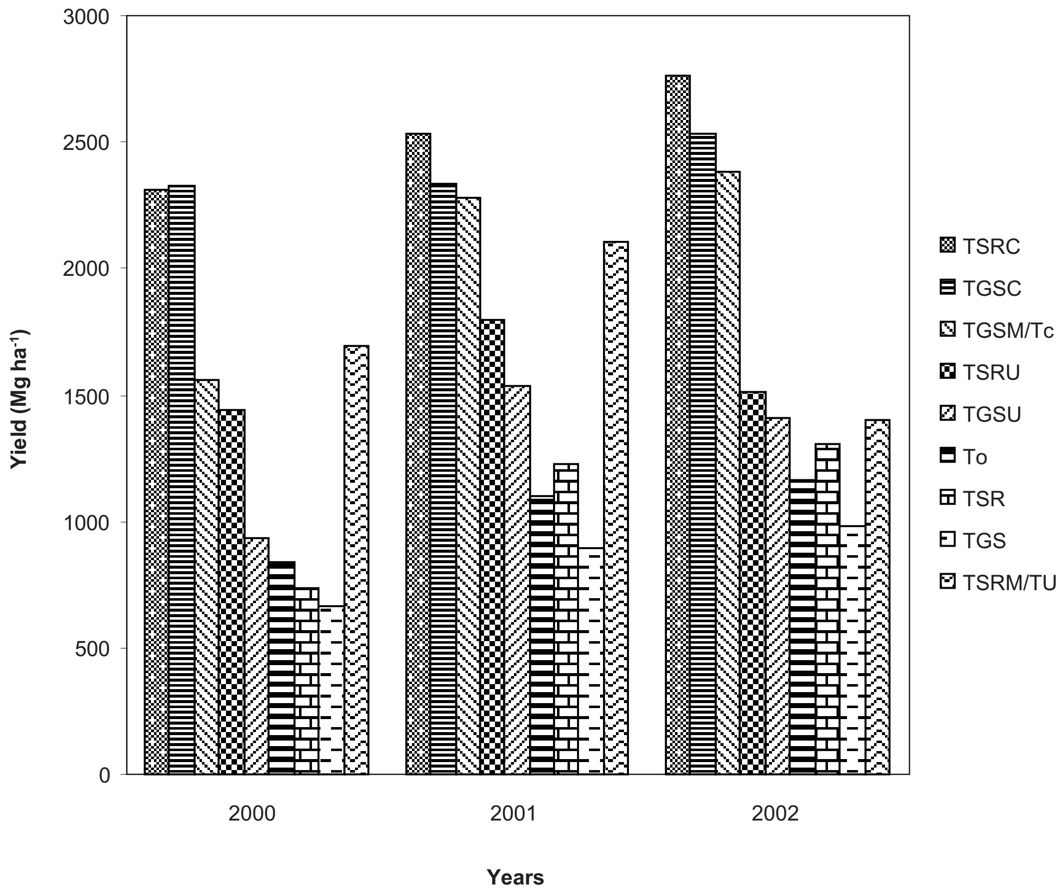

Figure 9. Effect of stone rows and grass strips and treatments on grain yields of sorghum at Saria, Burkina Faso (TSR: stone rows, no nitrogen supply, TGS: grass strips, no nitrogen supply, TSRC: stone rows + compost, TGSC: grass strips + compost, TSRM: stone rows + manure, TGSM: grass strips + manure, TSRU: stone rows + fertilizer N, TGSU: grass strips + fertilizer N, T0: no SWC measures, no nitrogen supply (control plot)).

(1990) and Maatman et al. (1998) indicate that the impact of stone rows is substantially enhanced when combined with other soil and water conservation techniques such as tied ridges and *Zaï*, which is an intensive manure management method.

The drop in soil pH (H2O) between 1992 and 1996 as a result of using stone rows reflected an increase in soil acidity. According to Piéri (1985), under continuous cropping, soil acidity increases due to the gradual replacement of basic cations by aluminum. This acidification was interpreted as a type of soil exhaustion, generally resulting in reduced yields and nutrient bioavailability to plants (Piéri 1985). Organic matter is an excellent indicator of changing fertility of cultivated soils, since concentrations co-vary with physical, chemical and biological characteristics of soil. The decline in organic C from 1992 to 1996 was likely from mineralization (Sessay and Stocking 1995; Bado et al. 1997) and soil erosion (Morin 1993; Roose 1994). The most significant losses in organic C and N were observed in plots P1 and P2, which suggests that the greater the number of stone rows in plots P3 and P4 helped to limit losses by controlling water erosion. Although wind erosion would have been less active than water erosion in this zone, organic C and N losses could have also occurred from loose crop residues blowing away from plots. We can also assume that given the higher humidity in plots P3 and P4, particularly during dry periods (Zougmoré et al. 2000), mineralization would have been more active and rapid in those plots. Ganry and Cissé (1994) stressed that in cultivated ferruginous soils in the dry tropics, organic C in the topsoil is crucial in relation to water balance and nutrient mobility. Total N in soil is very closely linked to that of organic C, and particularly to its net mineralization. In our case, the drop in N concentration was more marked than the drop in organic C, as is often seen in traditional cereal cropping systems without fertilizer application. The organic C and N changes were similar to the results obtained by Van der Pol (1991), who recorded a 30% drop in organic C reserves and 10% drop in total N reserves after 19 years of continuous cropping. Available P did not vary with time. This maintenance of reserves of exchangeable P may be due to a balance resulting from chemical retrogression of P. As there are often considerable internal exchanges between the available and mobilizable reserves (Frissel 1978), the variations in exchangeable base concentrations cannot be considered as changes in reserves. Instead, the concentration of exchangeable elements should be regarded more as an indication of the nutritional potential of a soil. Provided the soil is not exhausted, this potential oscillates around a stable value. This is consistent with Meyer et al. (1995), who found that contour barriers of grass or stone promote sediment deposition by slowing runoff velocity and trapping sediments. Studies by Hien (1995) and Zougmoré et al. (2000) showed that soil water varied depending on position relative to stone rows. Erosion and runoff from upslope contribute to the increase in water and nutrients upslope of stone rows.

Pougyanou site

At Pougyanou, the results of the effect of half-moon treatments on soil chemical properties in 1998 and on soil moisture contents in 1999 cropping seasons are presented in tables 7 and 8, respectively.

TABLE 7. Effect of half-moon practices on soil chemical properties, 1998.

Treatments		——— $g\ kg^{-1}$ ———		—$mg\ kg^{-1}$—	—— $cmol\ kg^{-1}$ ——	
	pH (H_20)	Org. C	Total N	Available P	TEB*	CEC†
T_o**	5.1ab‡	6.4a	0.51b	6.4ab	2.00a	0.10b
HM	4.6bc	5.9a	0.52b	5.9b	2.00a	0.13ab
HM_{an}	5.4a	8.3a	0.72a	8.3a	3.97b	0.15a
HM_c	4.6bc	5.5a	0.54ab	5.5b	2.00a	0.13ab
HM_{cp}	4.6bc	6.6a	0.58ab	6.6ab	2.00a	0.13ab
HM_f	4.5c	5.4a	0.53ab	5.4ab	2.00a	0.12ab

**T_o: control (neither half-moon nor amendments), HM: half-moon without amendment, HM_{an}: half-moon + animal manure, HM_c: half-moon + compost, HM_{cp}: half-moon + compost + BP (rock phosphate) and HM_f: half-moon + BP + NPK + urea

‡ same letter in same column are not significantly different at 5% (DMRT)

*TEB - total exchangeable bases

†cation exchange capacity

Soil moisture contents (mc) in the half-moon treatments (HM, HM_{an}, HM_c, HM_{cp} and HM_f) were significantly higher than the control treatments (To: surface planting with no amendment) (Table 8). In addition, results showed that mc increased with amendments. Grain and straw yields of sorghum for 1998 and 1999 as a result of the various treatments are presented in Figure 10. It is interesting to note that no straw and grain yields were obtained in the control plots. Indeed, the sorghum crop failed because of the harsh environmental and soil conditions (e.g., shallow rooting depth and with underlining compact hardpans).

