

Why has small-scale irrigation not responded to expectations with traditional subsistence farmers along the Senegal River in Mauritania?

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ABSTRACT

The objective of this paper is to evaluate why small-scale farmers do not persist with irrigation along the Senegal River Valley of Mauritania. Surveys of all households of 12 villages that combine traditional agriculture with irrigated rice production collected information on workload, inputs and productivity of cropping systems together with food requirement and costs in local markets. Analyses revealed that, at the scale of farming attempted, there is no shortage of labor within most households when irrigated rice is combined with traditional rain fall cropping in the wet season and flood-recession crops in the cold, dry season. There is, however, a major limitation to successful combination in the generally negative return of rice production to labor and inputs. While input costs for traditional systems are very small, real costs of rice production (4000 kg paddy/ha) exceed returns in most cases. Farmers only persist with irrigation for as long as the infrastructure functions with minimum maintenance. This explains the observed gradual abandonment of many irrigation schemes unless additional investment is available to repay initial loans and renew infrastructure. While operational, the schemes do add significantly to food security in the villages and offer paid labor to landless residents. Greater yields of rice, greater irrigation water-use efficiency through improved irrigation management, crops that demand less water and more intensive use of irrigated land are options to increase return to inputs. Success here would remove the food contribution from traditional agriculture currently required to sustain irrigated rice production, and establish a continuing and profitable contribution from irrigated agriculture.

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1. Introduction

Mauritania is a large country of 1.03 million km² with a small population of 3.4 million of whom 59% live in rural areas (World Bank, 2011). Low rainfall limits rural settlement and crop production to the south of the country, along the valley of the Senegal River. There, 17% of national land area receives on average, from west to east, annual rainfall ranging between 200 and 500 mm that is concentrated during the wet season (June–September). High temperatures combined with dry conditions in spring and autumn make the climate uniquely harsh (van Keulen and Breman, 1990).

Traditional crops are grown under rain fed conditions in the wet season on land away from the river (known locally as Dieri) and in the cold dry season on low lying land close to the river, as floods

recede annually (known locally as Falo), and in more extensive areas that flood intermittently (known locally as Walo). Average cultivated areas of rain fed and flood-recession crops in the south-west are 42,500 and 13,500 ha (DPCSE, 2009), respectively, representing 13% of potentially arable land of the country.

Irrigated rice was introduced in Mauritania to improve food security following a prolonged period with frequent episodes of low rainfall that started in the early 1970s. Following construction of the Diama Dam near the river mouth in 1986 that retains ample fresh water throughout the year and avoids salt intrusion during the dry season, irrigation schemes were developed on Walo land and protected from flooding by banks constructed for the purpose. One third (40,261 ha) of potentially irrigable area of around 135,000 ha has been developed to irrigation. Of this, 26% is in small and medium collective schemes (<100 ha) managed by associations of smallholder farmers within individual villages (FAO, 2005). Despite this substantial investment, less than 40% of the irrigable area remains in production (FAO, 2005; DPCSE, 2009).

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Despite these developments, Mauritania remains a net importer of cereals. National annual cereal consumption is 545,600 t, i.e. 176 kg/cap (40% wheat, 34% sorghum and maize and 26% rice). Almost all wheat and about 48% of rice are imported (FAO, 2007). *Per capita* cereal production (50 kg/person) is well below African average of 136 kg/person (FAO, 2007).

Various reasons have been proposed to explain abandonment of irrigation schemes, including, high investment for construction, operating and maintenance costs, absence of mechanization for land preparation, sowing and harvesting, low yields related to unsuitable planting dates and inadequate supply of fertilizer and herbicide, lack of extension advice, the mandated concentration on rice production compulsory to obtain credit, and deterioration of the schemes due to lack of maintenance and occasional flooding (MDRE, 1999; Haefele et al., 2001; García-Bolaños et al., 2011). There have, however, been few studies that help identify the causes at a time when international donors continue with development of new, and renovation of existing, irrigation schemes (Connor et al., 2008; Mateos et al., 2010; García-Bolaños et al., 2011).

The aim of this study is to evaluate two, nonexclusive, hypotheses to explain why irrigation has not responded to expectations in many villages of small-scale subsistence farmers. The first is that the workload and calendar of irrigated rice cropping does not fit with traditional rain fed and flood-recession cropping. The second is that return to effort of irrigated rice compares unfavorably with traditional cropping. For either reason, householders would behave rationally by giving priority to traditional crops that are the major supply of household cereal staples. Analyses are based on surveys of workload in traditional and irrigated cropping together with food production, requirement and costs in villages spaced along the length of the Senegal River Valley.

This study is presented at a time when irrigation is regaining attention as means for enhancing food security and hastening rural development in poor counties particularly in Sub-Saharan Africa (World Bank 2008a,b). This renewed interest is based in studies that have reviewed linkages between irrigation and poverty in Asia and some Sub-Saharan countries (e.g. Hanjra et al., 2009). These studies have identified increased agricultural productivity and less inequality (due primarily to more employment, higher wages and cheaper food) as the main pathways through which irrigation contributes to reduce poverty. While many authors advocate that external (namely socio-economic) factors also influence the success of irrigation in arid and semiarid agricultural systems (Rijsberman, 2003; Hussain, 2007), the effect of internal factors such as competition between irrigated cropping and traditional rain fed systems that conform livelihood in the same community have been studied more rarely.

2. Material and methods

2.1. Agricultural systems of target area

The target population is subsistence farmers living by traditional farming practices in small villages scattered on a strip of land, 580 km long and 40 km wide, along the north bank of the Senegal River. A small or medium collective irrigation scheme had been developed in each village in the late 1980s together with a farmers' association created to manage it.

All traditional crops are grown using local landraces without fertilizers or pesticides. Most operations are performed by hand; mechanization is practically nonexistent. In rain fed cropping, polycultures of sorghum (or pearl millet in areas of lowest rainfall) with cowpea and watermelon are sown once or twice after the first soaking rains, usually in July, and are harvested in October. Flood-recession crops are sown gradually during October–November as floods retreat and

are harvested in February–March. Common combinations are sorghum–cowpea on Walo and maize–cowpea on Falo (Ba, 2002).

