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Farmer Water Costs and Related Performance in Irrigated Systems: Case Studies from the Sahel

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كلفة المياه للمزارع والأداء المرتبط بذلك في الأنظمة المروية: حالة دراسية من الساحل

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خلاصة: تمت دراسة ثمان أنظمة ري نموذجية في جمهورية النيجر، تفاوتت بين المزارع الكبيرة التي تدار بواسطة الدولة والمزارع الصغيرة ذات الملكية الخاصة والأنظمة ذات الرفع اليدوي، وتم تقييم كلفة المياه الكلية للمزارع، والمكونات المختلفة لتلك الكلفة، وأداء المزارع، ونظام الري المرتبط بذلك وتم الحصول على اختلافات معنوية بين الأنظمة. وقد أظهرت أنظمة الري ذات الكلفة المرتفعة للمياه التي تسمح للمزارع بالسيطرة المباشرة على إدارة المياه فيها، أداءً مميزاً أعلى.

ABSTRACT : In the Republic of Niger, eight exemplary irrigation systems were studied, ranging from large, government-administered perimeters to small, privately-owned, manual-lift microsystems. The total cost to the farmer for water, the various components of that cost, and related farmer and system performance were evaluated and found to vary significantly among systems. Irrigation systems in which farmers incur the highest volumetric costs for water and which allow for greater direct farmer control over system water management tend to exhibit the highest performance characteristics.

The countries of the African Sahel represent some of the poorest of the world in terms of per capita GNP, human development, and natural resources (UNDP, 1994). Niger Republic is a landlocked country located in the agriculturally marginal zone of the West African Sahel, between the Sahara desert to the north (actually occupying the northern two-thirds of the country) and the Sudanic and Tropical climatic zones to the south. The Nigerien government, as well as external donor agencies, have been looking to agricultural intensification as the principal hope for national economic and nutritional sustainability. The role of irrigated agriculture is seen as an important component for attaining this sustainability within the region (Alam, 1991).

When the issue of long-term sustainability in agricultural production is concerned, the *cost to the farmer* becomes paramount. This paper addresses costs incurred by individual farmers for water delivered to the farm. The objective of this study is to evaluate this cost in detail, to evaluate the variation in this cost among existing irrigation systems, and to examine farmer and system performance in response to those costs.

In this context, initial capital costs which are not charged to the local farmer are not considered. All recurrent costs incurred by the farmer (e.g., maintenance of the main-system delivery infrastructure, and privately owned motor pumps) are included in the cost analysis. Costs are given in francs CFA, the standard currency of francophone West Africa. Recently, the FCFA was devalued by 50%, and the subsequent FCFA/$ exchange rate has been around 500 FCFA/$.

Eight irrigation systems typical of the Sahel and representing the major types of irrigation activities in Niger were evaluated. Four of these are small- to medium-scale irrigated perimeters, constructed and administered by the government. The four remaining irrigation systems are small, privately-owned, traditional "microsystems." Most of the field data used in this paper were obtained from studies initiated under the USAID-funded Niger Applied Agricultural Research Project during the 1991-1992 period (USAID, 1992).

An Overview Of Irrigation In Niger

Niger's agricultural zone, which is situated just north of the Niger-Nigeria border in the southern third of the country, receives a highly variable annual rainfall of 250 mm to 550 mm. The area is characterized by an

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8 to 9 month dry season, and a 3 to 4 month wet season in which millet and sorghum are the principal rainfed crops and the primary staple food crops of the sedentary population. While there is some supplemental irrigation activity during the wet season, the dry season period from November through April comprises the principal irrigation season. Irrigated dry season production primarily serves to generate cash income within the rural sector with onion production for export being the most important.

The estimates of total area under irrigation in Niger vary depending on the source (IBRD/FAO, 1990; Norman and Walter, 1993a), but a reasonable approximation is about 20,000 to 35,000 ha. The official estimate of irrigated lands under government-administered systems is about 13,000 ha, although this figure can vary from year to year. The remaining areas, and probably the greater part of irrigated lands, are found within indigenous, traditionally irrigated microsystems, most active during the long dry season.

The reason for the varying estimates of total irrigated area in Niger is the uncertainty of the amount of land under traditional irrigation. This uncertainty is compounded by significant annual variations in total irrigated areas among traditional systems as a result of farmer response to losses (or gains) sustained during the preceding rainfed crop season (Norman, 1995). Since it is usually a very labor-intensive activity, farmers often limit production in the microsystems to that which is necessary to generate the extra cash essential to meet household needs for the remainder of that year (Norman and Walter 1993b).