TABLE 8. Effect of half-moon practices on soil moisture content, 1999.

Treatments	September 1998			September 1999		
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	10-20 cm
T_o**	88b‡	95b	84b	128b	138b	148a
HM	233a	188a	168a	248a	212a	193a
HM_{an}	215a	200a	163a	248a	233a	193a
HM_c	220a	195a	173a	268a	273a	203a
HM_{cp}	213a	225a	195a	255a	215a	200a
HM_f	213a	190a	163a	245a	228a	236a

‡ same letter in same column are not significantly different at 5% (DMRT) (T_o: control (neither half-moon nor amendments), HM: halfmoon without amendment, HM_{an}: half-moon + animal manure, HM_c: half-moon + compost, HM_{cp}: half-moon + compost + BP (rock phosphate) and HM_f: half-moon + BP + NPK + urea)

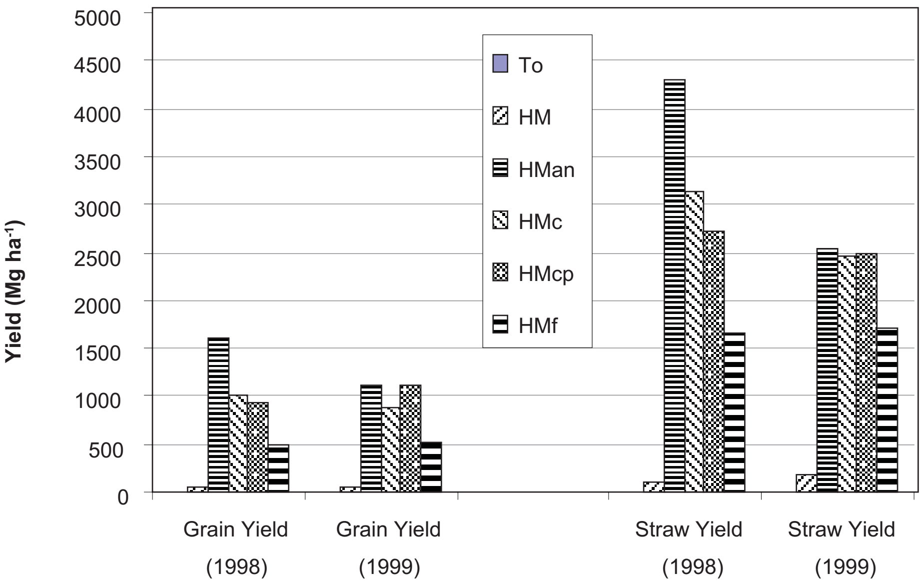

FIGURE 10. Effect of half-moon practices on the grain and straw yields of sorghum (T_o: control (neither half-moon nor amendments), HM: half-moon without amendment, HM_{an}: half-moon + animal manure, HM_c: half-moon + compost, HM_{cp}: half-moon + compost + BP (rock phosphate) and HM_f: half-moon + BP + NPK + urea).

RESEARCH FINDINGS IN NIGER

Selected soil properties (chemical and texture) at Damari and Kakassi are presented in Table 9. Soil analysis of the Kakassi site showed higher total N, effective cation exchange capacity (ECEC) and clay contents, compared to the Damari site. Furthermore, the soils at Damari were acidic in pH.

TABLE 9. Chemical and physical properties of the soils at Damari and Kakassi (0-20 cm depth).

Soil properties	Experimental sites	
	Damari	Kakassi
pH (water)	4.2	6.4
ECEC† (cmol/kg)	2.8	7.9
Organic C (g/kg)	2	2
Total N (mg/kg)	116	169
Sand (g/kg)	840	690
Silt (g/kg)	30	60
Clay (g/kg)	130	250

† Effective cation exchange capacity

Grain yields of millet grown using *Zaï* and traditional flat planting in both sites are presented in Figure 11 (1999 and 2000 cropping seasons). Results showed that grain yields on *Zaï* were significantly ($p<0.05$) higher compared to yields obtained in flat planting. Manure application led to higher grain yields at both locations regardless of the planting technique (*Zaï* or flat planting).

Furthermore, results showed that manure decomposition was slower in the *Zaï* compared to flat planting technique. The *Zaï* planting technique was also noted to increase N, P and K uptake by a factor of 2 to 3 compared to flat planting, especially in plots amended with manure (Table 10). Plant uptake in the *Zaï* was also reported to be higher than the amount applied. Higher P and K utilization efficiency in crop-residues-amended (CR) plots compared to manure-amended plots was observed when millet biomass was considered. Higher N utilization efficiency was also observed in plots with dry spells compared to plots with continuous irrigation when millet biomass yield was considered. Nitrogen utilization efficiency of grain was higher in the *Zaï* compared to the flat planting technique, whereas the reverse was observed with N use efficiency of millet biomass (Fatondji 2002). *Zaï* technique increases N, P and K agronomic efficiency (Table 11).

TABLE 10. Millet N, P and K uptake as affected by planting techniques (*Zaï* versus flat) at Damari, rainy season 2000.

Planting technique	Millet nutrient uptake during the cropping period (kg ha^{-1})											
	25 DAP			67 DAP			111 DAP (Stover)			111 DAP (Grain)		
	N	P	K	N	P	K	N	P	K	N	P	K
Flat	0.28	0.04	0.44	89.1	3.7	78.1	187.2	11.2	303.3	56.0	7.1	14.9
Zaï	0.39	0.04	0.76	75.2	4.5	74.4	161.2	4.0	244.7	139.5	18.9	38.8
$LSD^{\dagger}_{0.05}$	0.17	0.02	0.41	27.7	2.2	37.7	189.5	10.8	307.9	55.9	5.1	14.6

Source: Fatondji 2002
DAP - Days after planting
†LSD - Least significant difference at 0.05 probability level

TABLE 11. Millet N, P and K utilization efficiency as affected by planting techniques (Zaï versus flat) at Damari, rainy season 2000.