Irrigation is by flood in small plots managed by individual households with water pumped from the river and delivered by channels according to community agreements. Typical irrigated area managed by individual households is 0.2–1 ha (García-Bolaños et al., 2011). This system was developed for its suitability for rice. Most work is done manually, although in a few instances a tractor may be available to assist in land preparation, particularly in the west where rice is harvested by machine also. Rice cultivars are Sahel 108, Sahel 201 and Sahel 202 (FAO, 2003). Recommended fertilization rates are 100 kg/ha di-ammonium phosphate and 300 kg/ha urea but much lower doses are used in practice (Poussin et al., 2003).

2.2. Surveys

All households of 12 representative villages spaced along the Senegal River Valley were surveyed, 10 in 2008 and two in 2009 (1584 households in total). Survey information was recorded during personal interviews conducted by trained local technicians. Fig. 1 shows locations of all villages and distribution of annual rainfall across the region.

Information was collected on (1) land and crop areas of traditional and irrigated crops and (2) household characteristics, including number of adults, children, men and women active in agriculture, and emigrants. The latter, are members living away who contribute to household funds. Additional information was collected in all villages in 2009 using a stratified random subsample of 10% of each household type as established previously. Detailed information was collected on (3) crop yields, (4) workload calendar by crop and operation, (5) quantities and costs of inputs and investments, (6) household consumption of cereals and pulses (sorghum, maize, wheat, rice and cowpea). A weekly retail survey (7) of cereal prices for rice, sorghum, maize and wheat was maintained from October 2008 to October 2009 in the riverside towns of Rosso, Boghé, and Kaedi to supplement official statistics.

2.3. Analytical procedures

Analyses were made for individual households in each village classified into four groups according to activity in traditional (T) and irrigated (I) cropping, thus providing four categories, viz. 0 (no cropping), T, I, and TI. Derived parameters, included in analyses, were calculated from survey data as follows:

Net production of grain was calculated as gross production less costs including, by religious tradition, about 10% of harvest from traditional crops and 5% of paddy to people who support with their work and to the neediest people of the village. For traditional crops the only other cost is for seed. For rice, additional costs comprise direct input costs for individual crops and annual amortization of the irrigation infrastructure. Therefore two estimates of net production were made for rice, one using direct costs only, the other total costs including amortization.

The costs for rice were calculated as follows: direct input costs are incurred for consumption of diesel fuel, fertilizer, seed, and pesticides, machine hire for harvesting in villages (1–3) of Trarza Region, plus a credit charge of 15% p.a. for 5 months (sowing to harvest). Mean values were calculated and used for the four Regions individually. Amortization costs comprise two components and were applied equally to all irrigation schemes. First, 46,250 UM/ha that includes 15% interest according to national rules (UNCACEM, 2008) for a pump capable of irrigating 20 ha for 4 years. Second, 480,000 UM/ha that over 10 years repays 30% of construction cost, the remainder is government subsidy according to establishment conditions of the World Bank in Mauritania (World Bank, 2005).

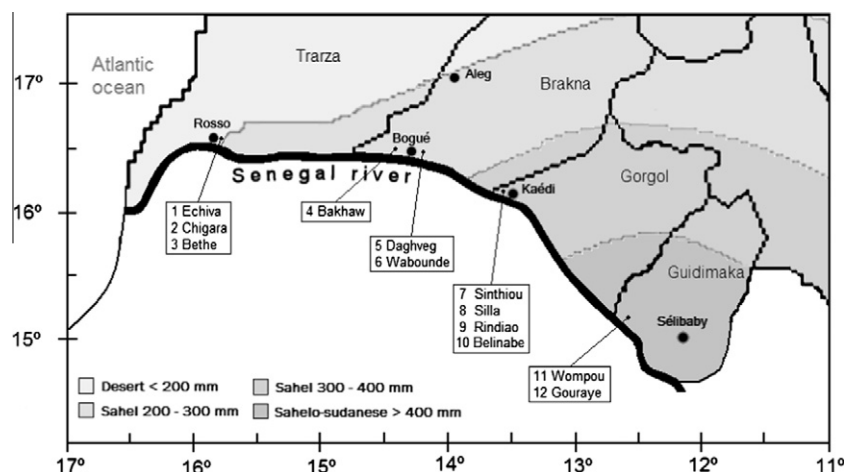


Fig. 1. Rainfall zones of southwestern Mauritania and location of 12 surveyed villages in four regions along the northern bank of the Senegal River. Village details are presented in Table 1.

Ratio of household production of human digestible energy to consumption provides an index of adequacy of food supply in subsistence agriculture. It was calculated from net production based on input costs only and consumption of cereal and cowpea flour. Flour yield, as proportion of grain mass produced, and its digestibility were taken as 0.85 and 14.6 MJ/kg for sorghum and maize, 0.85 and 13.9 MJ/kg for cowpea, and 0.62 and 15.1 MJ/kg for paddy rice (Burgess and Glasauer, 2004).

Return to labor was calculated as the ratio of value of net production to cost of labor at 800 UM/d. Prices received by farmers (selling price) were considered 80% of market price. In this case, calculation of gross production included straw as well as grain, using straw yield at $2.5 \times$ grain for traditional crops and $1.3 \times$ grain for paddy.

Statistical analyses were made using statistical program of R Development Core Team (2005).

3. Results

3.1. Survey overview

The survey sampled traditional farming systems on 1584 ha and 448 ha under irrigation, in 12 villages along the length of the river valley, with a population of 16,328, including 6930 children. Adults active in agriculture numbered 3680 men and 3593 women, i.e. 80% of adults and 45% of all residents.

Crop area varied greatly between villages as presented in Fig. 2, largely reflecting differences in population size. Smallest cropped areas were in villages close to ocean (Trarza Region, west) where reliance on irrigation reflects low rainfall and hence low productivity of rain fed cropping that are combined with relative absence of flood-recession crops due to local topography. Irrigated areas also vary widely between villages (15.5–70.2 ha) but total cropped area per resident is less variable with an average of 0.25 ha. The smallest cropped areas per resident are found in the extreme west (villages 1 and 2) where there is little land for traditional cropping, but also in the extreme east (Guidimaka Region, villages 11 and 12) where villages have large populations. Together, the 12 villages reflect wide variation in food production and dependence on subsistence farming.