Principal water sources for these microsystems are the Niger and Komodougou Rivers, and open wells in the *fadama* areas -- low-lying alluvial valleys or natural depressions found throughout southern Niger which are characterized by high water tables at 2 to 8 m. Of these, the open wells are the most common water source for the greater part of Niger's microsystems. They are stabilized in the traditional manner with wood and straw lining or with concrete rings which are often furnished on credit through various in-country development programs. These intensively cultivated systems vary in size from 0.05 to 2.0 ha, with an average size of about 0.1 ha. Water lifting is usually done by one of four methods: manually with a *puisette* or bailer (usually consisting of a short length of rope attached to a half-gourd or *calabash*); manually with a *chadouf* (a counter-weighted balance with rope and bailer attached to one end, constructed with local materials); by animal traction with a *dallou* system (constructed with local materials and employing a wooden frame, leather bucket, and pulleys; or with a small, portable gasoline-powered centrifugal pumpsets of 2.5 to 5.0 hp. Pumpsets, as well as parts and fuel, are usually purchased across the border in Nigeria. Water is usually delivered to small basins within the microsystem through a small network of hand-built, earthen channels with delivery flows on the order of 0.5 to 3.0 liters per second (L/s). Niger's microsystems are almost entirely privately-held, farmer- or household-managed systems. The only outside intervention usually comes in the form of occasional government or donor-sponsored credit programs which provide concrete-lined wells, pumps, fertilizer, and seed.

The introduction of developed irrigated perimeters in Niger since the 1930's has added a management dimension not common to the traditional irrigation subsector. While traditional experience in the management of *single-source, single-user* systems exists among the farming community, there is little traditional experience in the communal management of *single-source* irrigation systems having *multiple-users*. Virtually all perimeters in the country fall into this *single-source, multiple-user* category.

Over half of the land developed for irrigation by the government in Niger is found in rice-producing, pumping systems along the Niger River. These systems are jointly-managed by the government and local farmers. The remainder of developed perimeters are jointly-managed surface reservoir systems within the interior of the country, with the exception of one medium-scale tubewell system. These are administered by the National Office for Hydro-Agricultural Management (ONAHA), the irrigation parastatal agency charged with the development and management of the country's irrigated perimeters. Niger's perimeters are typically small to medium scale systems, ranging in size from 25 to 2,500 ha. Typical individual farmer holdings within perimeters range from 0.25 to 0.60 ha, although cultivated plots in the dry season may be less. Water delivery is through concrete-lined canal networks. The majority of these systems were constructed through foreign financing and at high costs ranging from \$25,000 to \$35,000 per ha in today's prices. Principal crops in these perimeters are sorghum, millet, cowpeas, maize, wheat, and onions. (USAID, 1984; Norman and Walter, 1993a)

Few studies which attempt to examine irrigation water use in detail have been conducted among Sahelian systems (ADRAO, 1985; Keller et al., 1987; Norman, 1991; Norman and Walter, 1993b). In Niger, ONAHA has maintained some records of water releases and related cropping areas among several perimeters, but the accuracy and details of the data vary greatly from perimeter to perimeter. Until recently, virtually no data existed on water use among traditional microsystems. However, several rapid-reconnaissance type studies which address various aspects of irrigation costs have been conducted in the past decade (Hart, 1986; Kohler,

TABLE 2

Characteristics of four private and farmer-managed irrigated microsystems

Region (System Code)	Tarka Valley(E)	Maradi Goulbi(F)	Tarka Valley(G)	Maradi Goulbi(H)
Size (ha)	0.17	0.06[1]	0.13	0.08
Water Source	concrete lined open well	concrete lined open well	2 traditional open wells	traditional open well
Water Lifting	2.5 hp motorized pump	3.5 hp motorized pump	manual with puisette	manual with chadouf
Pumping Head	2.9 m	6.1 m	2.0 m	5.8 m
Crops	onions	onions	onions	onions, carrots, lettuce

[1]This value represents the farm area monitored. Actual farm irrigated area is approximately three times this area.

pumps (E and F) for water lifting from open wells, while the other two (G and H) employed the puisette and chadouf manual lift methods. Microsystems E and G were selected among those found in the lower Tarka Valley -- an onion-producing region where 400-600 ha or more are irrigated within microsystems each year. Water is lifted manually among the majority of these microsystems.

Microsystem G was irrigated by direct hand lift from two shallow, open wells. Since this area usually floods at the onset of the wet season and is subsequently planted in sorghum as a flood recession crop, most traditionally constructed wells must be re-dug by hand each year. Usually, while one person is lifting water (generally an adult) a second (often a youth) distributes water to channels leading to small irrigated basins, of about 1.5 to 3.0 m^2 each. Typical pumping rates in this microsystems were about 0.6 L/s.