Planting technique	Millet nutrient uptake during the cropping period (kg ha^{-1})											
	25 DAP			67 DAP			111 DAP (Stover)			111 DAP (Grain)		
	N	P	K	N	P	K	N	P	K	N	P	K
Flat	28	204	17	35	831	40	88	2,339	58	42	338	163
Zaï	29	259	15	34	608	34	112	5,030	60	45	329	160
LSD[†]$_{0.05}$	4	34	2	8	267	7	30	1,973	16	4	55	11

Source: Fatondji 2002

DAP - Days after planting

[†]LSD - Least significant difference at 0.05 probability level

Water use efficiency during the rainy seasons (1999-2000) varied according to the planting techniques and the type of soil amendment. Water use efficiency using the *Zaï* technique was higher than in flat planting. Furthermore, combining the *Zaï* technique with manure significantly improved water use efficiency in all three sites (Table 12). The *Zaï* technique was observed to enhance soil

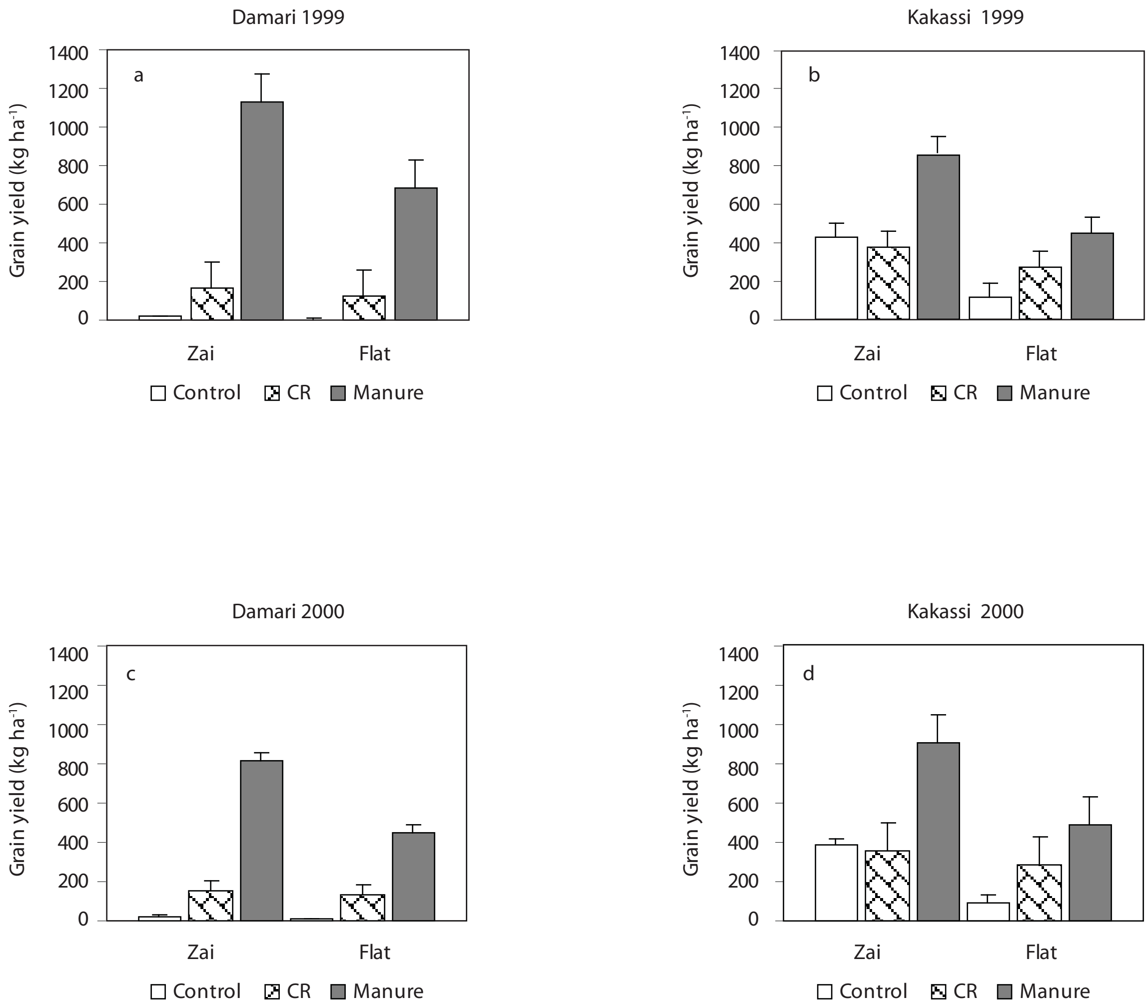

FIGURE 11. Grain yields at Damari and Kakassi (Niger) during 1999 and 2000 rainy seasons.

water storage and increase plant water availability resulting in higher yields compared to conventional flat planting.

TABLE 12. Water productivity of millet as affected by planting technique and type of soil amendment.

Sowing		Based on grain yield (kg/mm)				Based on total biomass (kg/mm)			
		Damari		Kakassi		Damari		Kakassi	
Technique	Amendment	1999	2000	1999	2000	1999	2000	1999	2000
Zai	Millet straw	0.34	0.43	1.19	1.07	2.17	2.09	7.09	5.59
	Manure	2.35	2.28	2.67	2.80	10.43	8.05	16.25	16.25
Flat	Millet straw	0.26	0.38	0.88	0.79	1.63	2.15	4.58	4.02
	Manure	1.43	1.25	1.41	1.38	6.01	5.39	10.32	5.44
	Sed† (±)	0.41	0.19	0.37	0.58	1.29	0.53	2.16	1.88

†standard error of mean;
Source: Fatondji (2002)

Trials at **Sadore** during the 1999 dry season were established to study water use efficiency of the *Zaï* technique under irrigation during the dry season. The experiment was conducted from March to May when air temperature ranged between 35-40 °C. It evaluated the effect of planting techniques (flat planting versus *Zaï)*, under weekly irrigation regimes of 20 mm and 30 mm using sprinklers on millet production. In both irrigation regimes, the progress of the wetting front was more rapid in the *Zaï* compared to the flat planting. Furthermore, rapid progress of the wetting front in the *Zaï* was observed at the beginning of the cropping period in all cases. Towards the period of harvest, however, the volumetric water content decreased, especially in plots treated with manure. In addition, the cumulative drainage at the maximum rooting depth (70 cm) was 140 mm at 65 DAS (days after sowing) in the *Zaï* under the 20 mm water regime. Drainage in flat planting was similar for both amended and non-amended plots. The change in volumetric soil water content in the *Zaï* was different from that of the flat planting technique, due to the water harvesting feature of the Zai technique. Under the 20 mm irrigation regime, 65% of the total irrigation was drained at harvest, whereas in the flat amended plot, only 2% of the irrigation water was lost beyond the maximum rooting depth (Figure12).

Results further showed that water use efficiency (WUE) varied according to the planting techniques and the type of soil amendment. The WUE in the *Zaï* is higher than in the flat planting. Combining the ***Zaï*** technique with manure significantly improved water productivity in all three sites. *Zaï* methods enhanced soil water storage and increased plant water availability, but in soil with low water holding capacity like *Sadore* and *Damari*, most of this water was observed to drain out. As a result of this, it is important to use good quality organic amendment (manure) as it was observed to promote rapid and deep root growth and helped limit water loss by drainage (Fatondji 2002).

Under irrigation, *Zaï* planting produced significantly ($p<0.05$) higher yields than flat planting. Imposed dry spells induced considerable loss in total dry matter yield compared to continuous irrigation regardless of the planting technique (34% yield loss for a 3-week dry spell and 49% for 4-week dry spell in the *Zaï* 34% and 59% in flat planting in 2000). Dry spells affect water storage capacity under both planting techniques, but the effects were more severe in plots not treated with *Zai* (Figure 13). Plants under the *Zaï* treatment were less affected by dry spells. Total dry matter produced by the crop under the *Zaï* treatment after a 4-week dry spell was similar to that of the flat planting technique under continuous irrigation (2,225 versus 2,148 kg ha^{-1}) (Figure 13).