3.2. Household types

The distribution of the 1585 households in the survey within the four groups used for analysis is presented for each village in

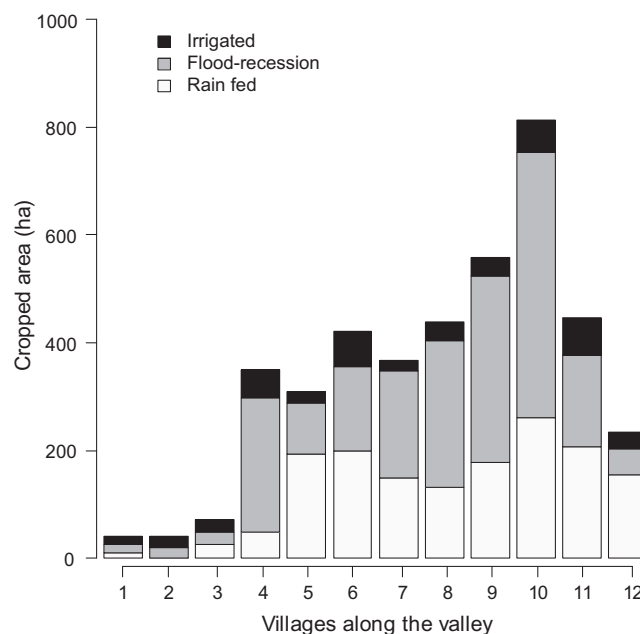


Fig. 2. Areas of traditional and irrigated crops, and total cropped area per resident, in 12 villages along the Senegal River Valley.

Fig. 3. The average proportions of household types, 0, T, I, and TI are 24%, 24%, 5%, and 47%, but with large variation between villages. The most common type is TI while few households practice irrigation (I) alone. The analysis also reveals that villages 1 and 2 in the extreme west have the greatest proportion of households without crops (type 0). To evaluate impact of irrigation on traditional cropping, analyses presented here focus on the comparison between household types T and TI, across the 12 villages in the survey.

3.3. Cropped areas and crop intensity

There are large differences in areas cropped between household types within the villages. The distribution presented in Fig. 4 is positively skewed revealing that few households crop large areas compared to the overall median. Overall, TI households crop greater areas than T households, such that median values for TI and T households are 3.1 and 1.8 ha, respectively. While total cropped

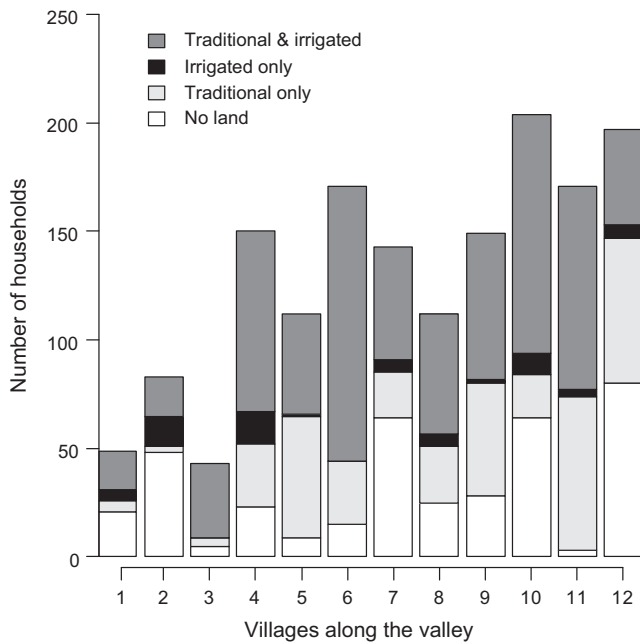


Fig. 3. Distribution of household types, according to cropping activity, in 12 villages along the Senegal River Valley.

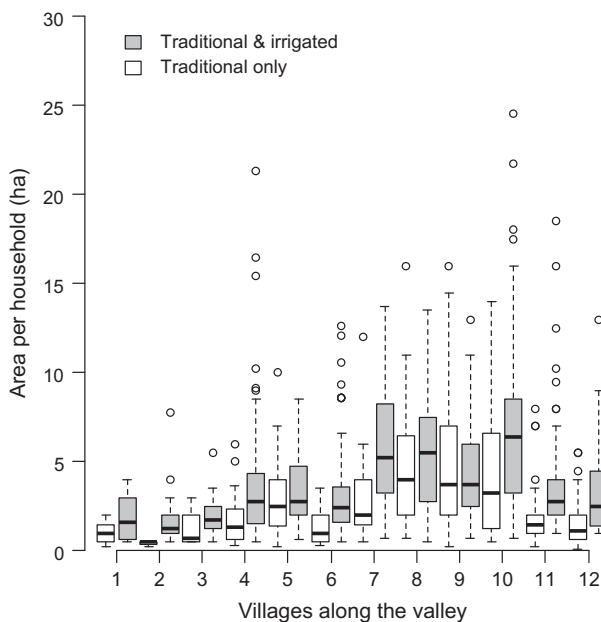


Fig. 4. Cultivated area of households with traditional crops alone (T) or combined with irrigated crops (TI) in 12 villages along the Senegal River Valley. Box plots show smallest observations, quartiles 1, 2 (median) and 3, largest observations, and outliers.

area exceeds 5 ha in one TI household in village 10, it is less than 1 ha in village 2. Median irrigated area per household is 0.5 ha and is relatively constant along the valley because schemes were developed along standard lines to offer irrigation to as many households as possible.

Villagers do not crop all land available to them every year. During the 2 years of the survey, the proportion cropped averaged 0.80 in Dieri (rain fed), 0.81 in Falo and 0.58 in Walo (flood recession). Curiously, crop intensity for irrigated rice at 0.76 was lower than that for rain fed crops.