The physical layout and water distribution method used in microsystem E were essentially the same as for microsystem G. Microsystem E, however, made use of a small motorized pump and a permanent, concrete-lined well. Concrete-lined wells are preferred with pump use since rapid drawdown can cause poorly stabilized wells to collapse, and storage volume within the well is usually greater than the unlined wells. Generally, only one person is needed to irrigate this type of system, as once the pump is running the operator is then free to divert water among basins. Typical pumping rates in this system were about 1.8 L/s.

Two microsystems were also selected in the Maradi Goulbi in which water tables tend to be considerably lower than that found in the Tarka Valley. Water is lifted in microsystem H with a chadouf, which provided average flows of 0.6 L/s. Two persons are needed to lift and distribute water similar to microsystem G. This system made use of one traditionally constructed well, which usually has a life of 4 yr. Microsystem F used a motorized pump and concrete-lined well, with a typical flow rate of 2.0 L/s.

Methodology

For each of the systems studied, a field assistant was placed at the site on a full-time basis throughout one growing season. This provided the opportunity to monitor all systems and farmer activities on a daily basis as they occurred. Full-time monitoring began with land preparation and planting, and culminated after the last irrigation and harvest were complete. Crop market values and labor wage rates were also monitored, and a detailed farm activities calendar was maintained. At the end of the season, yield measurements were taken of each irrigated crop in the monitored areas. Most of the data retrieved during the field study that were not measured directly in the field were obtained through both formal and informal surveys among the local farmer population at each study site. Based on these data, variables characterizing irrigation water costs and related farmer performance were determined. All data were collected during dry season growing periods.

IRRIGATION SUPPLY AND CROP WATER DEMAND: In the two reservoir systems, the main release gates at the head of the principal canals were calibrated and discharges were then recorded. Records were kept at the River perimeter by a government agent. At Djirataoua, two representative tubewells and their associated delivery areas were selected and monitored. At each tubewell, daily electrical consumption, pumping h, and areas irrigated were recorded. The groundwater table was monitored on 10-day intervals and discharge rates of each tubewell were calibrated accordingly.

For the microsystems using small motorized pumps, all starting and stopping times were recorded to determine time of operations. Discharges were monitored at 30-min intervals.

All starting and stopping times were also recorded throughout each day of irrigation in the two microsystems employing manual water lifting methods.

On 15-min intervals, the number of puisettes (bailers) raised and discharged over a 2-min period were recorded. On 30-min intervals, two full puisettes were weighed. From these data, average discharge rates for the day were calculated. Water table depths were also recorded.

System losses (both operational and seepage) were measured between the water source and its delivery point at the farmer field. (Thus, such losses only apply to perimeters and not to microsystems where water is discharged directly to the field.) Perimeter operational losses were monitored on a daily basis while canal seepage loses were determined by the ponding method where representative canal sections are blocked, filled with water, and the depletion rate is then measured.

Electrical conductivity of irrigation water (a measure of salinity) was monitored in all systems to determine leaching requirements. Water quality was good in all the systems except the two in the Tarka Valley.

The actual irrigation supply (I_s) to the farmer (i.e., to the field level) was determined using the above water delivery data. Percent seepage losses and leaching requirements were included where applicable.

Studies have been conducted in the Sahel, including Niger, to determine maximum evapotranspiration values for irrigated crops in the region (Charoy, 1971; CTGREF, 1979). Crop water requirements were determined from these maximum crop evapotranspiration values which relate to a healthy crop grown under optimal soil water and fertility conditions achieving "full production potential", and were applied to the observed season length of each crop in the system studied. System water losses and leaching requirement were then added to crop water requirements to obtain an irrigation demand value (I_d) for each system.

ENERGY/PUMPING COSTS: This study was limited to the costs related to getting water from its source to the farmers's field. For this reason, the energy and/or labor costs involved in lifting and conveying that water represent the primary variable costs considered in this study. Tubewell system (D) electrical power consumption was monitored, and at both the river and tubewell perimeters (C and D) power consumption rates were recorded from monthly utility bills. The two pump microsystems (E and F) were monitored using a fuel-filled bottle (the type normally used for medical intravenous applications) suspended above the pump and attached directly to the carburetor intake with plastic tubing. Fuel consumption, rpm, and flow rates were simultaneously recorded. Local fuel costs were monitored throughout the season. Costs for manual lift systems (G and H) were derived from monitored daily time expended by the farmer for water lifting and from equivalent labor wage rates in the local vicinity.