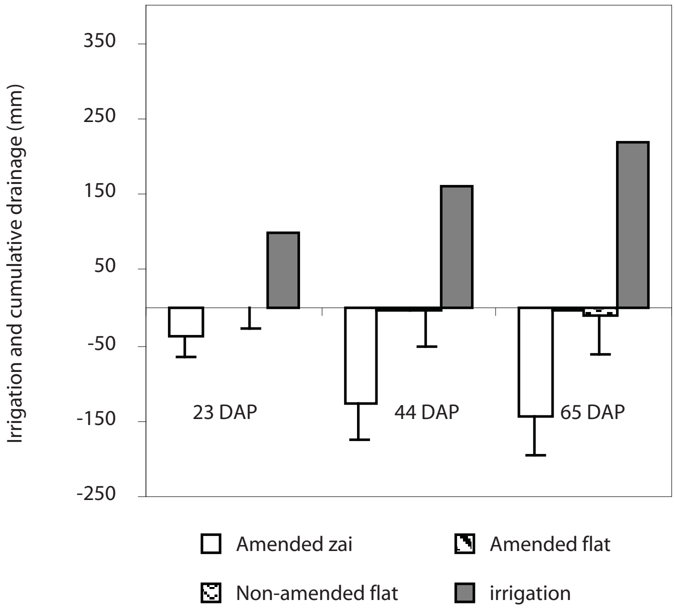

FIGURE 12. Water loss by drainage as affected by planting techniques *Zaï* versus flat planting at Sadore, 1999 dry season (20 mm weekly irrigation).

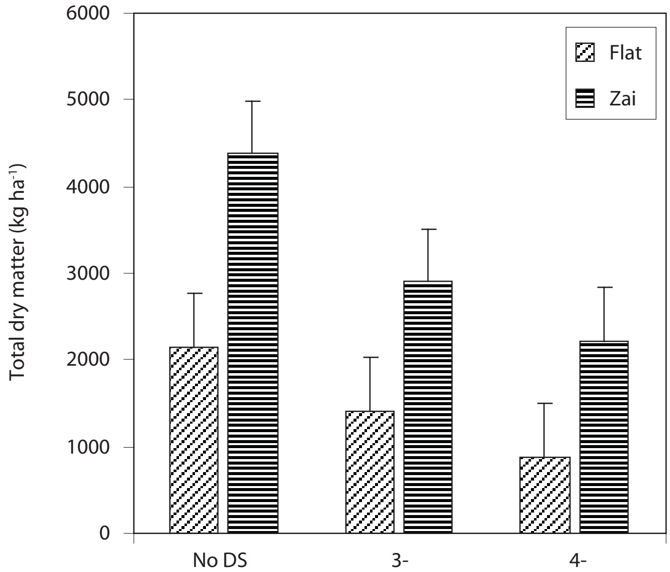

FIGURE 13. Drainage as affected by planting technique under 20 mm weekly irrigations; Sadore, 1999 (3-W.DS= 3 weeks of dry spells and 4-W.DS= 4 weeks of dry spells) (*Source:* Fatondji 2002).

The *Zaï* planting technique was noted to improve rainwater use by a factor of 1.6 compared to flat planting (Fatondji, 2002; See Figure 14). The *Zaï* technique was also observed to increase the nitrate content in the soil layers regardless of the water regimes. Fatondji (2002) also reported that the dynamics of the nitrate contents in the soil profiles suggest higher leaching with the *Zaï* treatment due to a higher rate of infiltration compared to the flat planting technique, especially in the early growth stages of the plant. However, this trend ceases during the active vegetative growth stage which suggests plant uptake.

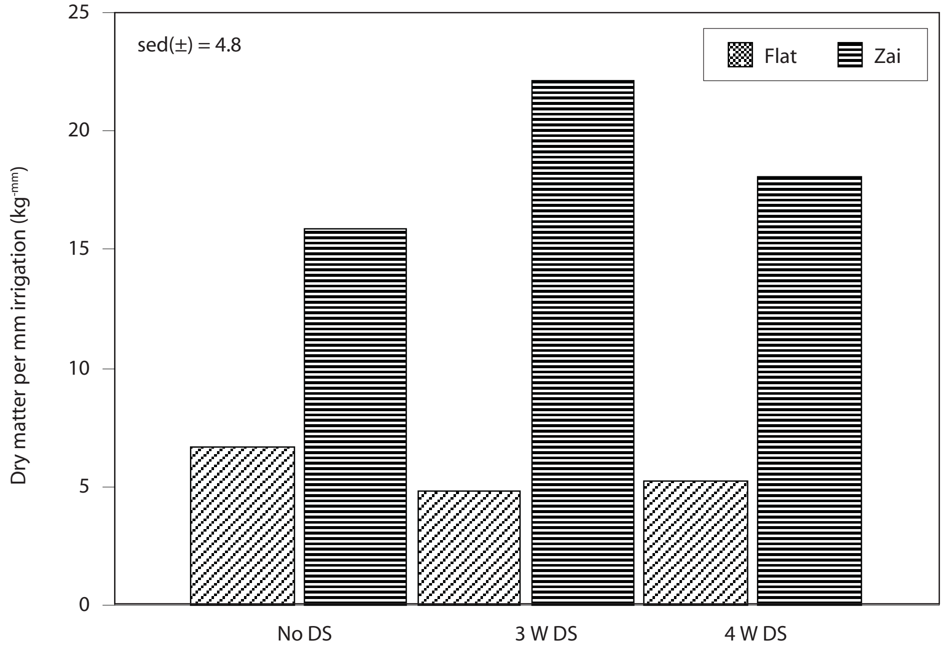

FIGURE 14. Millet water use affected by dry spells (3-W.DS = 3 weeks of dry spells and 4-W.DS= 4 weeks of dry spells) (*Source*: Fatondji 2002).

ECONOMIC ANALYSIS OF RAINWATER HARVESTING TECHNOLOGIES AND IMPACT OF ZAI ON FOOD SECURITY IN THE SAHEL

Economic Analysis

An economic analysis of different rainwater harvesting technologies by Zougmoré et al. (2000), suggests that the NPV (net present value) stone rows on the Central Plateau of Burkina Faso depends on the type of construction, transport cost and organization of labor. Because of high labor inputs, yield increases do not cover the cost of stone row construction in the community project. Stone row construction is only profitable if the investment costs are reduced by providing free transport of stones. Furthermore, crop yield increases in 2001 and 2002 cropping seasons did not cover the annual costs of stone rows or grass strips alone (Table 13). It is, thus, clear that, the construction of stone rows alone (i.e., not combined with the application of nutrient inputs) is not economically beneficial for individual farmers, as grain yield increases do not cover the high cost of construction. In the same region, FAO (2001) reported that the cost of constructing stone rows is too high for the individual farmer. This, therefore, suggests that the construction of stone rows is only profitable if the investment costs are reduced (i.e., if stones are transported free of charge). Results presented in Table 14 show that when sorghum was grown with compost, the economic benefits from sorghum yields in the two experimental years were higher compared with yields from sorghum grown with inorganic fertilizer (urea). When compost and Urea fertilizer were combined with grass strips or stone rows, the economic benefits were higher (Table 15) than when these were not used.

Table 13. Economic benefits of single stone rows or single grass strips in 2001 and 2002 without nutrient amendments.