3.4. Workload in traditional systems and irrigated rice

Analysis of workload in both traditional cropping and irrigated rice is presented in Fig. 5 and Table 1 for successive 15-d periods starting from June 1. Table 1 identifies the individual activities while Fig. 5 emphasizes timing and potential for clashes between competing activities. Interpretation is limited, however, because the survey does not capture variation between years in starting dates for cropping activities. Traditional cropping depends, respectively, on opening of wet season rains and flood recession in the dry season. The start of rice campaigns also depends on opening rains because they facilitate land preparation for planting and avoid costs of pre-irrigation. In practice, however, availability of credit also determines when rice cropping can commence. Data in Fig. 5 do, however, capture the major persistent issues of competition between cropping activities because workload for each operation is stable from year to year.

The data reveal that the two components of traditional agriculture are largely complementary. Work on rain fed land starts with wet season rains (June–July) and harvest is well underway or complete (October) when flood-recession crops are progressively sown (October–November). Traditional cropping lands are often located 2–5 km from villages so considerable time is devoted to transport on foot or by donkey. Overall, annual workloads in rain fed and flood-recession cropping require 115 and 97 person-d/ha, respectively (Table 1). Operations that demand most time are weeding, bird control and harvesting. Analysis in Fig. 5 reveals that maximum area manageable by an active household member is around 0.5 ha in rain fed and 0.7 ha in flood-recession cropping due mainly to requirements for late weeding and bird control in the second fortnight of September (28 person-d) in rain fed cropping and for bird control and harvest in the second fortnight of February (21 person-d) in flood-recession cropping. However, because these operations are well separated in time, the same people may undertake these tasks and in that way one person active in cropping can manage about 1.2 ha over the entire year (0.5 ha in rain fed and 0.7 ha in flood-recession).

Rice, however, adds considerable competition, clashing with sowing and management of both rain fed and flood-recession cropping. Rice planting overlaps with sowing of rain fed crops and rice bird control with thinning and weeding of flood-recession crops.

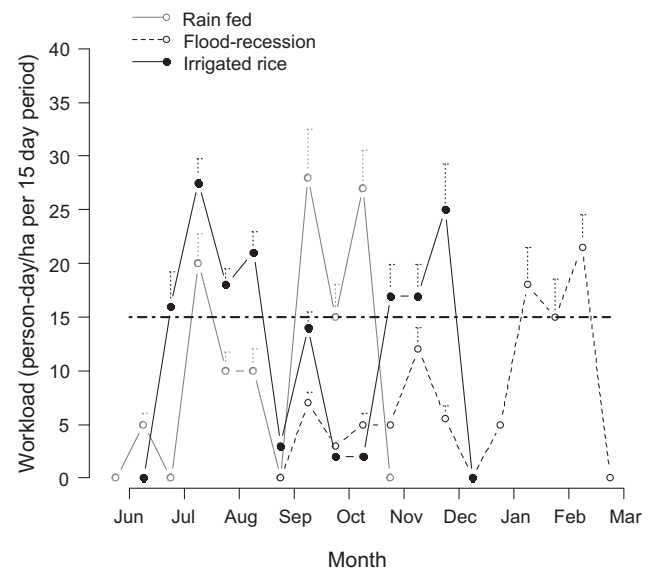


Fig. 5. Average workload (person-d/ha) with standard deviations required in rain fed, flood recession and irrigated (rice) cropping in 12 villages along the Senegal River Valley.

Table 1
Mean and standard deviation of workload (person-d/ha) required in rain fed, flood recession and wet season irrigated rice cropping in 12 villages along the Senegal River Valley.

			mean		SD							mean		SD						
June	Fence building		5	2																
July	Hoeing & sowing	12	2.5									Seed-bed prep., irrigation & seeding	4	1						
	Sowing												7	3.5						
	Weeding	8	3										Dyke maintenance	5	2					
													Basal fertilisation	1	0					
							Pre-irrigation	1.5	0.5											
							Plot tilling & levelling	1	0											
							Irrigation	3	1											
							Transplanting	24	4											
August	Weeding	5	1.5									Re-transplanting	12	2						
	Re-sowing	5	2										Irrigation after transplanting	3	1					
	Weeding	5	1.5										Weeding	20	4					
	Thinning seedlings	5	2.5										Top dress fertilisation	1	0					
September	Weeding	10	2									Irrigation	3	1						
	Stem borer treatment	3	1										Weeding	10	2					
													Irrigation	3	1					
	Bird control	15	6	Residues removal	7	2		Top dress fertilisation	1	0										
October	Bird control	15	6									Irrigation	2	0.75						
	Harvest	10	2										Sowing	3	1					
	Bird control	5	1																	
	Threshing & winnowing	8	2										Sowing	5	2					
	Bagging	2	1																	
	Transport	2	1										Irrigation							
November												Irrigation	2	0.75						
													Re-sowing	5	1	Bird control	15	5		
													Thinning seedlings	6	2	Irrigation	2	0.75		
December												Bird control	15	5						
													Weeding	6	2					
													Weeding	5.5	2.5	Bird control	5	2.5		
																Harvest	8	2		
January												Threshing & winnowing	7	2						
													Bird control	5	1	Bagging	3	1		
													Bird control	15	6	Transport	2	1		
February																				
															Stem borer treatment	3	1			
															Bird control	15	7			
															Harvest	10	2			
			Threshing & winnowing	7.5	2															
			Bagging	2	1															
			Transport	2	1															
Total work load (person-day/ha)																				
RAIN FED		115	FLOOD RECESSION		97	WET SEASON RICE		163												

Fig. 5 displays the high workload during land preparation and transplanting (June–July) and later during bird control (November–December) and harvesting (December). Total workload for irrigated rice of 163 person-d/ha is also greater than for either traditional crop. In the west (villages 1–3, Trarza region), however, rice is sown (broadcast) rather than transplanted and harvesting is done mechanically, workload there is about 85 person-d/ha. Peak activity in rice, except in the west region, restricts manageable crop area to around 0.5 ha per active member mainly due to crop transplanting. In the west, by comparison (villages 1–3), where weeding is the most demanding operation, the corresponding area is 0.70 ha. Also, in practice, rice production requires a dedicated worker full-time.