	Stone rows		Grass strips	
	2001	2002	2001	2002
Annual cost (FCFA ha^{-1})†	48,300	48,300	26,180	26,180
Sorghum average price (FCFA kg^{-1})	140	140	140	140
Minimum yield (kg ha^{-1})	345	345	187	187
Economic benefit (FCFA ha^{-1})	-30,520	-28,140	-54,600	-51,520

ΔY stands for yield increase for stone row or grass strip treatments compared to the control treatment.
†500 FCFA = US$1.00
Source: Zougmoré et al. 2004b

Table 14. Economic benefit of single urea-N or single compost-N in 2001 and 2002.

Treatments	Urea-N		Compost-N	
	2001	2002	2001	2002
N-input cost (*FCFA kg^{-1} N)†	546	546	756	756
Sorghum average price (FCFA kg^{-1})	140	140	140	140
Minimum yield increase (kg kg^{-1})	3.9	3.9	5.4	5.4
‡ΔY/ΔN (kg kg^{-1})	20.2	4.8	23.6	24.4
Excess yield increase (Kg kg^{-1})	16.3	0.9	18.1	19.0
Excess yield (Kg ha^{-1})	813	44	907	950
Economic benefit (FCFA ha^{-1})	113,820	6,160	127,020	133,040

†Nitrogen input cost (in FCFA) per kilogram
‡ΔY stands for yield increase and ΔN for applied N amounts of 50 kg N ha^{-1}
*500 FCFA (CFA Franc) = US$1.00
Source: Zougmoré et al. 2004b

Table 15. Economic benefits of combining stone rows or grass strips with compost-N or Urea-N in 2001 and 2002, Saria, Burkina Faso.

	2001				2002			
	Treatments†							
	T_{SRU}	T_{GSU}	T_{SRC}	T_{GSC}	T_{SRU}	T_{GSU}	T_{SRC}	T_{GSC}
Minimum yield for N inputs (kg ha^{-1})	195	195	271	271	195	195	271	271
Minimum yield for SWC measures (kg ha^{-1})	345	187	345	187	345	187	345	187
Minimum yield for SWC+N input (kg ha^{-1})	540	382	615	457	540	382	615	457
Excess yield (kg ha^{-1})	158	54	821	782	-193	-135	987	915
Economic benefit (FCFA ha^{-1})	22,120	7,560	114,940	109,480	-27,020	-18,900	138,180	128,100

†T_{SRC}: stone rows + compost; T_{GSC}: grass strips + compost; T_{SRU}: stone rows+ urea; T_{GSU}: grass strips + urea;
Source: Zougmoré et al. 2004b

Zougmoré et al. (2004b) reported that installing stone rows or grass strips without the addition of nutrient inputs was not cost-effective, although it induced increases in sorghum yield (12-58%) particularly under a poor rainfall regime (Table 16). Combining compost with stone rows or grass strips significantly increased sorghum yields (mean added effects of 185 kg ha^{-1} for stone rows combined with compost-N and 300 kg ha^{-1} for grass strips combined with compost-N). Economic benefits were substantial (145,000 to 180,000 FCFA ha^{-1}) when compost-N was added to both stone rows and grass strips whereas limited economic benefits were observed with the application of urea-N (1,120 to 62,500 FCFA ha^{-1}).

TABLE 16. Economic benefits of grass strips and stone rows with compost-N or Urea-N in 2001 and 2002, Saria, Burkina Faso.

	Grass strips	Stone rows	Compost	Urea	Grass strips and urea	Stone rows and urea	Grass strips and compost	Stone rows and compost
Grain yield (kg/ha)	848 (-15%)	1,091 (12%)	2,332 (106%)	1,755 (57%)	1,293 (24%)	1,584 (55%)	2,399 (136%)	2,536 (148%)
Straw yield (kg/ha/year)	2,015	2,606	4,304	3,146	2,905	3,646	4,768	4,860
Economic benefit* (CFA/ha/year)	-53,060	-29,330	130,030	59,990	47,530	26,880	171,750	155,790

Source: Zougmoré et al. 2004b; *500 FCFA=US$1.00

Impact of Zaï on Food Security in the Sahel

One of the major constraints to the agro-sylvo pastoral development of West African arid and semi-arid zones is the degradation of natural resources. Cultivated lands are characterized by a gradual loss of structure, hardpan formation, reduced permeability, compaction, inadequate aeration, and limited plant root development (Piéri 1985). Increasing erosion has ultimately resulted in bare and indurated (or hard) soils called Z*ipelle* in Burkina Faso. According to Maatman et al. (1998), about 24% of the country's arable land is highly degraded; in the northern part of the Central Plateau, progressive increase of these degraded soils over the years has reduced the availability of cultivable lands (Figures 15a and 15b). In addition, the soils are described as ferrallitic, and generally poor in nutrients and having low water holding capacity. Although improved traditional planting pits (*Zaï*) have been increasingly used since the 1980s in the Sudano-Sahelian zones of West Africa, there are no reliable recorded yield datasets to illustrate the effects of *Zai* on crop performance. In Burkina Faso, for example, researchers have rarely measured the impacts of these technologies on biomass and grain yields on the same fields for more than two years. Kaboré and Reij (2004), suggest that the influence of inter-annual rainfall variability has not been fully understood. Recently, increasing degradation of land has compelled scientists to document the levels of crop yields grown on degraded lands. It was reported that the number of pits (*Zaï*) per hectare varies between regions and countries. In Yatenga, Burkina Faso, for example, the number of pits varies from 8,000 to 18,000/ha (Hien and Ouédraogo 2001). Elsewhere in Burkina Faso, their numbers range from 23,000–31,000 in Dosin Village to between 46,000–51,000/ha in some villages in the Yako region (Slingerland and Stork 2000).

During an impact assessment of soil water conservation (SWC), agroforestry and agricultural intensification in five villages in the northern part of the Central Plateau of Burkina Faso, farmers unanimously agreed that SWC and, in particular, Z*aï* planting had a positive impact on grain production and household food security (Reij and Waters-Bayer 2001). It was reported that in years of good rainfall, many farmers produce surplus grains, which provide a buffer in years of low rainfall (Kaboré and Reij 2004). A similar picture also emerged in Niger where farm families with SWC produced an estimated grain surplus of 70% in years of good rainfall, while they had an estimated deficit of 28% in years with low rainfall (Hassan 1996). Average sorghum yields in the Yatenga Province of Burkina Faso increased from 594 kg/ha in the 1984-1988 period to 733 kg/ha in the 1995-2001 period as a result of the adoption of SWC technologies such as *Zaï*. For millet, the figures are 473 kg/ha and 688 kg/ha in the 1984-1988 period and the 1995-2001 period, respectively (Reij and Thiombiano 2003). This increase may be attributed to considerable investment in soil and water conservation measures applied during that period. High population densities make fallowing impossible and virtually all lands are cultivated continuously. According to Mando et al. (2001), soil fertility parameters under Z*aï* treatment showed a systematic improvement after 3 and 5 years. For example, organic matter content increased from 1 to 1.4% and nitrogen increased from 0.05 to 0.8%. Soil structure also improved considerably with an increase in its clay content and a decrease in the sand fraction. This is not surprising since pits (*Zaï*) are generally dug on barren, crusted soils which do not allow water infiltration.