3.5. Impact of irrigated rice on workload in traditional crops

Farmers who grow traditional crops and rice do report that they prioritize irrigation in response to the large investment they have made in their crops. Therefore, comparison of areas of traditional

crops managed per active member in T and TI households allows assessment of the effect of irrigation on allocation of work capacity to traditional crops. Such an analysis of workload in T and TI households is presented in Fig. 6 using log-transformed scale because the distribution of workload is highly skewed. The horizontal line in the diagram presents full activity per active member (1.2 ha) and so defines when demand exceeds labor available from households, and hence where external assistance is required. Despite the variation within villages, two features stand out. First, TI households have larger areas (more effort) of traditional crops per active member than do those in T households. Overall, the median area of traditional crops managed per active member is 0.7 ha in TI compared with 0.4 ha in T households. Second, workload on traditional crops exceeds the maximum of 1.2 ha per active member less frequently in T than in TI households. The mean probabilities are 0.17 and 0.31, respectively, revealing the frequency when outside assistance is required with traditional crops.

Survey data also reveal that 74% of households without access to land report work in cropping activities. The proportion of active

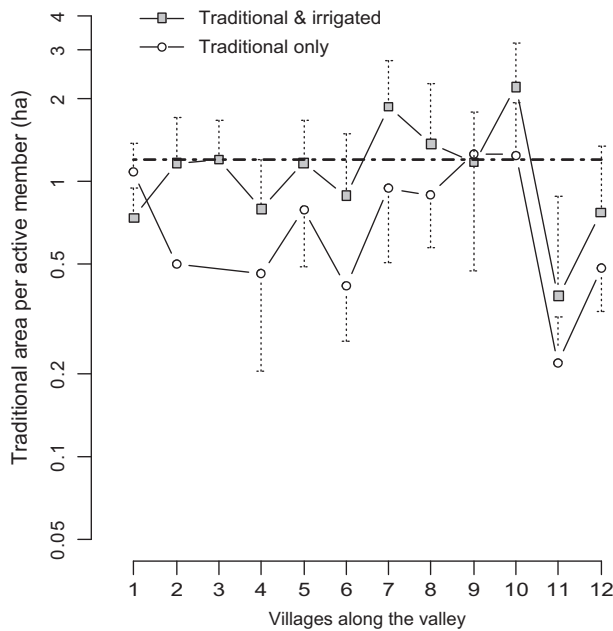


Fig. 6. Average managed area of traditional crops per active member and standard deviations, required throughout the year by households with traditional crops alone (T) or combined with irrigated rice (TI) in 12 villages along the Senegal River Valley. The horizontal line depicts 1.2 ha that is the maximum area of traditional crops that can be managed by one person.

members of such households is on average 48%, which is the same as for other household types. Payment for extra-household labor is included later in analyses of household performance.

3.6. Crop production and consumption

The survey recorded consistently increasing grain yield of rain fed crops with increasing rainfall from west to east (villages 1–12). In Trarza Region (west), mean yields are smallest, 220 and 70 kg/ha for sorghum and cowpea, respectively, but increased gradually through the central regions of Brakna and Gorgol to reach 495 and 220 kg/ha in Guidimaka Region (village 12). Flood-recession crops show similar trends with sorghum yield ranging from 320–600 and cowpea from 96 to 380 kg/ha, respectively, over the west–east transect. Rice crops present a reverse trend in yield, ranging from 3800 kg/ha in west to 3300 kg/ha in east. On average standard deviations of intra-annual yield values were about 62%, 88% and 26% of average grain yields in rain fed, flood-recession and irrigated rice, respectively.

Human consumption is similar for all food items along the valley. Cereals form the household staple food of two meals daily, supplemented by pulses, meat, fish and milk. Midday meals are based on rice and evening meals on sorghum, maize or wheat. Average annual consumption of cereal and pulses per household member is 86 kg of cereal flour (sorghum, maize or wheat), 75 kg rice, and 15 kg cowpea. The daily digestible energy and protein content of that diet is 7.1 MJ and 46.2 g protein, respectively. These values include children and represent a reasonable proportion of energy (61%) and protein (94%) requirements for medium-framed adults of 11.7 MJ and 49 g of protein, respectively (Burgess and Glasauer, 2004). The balance of required nutrition comes mainly from meat and fresh and powdered milk for which the annual consumption is 30, 39 and 11 kg respectively.

Survey data on average crop production costs, without labor, and average market prices for products are presented in Table 2. Comparison of selling prices (80% market price) with costs for

Table 2

Mean costs of production of rain fed, flood recession and irrigated crops relative to surveyed yields and mean market prices for those grains and their straw in four regions of the Senegal River Valley, Mauritania.

	Region (from west to east)			
	Trarza	Brakna	Gorgol	Guidimaka
<i>Costs of production (UM/kg grain)</i>				
<i>Rain fed</i>				
Sorghum	10	7	6	4
Cowpea	64	47	44	19
<i>Flood-recession</i>				
Sorghum/maize	7	7	5	7
Cowpea	51	34	18	12
<i>Irrigated paddy</i>				
Inputs	55	47	49	53
Pump	12	13	13	14
Scheme	13	13	14	14
<i>Market prices (UM/kg)</i>				
<i>Grain</i>				
Sorghum	164	148	165	130
Maize	150	145	163	120
Cowpea	180	160	170	140
Paddy	74	90	89	95
<i>Straw</i>				
Sorghum and maize	32	25	25	12
Cowpea	60	50	50	20
Paddy	9	12	12	5

385 UM = 1 € (<http://www.mauritania.mr/fr/index.php>).

traditional crops, reveal a significant advantage for villagers on cost of food. Sorghum selling prices are 15 times greater than production costs as collected in the survey. Average selling price for rice is 90% of production cost. Average cost of rice production, expressed in kg of paddy/ha, is 2650 kg/ha when only direct inputs costs are considered. If additional amortization costs of pump and scheme, 670 and 695 kg/ha, respectively, are included, the break-even yield is around 4000 kg/ha compared with actual average yield of 3500 kg/ha (3800–3300 kg/ha, west to east).

The ratio of household production of net human digestible energy to consumption provides an index of adequacy of food supply in subsistence agriculture. Here, that ratio, calculated to compare T with TI households in the 12 villages, is presented in Fig. 7. Again, the distribution of data is heavily skewed requiring scale transformation before analysis.

Regardless of variation within villages, the results reveal clearly that, as a sole activity, traditional cropping provides insufficient digestible energy for recorded household consumption. The average probability of success is 0.16, although for villages located in the central region of Gorgol (villages 7–10) the probability is higher at 0.35. In TI households, the food supply situation is improved but still generally inadequate because the ratio of net production to consumption approaches unity. For this scenario, average probability of sufficient household production is 0.20 overall, but is 0.44 in the central villages. The graph also reveals that if rice yield were increased by 60% to 5600 kg/ha (yield achieved in the best performing scheme of the sample evaluated by García-Bolaños et al., 2011, also in 2008), then within the established cost structure most, but not all, households could produce adequate food. For this scenario, average probability of success would be 0.46 and 0.61 in the villages of Gorgol, the central region.

3.7. Return to cropping from inputs and labor

Whereas, traditional agriculture has virtually no cost apart from seed, irrigated rice has significant direct operating costs plus an-

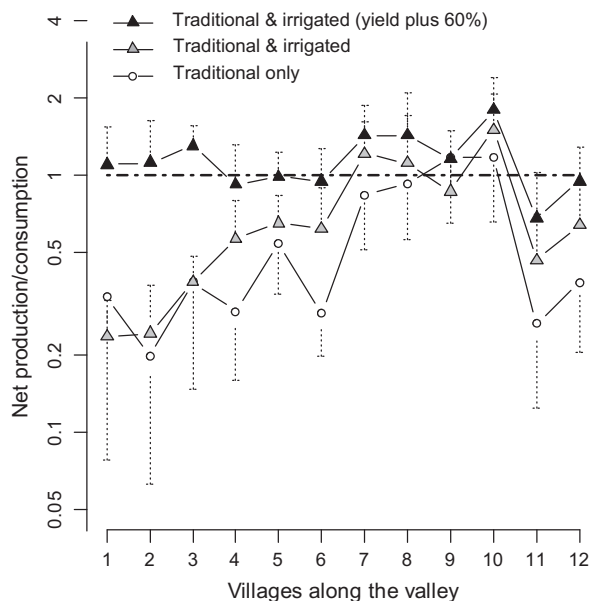


Fig. 7. Ratio of net cereal production to cereal consumption with standard deviations for households in 12 villages along the Senegal River Valley with traditional crops alone (T) or in combination with irrigated rice (TI). The horizontal line depicts equality of production with consumption.

nual amortization costs for irrigation pump and scheme construction. However, even in these subsistence systems it is of interest to evaluate the ratio of net production to labor because it is a measure of the opportunity cost of agricultural labor. Two analyses of return to labor are presented. The first in Fig. 8 compares T with TI households with net production calculated for either total or for direct input costs only. The second in Fig. 9 repeats the comparison for TI households but with paddy yields set 60% greater than currently achieved values. Here, variation within villages is smaller because irrigation dominates total costs and the areas involved are less variable than for traditional crops.

Fig. 8 shows the trend in return to labor. For T households, on average, the return is below cost for the western villages (1–3), po-

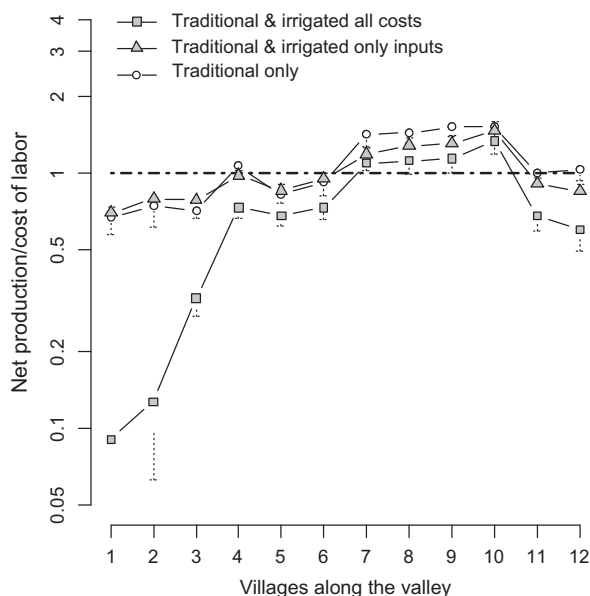


Fig. 8. Ratio of value of net cereal production to costs of production and standard deviations, for households in 12 villages along the Senegal River Valley that practice traditional cropping alone (T) or in combination with irrigation (TI). Rice yields are analyzed at current values with all costs and with input costs only.

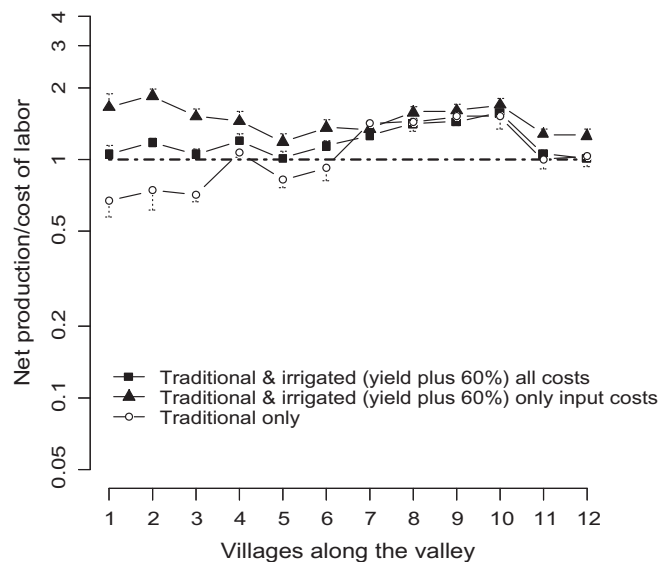


Fig. 9. Ratio of value of net cereal production to costs and standard deviations, for households in 12 villages along the Senegal River Valley that practice traditional cropping alone (T) or in combination with irrigation (TI). Rice yields are analyzed for current values plus 60% with all costs and with input costs only.