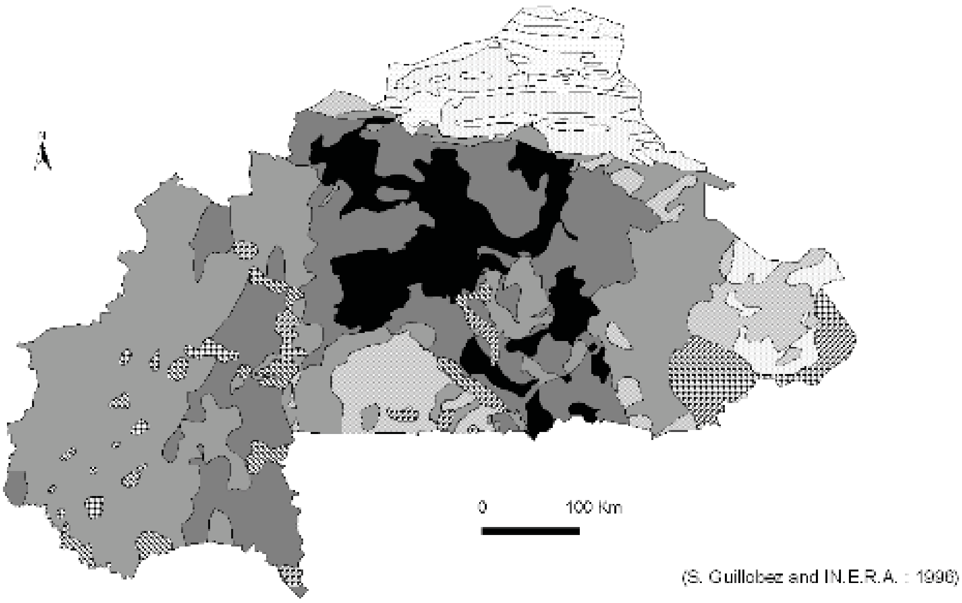

FIGURE 15a. Magnitude of soil erosion from 1985 in Burkina Faso: Impact of soil and water conservation practices (*Source:* After Guillobez 1996).

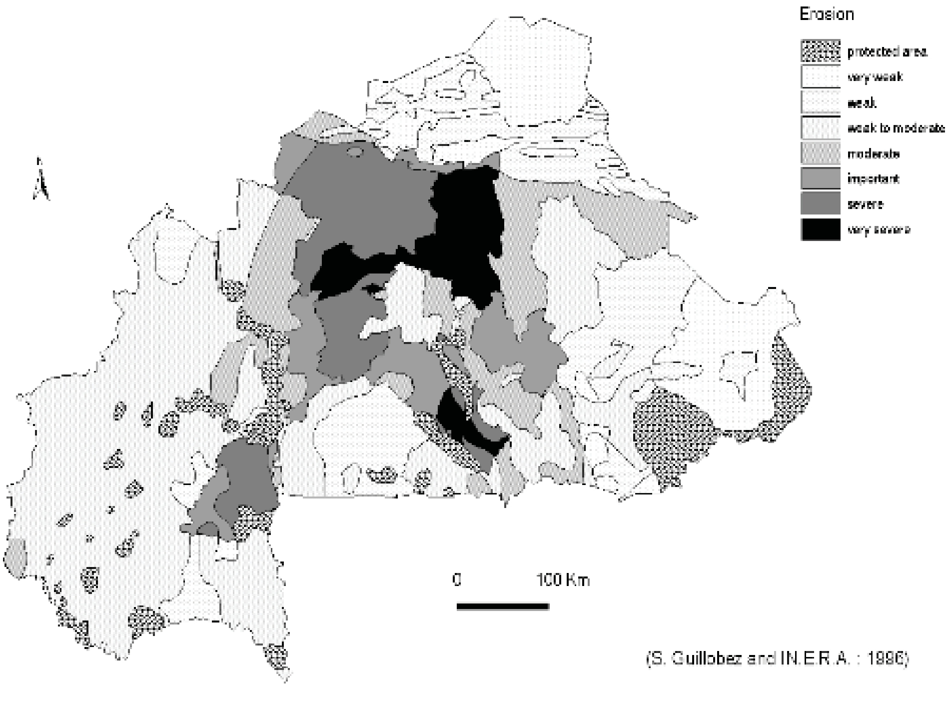

FIGURE 15b. Magnitude of soil erosion in Burkina Faso, 1995: Impact of soil and water conservation practices (*Source:* After Guillobez 1996).

Socioeconomic Impact of Rainwater HarvestingTechnologies

A cost-benefit analysis by the World Bank reported by Gubbels (1994) calculated an internal rate of return (IRR) to investment of 37% using a conservative estimation method. Flexibility in redirecting the content and approach of the research in response to feedback of farmers' needs, and the integration of research and extension by promoting farmer-to-farmer extension, were the keys to success.

In Niger, rainwater harvesting techniques have been introduced to the area of Tahoua, about 650 km northwest of Niamey, through the 1988 IFAD-funded Soil and Water Conservation Project. This densely populated region is located on the border of the desert steppe with sparse vegetation and an average annual rainfall of 400 mm. Severe droughts in the 1970s and 1980s led to degradation of croplands, pastureland and wood resources. The project started in 1988 as a food-for-work scheme comparing contour bunds and half-moons in the Illéla District. Through a participatory approach and especially after several farmers were sent to the Yatenga Province of Burkina Faso to visit various SWC projects, the project completely changed course in the second year. Improved *Zaï* became the first choice of farmers with regard to RWH technologies. By 1990 about 70 ha were under improved *Zaï*; 1,000 ha in 1992 and by the end of 1995, more than 3,800 ha.

The use of improved traditional planting pits (*Zaï*) can be mastered by every farmer, rich or poor (Kaboré and Reij 2004). Yet, the indications are that the "rich" and medium farmers use this technology more than the poor, simply because they have the resources to pay for their labor when needed. The main disadvantage of the Zaï techniques is that they require considerable physical effort. Farmers use soil and water conservation techniques, but only able-bodied people can dig *Zaï* over a large area. Families that are short of labor must pay for the services of the young people's association. *Zaï* construction is hard work and is increasingly being done by hired labor at the rate of 5 FCFA/hole. At current rates, a sorghum field with a sowing density at a spacing of 0.8 x 0.8 m costs 80,000 FCFA/ha (or $130/ha). To reduce the amount of work for digging the holes, the animal-drawn rake IRI2 (mini-tooth) has been developed. This tool is used on dry ground in alternating directions, and the hole is made at the intersection of these scratches. In general, oxen and donkeys are used for traction, and the system is called "mechanized *Zaï*." Land such as sandy or clayey soils in the valley bottom and rice-growing areas are not suitable for *Zaï* techniques. There are also problems with the transport and availability of manure for farmers who have no carts and insufficient livestock.

According to Kaboré and Reij (2004), some micro-level studies showed that technologies such as Z*aï*, stone rows, half-moons, complementary irrigation from micro-reservoirs (Table 17), and other SWC have contributed to increasing food production and reducing rural poverty in several areas of Burkina Faso.

TABLE 17. Yields (kg/ha) of sorghum under different management practices in 1985 at Sabouna with 600 mm of rainfall and an experimental micro-reservoir (*Source:* Dugué 1986).