sitive for central villages 7–10 and zero for villages 11 and 12. The overall probability of recovering labor cost is 0.52, ranging from a small value of 0.07 in the western villages (1–3) to 0.96 for the central villages. When irrigated rice production at current yield levels and total costs is added to traditional cropping, the result for TI households is always a financial loss, although least in central villages 7–10, with the level of contribution from traditional cropping increasing from west to east as rainfall and productivity of rain fed crops increases. Average probability of recovering labor cost in TI households is 0.26, but almost zero in western villages where traditional agriculture has smallest productivity. By comparison, if infrastructure costs are ignored, TI households perform comparably to T households because under that condition (only inputs considered), the net benefit to irrigated cropping is close to zero. Overall for this scenario, the probability of recovering labor cost is 0.40 but is close to zero in the western villages (1–3) even though the net production ratio approaches unity (value of net production equals cost of labor).

To further investigate the impact of irrigated rice on profitability of TI households, analysis of return to labor was extended to evaluate the impact of increasing rice yield by 60%, again considering direct input costs only or total costs including amortization. The results, presented in Fig. 9, reveal that increasing yield offers major benefits across the entire valley. Return to labor is positive in all locations with the biggest benefits achieved in the western villages where the relative contribution of irrigation to TI households is greatest. Average probability of success while accounting for all costs is 0.80, rising to 0.97 for input costs only.

4. Discussion

4.1. Surveys

This study aimed to extend analysis of interaction between traditional agricultural practices and irrigation made previously in one village (Connor et al., 2008) to other villages along the Senegal River Valley. The objective was to obtain reliable field data to support a broader analysis of development scenarios with a particular focus on the question of why small-scale irrigation undertaken

there alongside traditional cropping has not responded to expectations such that many schemes have been progressively abandoned.

Data are presented from 12 villages that cover the length of the valley and a range of annual rainfall (200–500 mm) that, together with small-scale topography and socioeconomic factors, determine relative distribution and productivity of land resources. The villages are tribal communities with traditions of self-help and auto-sufficiency. Until the advent of irrigation, following the serious droughts of 1970s, farmers survived by traditional activities of raising livestock and cultivating rain fed and flood-recession crops. As activities have expanded to include irrigated farming, the population of the area has increased along with possibilities for non-agricultural activities in larger towns. The resident population in the survey comprises 2.7% of the rural population, 7% of traditional farming and 2.7% of irrigated areas of the south-west region. The mean proportion of household members that are active in agriculture (45%) is quite stable in all household types along the valley and is slightly less than the national average of 52% (ONS/MAED, 2008).

Surveys also identified a substantial number of adult emigrants, i.e. non-resident members who contribute funds to their respective households, 1690 in total, equivalent to 10% of overall population, although with differences along the valley. Households in the central valley had the largest proportion (13%) while the western areas of lower rainfall (Trarza Region) had the least (2%). Overall, households with irrigation have more emigrants than their counterparts without irrigation. The survey was not able to collect information on their financial contributions to households, but it is judged to be the most important source of cash, apart from credit obtained for rice production.

4.2. Traditional cropping

Analyses reveal important features of traditional cropping. First, the high degree of compatibility of workload between its components viz. wet season rain fed and cold, dry season flood-recession cropping. Second, the low productivity of these activities (average 0.3–0.7 t/ha) and reported high variability from year to year, especially of wet season rain fed crops, as supported by simulation studies (Connor et al., 2008). Yield is, however, just one component of production, the other being area of crops established. Here, an important additional feature of traditional cropping is the small area of land that can be managed by hand labor. The survey demonstrates that one person can manage the required tasks of sowing, weeding, protection, and harvest of around 1.2 ha annually by combining compatible activities in wet and dry seasons crops. Consequently, production is also small and variable (360–840 kg/active person) at the mercy of small or late wet season rains and/or failure of flooding.

Despite the differences between households and villages, the survey results reveal clearly that, on average, traditional cropping does not provide auto-sufficiency of grains in terms of human digestible energy in all locations (Fig. 7). Supply is inadequate at both ends of the surveyed transect. The performance of western villages (1–4) is explicable by low rainfall and productivity; in the east (villages 11 and 12) where rain fed productivity is greater, the cause is found in large household size. Despite low yields, the relative return to inputs and labor in traditional cropping is large, except in western villages (1–4), because cost of seed is small and no fertilizer or other agrichemicals are applied. Interestingly, in three decades since irrigation was established, there has been little if any development work on the productivity of rain fed and flood-recession crops, or on range management to improve productivity for grazing, despite activity in related environments. In comparable locations in the Sahel, improved techniques have been evaluated for rain fed (Tabor, 1995; Ouédraogo et al., 2007; Yamoah et al.,

2002; Marteau et al., 2011), and flood recession (Comas and Gómez-Macpherson, 2002) crops. Animal husbandry on common grazing land is the strategy for survival through years of low rainfall in such systems (Kosgey et al., 2008) even though its utility is then limited by low productivity and loss of animals when buffering of household production is most needed. Although not included as part of the present analysis, positive interactions between crop and livestock production for fodder supply and nutrient transfers are recurring themes contributing to success in analyses of small-holder farming systems of Sub-Saharan Africa (e.g. Kaya et al., 2000; Tittonell et al., 2009; van Wijk et al., 2009).

4.3. Combining rice with traditional crops

Reported paddy yields in the range 3300–3800 kg/ha are close to those measured by García-Bolaños et al. (2011), below those recorded in official statistics (4, 6 t/ha, DPCSE, 2009), and well below attainable levels of 8–10 t/ha (Haefele et al., 2001; Wopereis et al., 1999; de Vries et al., 2010). Reports identify the cause of low yields as delays beyond optimal time in farming operations of sowing or transplanting, weeding, and irrigation, often a result of difficulty in accessing credit (Kebbeh and Miezán, 2003). In addition, fertilizer applications are often too small, also contributing to large yield loss (Wopereis et al., 1999; Haefele et al., 2000, 2004).

When irrigated rice is combined with traditional crops there are significant potential clashes with workload, and data presented here demonstrate the extent of that overlap. In order to minimize water demand and assist in preparation of soil, rice cropping commences with the same wet season rains that require quick attention to establishment of rain fed crops. Analyses reveal, however, that there is little evidence of labor shortage in those households that combine irrigation with traditional cropping (Fig. 6).

The average area of 0.5 ha of irrigated rice per household produces around the same human digestible energy as the 2-ha average of traditional farming (1 ha rain fed and 1 ha flood-recession cropping), and with much less year-to-year variability. The workload is, however, considerably less at 82 d (163 d/ha in rice production) compared with 212 d (115 and 97 d/ha in rain fed and flood-recession, respectively). The main problem, therefore, with combining irrigated rice with traditional is not labor but high cost of producing rice at the relatively low yields achieved. When all costs are included, viz. amortization of the scheme and pumping equipment and annual costs of seed, fertilizer and irrigation, average cost of production, estimated at 4000 kg/ha, exceeds achieved yields that according to the survey range from 3300 to 3800 kg/ha from Trarza Region (west) to Guidimaka Region (east). Therein lies the explanation to the lack of success; returns to rice cropping are insufficient to meet the required payments so that, without proper maintenance, condition of irrigation schemes gradually declines (García-Bolaños et al., 2011). As some farmers abandon their land, the challenge of maintenance for those who remain increases until failure is complete. Under those conditions, it is rational for farmers to give priority to traditional crops because the larger areas involved provide around half household food supply. Without intervention by government or donor agencies to forgive debt and ultimately in the form of major rehabilitation, individual schemes are lost to production. Without intervention, contribution of schemes to food security is temporary and during that time, under current systems of production, irrigated rice is subsidized by the much higher relative productivity of traditional cropping to inputs and labor.

4.4. Future directions

Solutions can be found within the current social order by increasing the productivity of irrigated rice, growing alternative

crops that require less water, and additional crops out of the wet season. The key to success is to find irrigated crops, or combinations, that yield more and/or cost less to grow. This will require a major effort to recommence agronomic research and extension activities that have fallen into disrepair.

Greater yield of rice is possible, including during the dry season. Irrigation requirement is a major contributor because cost of pumping water is high, being on average 28% of operating cost. Restriction of paddy rice to soils of low infiltration rate is critical to reduce loss of water to infiltration. Current work in the local area (García-Ponce et al., submitted for publication) has shown the advantage of diversification of cropping using appropriate cultivars of grain sorghum to produce high yields of a valued grain crop at around 60% of the water requirement of rice. But more work is required, including evaluation of double cropping, either in the wet season or extending into the dry season. None of this is new. Analysis of crop performance and in one village (# 10 of this study) made the same recommendations to resolve the poor performance of irrigation there (Connor et al., 2008). In the case of that village, the original proposal to establish the irrigation scheme was predicated on a FAO financial analysis that projected rice yields of 6000 kg/ha and two crops per year.

The analysis presented here provides guidance to further development work by demonstrating that different solutions are needed along the length of the Senegal River Valley. The driving force to crop productivity is the gradient of increasing rainfall from west to east that increases yield of rain fed crops and reduces water requirement of irrigated crops. That also explains the greater profitability of traditional agriculture, alone and in combination with irrigation, in the eastern villages. The likely consequence is the need for different solutions to profitable irrigation along that transect also.

Solutions might also be found outside the current social order. The analyses presented here reveal the need for a change of attitude to development of irrigation schemes. Traditional farmers have demonstrated that they do not have incentive to increase attainable yields and/or extend irrigation into the dry season. The financial analysis explains why that is so at current yield levels, but greater yields are possible and, if achieved, the rules of engagement may change radically. The question is how to achieve that and make better use of investments in irrigation to improve food security with greater and less variable grain production. Perhaps a trained and dedicated irrigation work force is required to better manage irrigation, and seek profitable yields by gradually applying more inputs and with mechanization to optimize crop production practices at an affordable cost to farmers.

5. Conclusions

Analysis of survey data demonstrates that while there are potential clashes and overlaps in the workload of traditional and irrigated rice cropping, the majority of households that combine both activities were working within the capacity of their household members active in cropping. The reason why irrigated rice cropping does not combine successfully with traditional cropping for small-scale farmers in the Senegal River Valley of Mauritania is because it is uneconomic. When all costs are included, viz. amortization of the scheme and pumping equipment, and annual costs of seed, fertilizer and irrigation, the average cost of production was estimated at 4000 kg/ha, which exceeds the achieved yields, according to the survey, of 3500 kg/ha. Therein lies the explanation to the lack of success; returns to rice cropping are insufficient to meet the required payments and maintenance of infrastructure, without which condition of schemes gradually declines until failure results.

Solutions to negative financial impact of rice production on household economy can be found in increasing productivity of irrigated farming, e.g. approaching achievable yield of 8000 kg/ha from the current 3500 kg/ha by respecting advocated planting dates, using suitable cultivars, improving weed control and fertilizer management (Haefele et al., 2001; Poussin et al., 2003, 2006; Saito and Futakuchi, 2009; Traoré et al., 2010); finding more profitable alternatives, including dry season crops; and, changing production systems away from small hand-worked plots to larger, shared areas that can be managed with machinery. Greater yields would also increase returns to labor and investment but this is only possible within an institutional environment that is sufficiently robust to ensure that research, extension and suppliers of inputs and credit function properly. This in turn allows more time for other activities. Otherwise, villagers cannot compete with the low price of imported rice (Seck et al., 2010) and, where land is available, would be better advised to dedicate more time to traditional rain fed or flood-recession crops than continue irrigation under the present system of production and price structure for rice.

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