	Direct sowing	Plowing	Tied ridges
Without irrigation	810	1,114	1,654
With irrigation (92 mm)	1,250	2,060	2,700
Increase (%)	54	85	63

In villages of Ranawa (Burkina Faso), the number of poor families decreased by 50% between 1980 and 2001 (Hien and Ouédraogo 2001). This was largely due to the wide range of RWH and SWC activities undertaken in these villages since 1985, which led to the progressive rehabilitation of about 600 ha of degraded land which became available for food production. The environmental and socioeconomic situation in the village was critical in the early 1980s. Due to recurrent droughts and food shortages, 49 families were reported to have left the village between 1970 and 1980 (25% of all families) and settled in neighboring Cote d'Ivoire or in more fertile and higher rainfall parts of Burkina Faso. However, through the wide use of RWH and SWC technologies, more land is now cultivated and grain yields have significantly increased. This has led to a significant improvement in household food security and a noticeable number of people have come back to cultivate their previously abandoned land.

The Potential for Outscaling of Rainwater Harvesting Technologies in West Africa

Although, many case studies of water harvesting have shown positive results; rainwater harvesting technologies are yet to be widely adopted by farmers. One reason is that most farmers in arid or semiarid areas of West Africa do not have the resources to move large quantities of earth or stones necessary for larger water harvesting systems (Rosegrant et al. 2001). Successful projects such as the OXFAM "Projet Agro-Forestier" in the Yatenga Province of Burkina Faso used a participatory approach, capacity building of the beneficiaries (farmers), and farmer-to-farmer extension approach to get farmers fully involved in developing, testing and evaluating technologies. The project started in 1979 as a forestry project based on micro-catchment-techniques, but farmers were more concerned with improving food production. Therefore, in 1981, the project changed its objectives to increase crop production. Farmers were involved in designing the "improved *Zaï* or composted pits," and had a clear preference for using stone bunds, which is basically a traditional practice (IFAD 1992).

A combination of improved *Zaï* and stone bund techniques has led to a real success of the OXFAM project. Between 1983 and 1991, 4,542 farmers from 406 villages were trained in various techniques such as stone bund techniques, composting, and intensifying animal husbandry to get more manure for soil fertility. Adopting these practices results in an increase in crop yields by 40-100% on improved land management, and the rehabilitation of about 8,000 ha of degraded land. Stone bunds and "improved *Zaï*" are now found everywhere in the Yatenga Province (Burkina Faso) and in the Illéla District (Niger). The potential for expansion of *Zaï* in Burkina Faso and other Sahelian countries in West Africa is considerable, and some expansion has already occurred (Kaboré and Reij 2004). The distribution of *Zai* in Burkina Faso is presented in Figure 16.

In an attempt to evaluate the impact of several RWH/SWC technologies on poverty reduction and improvement in livelihoods, a workshop on Water Conservation Technologies for Sustainable Dryland Agriculture in SSA was organized by IWMI and FAO in 2003 (Drechsel et al. 2005). The workshop documented these technologies, ascertained their geographical spread in sub-Saharan Africa and identified the adoption constraints. Adoption drivers for RWH are summarized in Figure 17); are mainly soil conservation, improved nutrient availability, yield increase, low labor demand, secured land tenure, low capital requirement, low risk perception, and accessibility to information. The highest adoption drivers for RWH technologies are yield increase, soil conservation and improved nutrient availability. Only 10 to 20% of the captured RWH technologies can claim low labor or capital requirements. Secure land tenure is essential for the uptake of 50% of these technologies. These findings are in agreement with those of other authors (See Ngigi 2003; Kunze 2000; and IFAD 1992).

In 1989, an IFAD-funded SWC project in Niger's Illéla District sent 13 farmers on a study visit to the Yatenga region (Burkina Faso) where they observed *Zaï* and other conservation practices. Upon returning home some of them tried these techniques on their own fields and obtained impressive

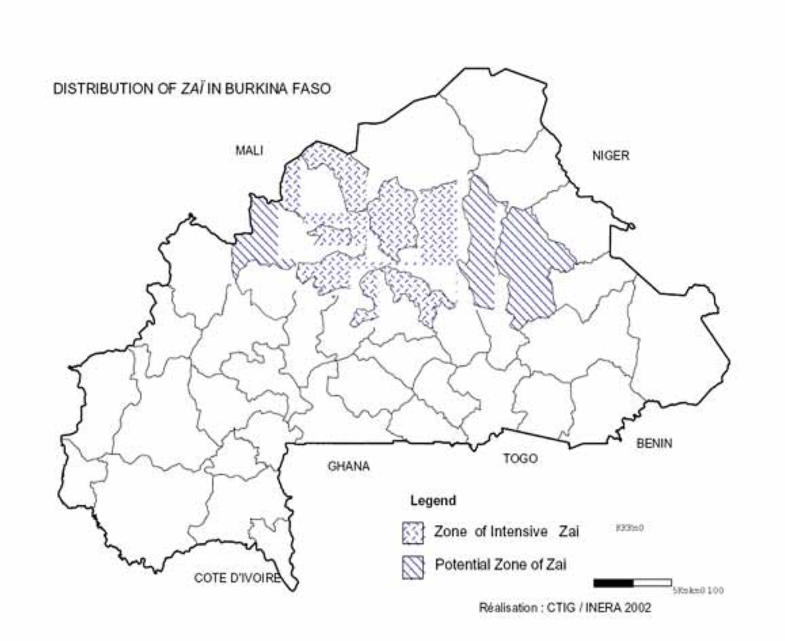

FIGURE 16. Distribution of *Zaï* in Burkina Faso (*Source:* Zougmoré et al. 2004a).

results. As a result of these successes, more farmers started trying *Zaï* (or *tassa* as it is called in the Hausa language) from 1990 which was a year of drought. Observations showed that only fields treated with *Zaï*/*tassa* produced reasonable crop harvests (Kaboré and Reij 2004). From this moment, Zai/*tassa* became increasingly popular in the Illéla District and farmers started buying degraded land for rehabilitation, which resulted in prices for degraded land doubling between 1992 and 1994.

Also, the buying and selling of degraded land in Illéla and in neighboring districts is not an isolated phenomenon anymore as many farmers are involved in the land market (Hassan 1996). Since *tassa* was introduced in Illéla District in 1989 they have spread not only to neighboring districts, but also to other parts of Niger. When asked about the conditions governing prospects for future expansion, Roose et al. (1993) responded that Z*aï* planting functions better in areas with a minimum rainfall of 300 mm and a maximum of 800 mm. With less than 300 mm, the risk of crop failure becomes too high and with more than 800 mm of rainfall, the crop may receive too much water. In addition, the soil surface should be barren, flat and hard, in order to generate sufficient runoff.

Adoption Constraints

There are two major constraints for the adoption of RWH and SWC technologies in West Africa: labor shortage and land tenure. Soil and water conservation activities are influenced by labor constraints because they are usually conducted between January and June, which is the period of intensive vegetable cultivation and harvesting as well as the migration of the most able-bodied villagers. Annual migration patterns of youths from rural areas to urban centers have reduced the availability of seasonal farm labor in many regions emphasizing the temporal importance of labor productivity. A case study of an estimate of labor required for the construction and maintenance of rock bunds is presented in Table 18. The data showed that in each case significant labor input is required but also that different technologies can have very different requirements. Maintenance, on the other hand, requires little input. Consequently, the setup of such “best practices” is a luxury for families who are short of labor unless they can pay for additional help or can exploit the services of the local community.

TABLE 18. Labor input for the construction and maintenance of rock bunds.

Activity	Type of construction	Labor input (person-day/ha)
Construction	Rock bunds	97
	Stone dikes	183
	Stone dams	279
Maintenance	All types	1.7

Source: Kunze 2000

Many farmers are resource-poor and may lack land security; thus, they are unable to invest in the adoption of such technologies. Certain technologies such as SWC are inherently long-term, requiring security of tenure over land for an extended period of time. Even where land tenure security is provided, benefits might only accrue after some years. Many smallholder farmers who apply these technologies on leased land lose the benefit of their investments because the owners withdraw the land for their own use soon. In the case of women’s groups, access to some natural resource management technologies is equally problematic due to the difficulties they face regarding land ownership or acquisition for farming.

Small-scale, low input and long lasting technologies are most beneficial for farmers and are the most promising for achieving sustainable outcomes. This is especially true for small and medium stone construction, terraces, vegetation barriers as well as soil pits and half-moons, the former being more low cost and sustainable and the latter being easier to individually setup and manage (FAO 1999).

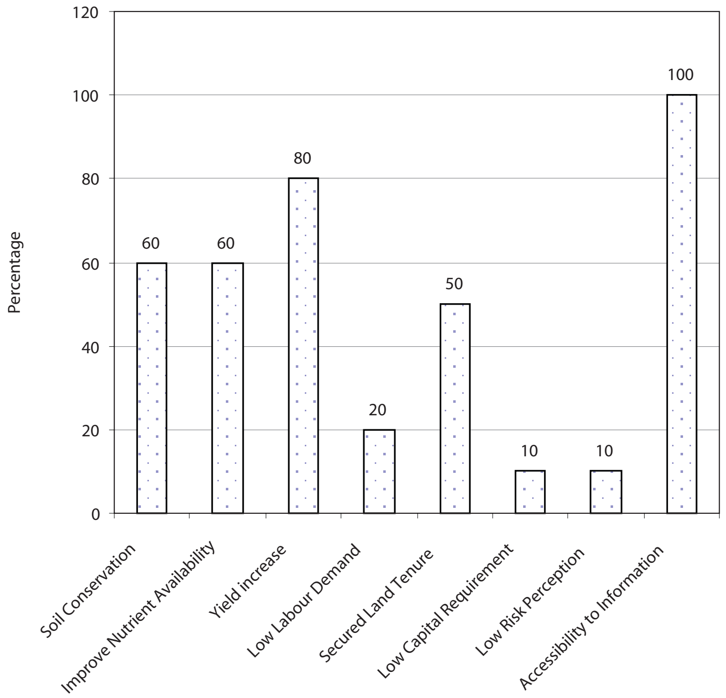

Figure 17. Adoption drivers for RWH technologies in West Africa (*Source:* Drechsel et al. 2005).

CONCLUSION AND RECOMMENDATIONS

Factors underlying the success of technologies such as *Zaï* in rehabilitating degraded land in the Central Plateau (Burkina Faso) are:

- The technology is endogenous and facilities for application are readily available in the area (mattock for digging, manure, etc.),
- The harsh climate and soil conditions create challenges for human survival in the area, and
- The application of this technology occured when there was low competition in labor.

Successful dissemination of technologies such as Zai in the Sahelian zone of West Africa should be based on the principles and practices of adult education, farmer-led experimentation, farmer-to-farmer extension communication and local organizational management. Data from a 9-country survey of 216 NGOs involved in agricultural and Natural Resources Management technology diffusion in West Africa indicates that some of the most important and successful examples of participatory methodologies which can be adopted for outscaling the rainwater harvesting technologies includes:

- The farmer field school (FFS) and Farmer-to-farmer communication programs which have been developed in at least four countries (Ghana, Mali, Burkina Faso and Senegal). FFS covers a range of production systems, from irrigated rice to rainfed cereals, cotton, plantains and vegetables. FFS was introduced to West Africa from Southeast Asia in the mid-1990s, through the assistance provided by the FAO Global Integrated Pest Management (IPM) Facility;
- Community-Based Natural Resource Management (CBNRM). This was introduced through a broad range of efforts (e.g., FAO, NGOs and bilateral assistance). The CBNRM approach has been successfully used within the subregion in the management of soil fertility, grazing lands, water resources, fisheries and wildlife;
- Rural Radio. The rapid growth in the number and diversity of private radio enterprises in recent years, particularly in Mali and Burkina Faso, has stimulated interest in using various mediums to accelerate the dissemination of information on new technologies to rural areas.
- In the Sahel, the choice of technological options that can be used for optimizing rainfall water-use depends on the relative risk of occurrence of climatic or edaphic droughts as well as on the ability of crops to make optimal use of water stored in the soil. If a high risk of climatic or edaphic drought exists, technologies must be applied to deal with this problem first, to ensure that technologies aimed at optimizing soil water use will be profitable. Reducing the risk of drought is not only a matter of ensuring adequate water supply, but also ensuring that this water supply is readily available to crops.
- Technologies for reducing production risks in drought-prone areas are based on runoff water collection or on harvesting and storage of runoff water for later use. They are often combined with the soil fertility management practices. Such technologies include the *Zaï*, half-moon, stone bunds as well as surface management practices as tied ridging and plowing or crop residue management.

- Small-scale, low input and long lasting technologies are most beneficial for farmers in West Africa, and are most promising for achieving sustainable food production. This is especially true for small and medium size stone lines, vegetation barriers, and for soil pits (*Zai*) and half-moons. The former are lower-cost and more sustainable, while the latter are easier to establish and manage individually. Under water-limiting conditions, technologies such as *Zaï*, stone lines, grass strips and half-moons significantly improve soil water content through runoff control and yield two to three times more crop. These technologies can also be harmful to crop production when they create waterlogging conditions. In Burkina Faso, Niger and Mali, improved traditional planting pits and half-moons have made it possible to seriously rehabilitate degraded land and every kilo of sorghum, millet, cowpea or maize harvested in such land is perceived as additional to what they would have otherwise harvested.

- When annual rainfall is well-distributed (as was the case in 2001 and 2002 in Saria, Burkina Faso), installation of stone rows induced limited increases in sorghum yield and grass strips induced a decrease in sorghum yield. These yields were not enough to support the installation costs due to high labor, transport and material inputs. In the Sahel, opportunities exist for making more efficient use of local sources of nutrients such as compost in combination with locally accepted RWH and SWC technologies, such as *Zai*, stone lines, half-moons and grass strips. This may empower farmers to invest in sufficient nutrient replenishment to reverse declining soil fertility.

- Poor families are more likely to benefit from project-supported construction of stone bunds, which are usually done by groups of farmers on blocks of land selected for this purpose. Such blocks of land include fields of small farmers as well as fields cultivated by women. Technology access and usage depends primarily on the socioeconomic conditions of each social class. Generally, men are more involved than women in making decisions relating to water use for food production in water harvesting and irrigation schemes. Women's lack of decision-making power follows from the position of men and women in relation to ownership of land.

- This review of research findings and the results of projects in Burkina Faso and Niger demonstrate the high potential for scaling up several improved-indigenous rainwater harvesting technologies combined with soil water management practices. It is critical in most cases to integrate both: capturing rainwater without improving soil fertility will not have much impact. It is also critical to match the technology to the local climate and soil conditions—building stone terraces or Zai in areas with high rainfall, for example, is counterproductive. It is also absolutely essential to work closely with local communities following a participatory learning process for dissemination of these techniques.

- Finally, we believe that more adaptive research is needed to address three key issues: 1) improving and adapting technologies further to increase cost-effectiveness; 2) pilot testing innovative ways to improve the institutional framework (for example, land tenure) and women's access; and 3) developing ways to help farmers move into higher value crop production in order to improve their incomes and livelihoods.

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