LAND TAX OR RENT: Every parcel holder within government-administered perimeters must pay a seasonal *redevance* or perimeter tax, as a function of the area he cultivates. The *redevance* is recalculated after each season based on the actual costs incurred. This fee varies among perimeters and from season to season, but generally covers the costs for all collectively used inputs such as energy, repairs and up-keep within the perimeter, equipment depreciation, and part of ONAHA's operating cost. Thus, all recurrent costs to perimeter farmers which are related to the delivery of water from its source to the farmer's field are covered by the *redevance*. However, no direct charges are applied to the quantity of water used. For perimeters C and D, which have pumping systems, the associated energy costs usually account for an important portion of the *redevance*. For this reason they are separated from the seasonal *redevance* and included in the energy/pumping cost component. (Most individually used inputs such as seed, plowing services, farm labor, pesticides, and fertilizers are purchased individually and are not included in the *redevance*. Since these production costs are not related to farmers' access to irrigation water, they are not included in the water cost calculation for perimeters.)

Some microsystem farmers do not own land in zones favorable to traditionally irrigated production where the water table is high. In the dry season when their rainfed holdings are not being cultivated, these farmers often pay a seasonal rent for a plot (usually belonging to another local farmer) in order to gain access to irrigation water. In such cases, this rent is included in the water cost calculations formicrosystems.

INVESTMENT AND DEPRECIATION COSTS: Investment costs for privately-owned microsystems include the cost of pumps, material for water lifting devices, and the construction of wells. Motorized pump costs include maintenance and replacement every 4 yr. A well life of 10 yr was set for concrete-lined wells, 4 yr for traditional wells in the Maradi Goulbi, and a life of only one season was given to traditional wells in the Tarka Valley. (These figures, which were obtained through farmer surveys, correspond well to those obtained by Hart, 1986 and Keller et al., 1987.)

Among perimeters, the initial costs of construction and the original provision of equipment (pumps, etc.) were not incurred by the farmer and are therefore not considered. Equipment depreciation is included as a small part of the seasonal perimeter *redevance* and is therefore covered in the land/tax cost component.

TOTAL FARMER WATER COST: Farmer cost per unit of irrigation water actually delivered to the field during the study season is given as

$$C_w = \frac{E + N + (R*A)}{I_s} \qquad (1)$$

where,

C_w	=	cost of water FCFA/m^3
E	=	cost of energy or labor, FCFA
R	=	land tax or rent, FCFA/ha
N	=	investment and depreciation costs, FCFA
A	=	area irrigated, ha
I_s	=	observed irrigation supply at the field level, m^3

This variable (C_w) describes the actual cost the farmer incurred during the growing season, as a function of observed irrigation supply (I_s).

OPPORTUNITY COSTS: The assumption is made in this study that during a typical irrigation season the need (or incentive) to recuperate invested capital has a more critical and immediate effect on farmer performance than does the forgone opportunity of the investment (Ellis, 1988; Paris and Herdt, 1991). For this reason, opportunity costs are not included in the principal estimation of water costs (Equation 1) in this study. However, general comparisons are made in the discussion of C_w with, and without opportunity costs included. When this is done, the opportunity costs -- for initial investments, labor and non-labor inputs -- is assumed to be equal to 50% of the average investment for the crop season. This 50% reflects the estimated opportunity cost of private capital in rural areas of Niger. Opportunity costs are calculated according to the method used by Keller et al. (1987).

PERFORMANCE VARIABLES: Several variables were selected to provide measures of system performance in relation to the cost of irrigation. One performance variable is irrigation efficiency (EFF), a standard irrigation engineering variable relating crop water demand to the actual amount of water supplied (Burman et al., 1983). This is given in percent as

$$EFF = \frac{I_d}{I_s} * 100 \qquad (2)$$

where,

I_d	=	estimated crop water demand (and leaching requirement) at the field level, m^3

Since the demand and supply components are taken at the field level, the EFF variable primarily reflects water management practices of the individual farmer, rather than of the system as a whole. A minimum irrigation efficiency of 60% is often included in the design of surface systems to accommodate for crop water needs and anticipated losses. Efficiencies below this value would normally be considered unacceptable, while values above 100% may indicate that maximum potential crop yields are not being attained. Leaching requirements were added only to microsystems (E and G) in the Tarka Valley as necessitated by well water quality.

A second performance variable is the labor allocated by farmers to water distribution within their fields (L_d). The cost of labor to *distribute* that water is not included in the C_w variable. The L_d variable serves as an indication of what farmers are willing to expend (in terms of labor) based on the relative "value" of the water they pay to have access to. This variable is defined as

$$L_d = \frac{T_d}{I_s} \qquad (3)$$

where,

L_d	=	water distribution labor allocation, h/m^3
T_d	=	total hours of labor allocated to distribute I_s within the field, h

A third measure of performance (production benefit, P_w) is derived from the market value obtained by farmers for crop production (Rao, 1993). Yields at harvest are taken with the produce market value obtained by farmers to obtain the total value of the season's production. This value is then divided by the amount of irrigation water used to produce the crop. Thus,

$$P_w = \frac{Y * A * M}{I_s} \qquad (4)$$

TABLE 3

Irrigation system performance variables

	Perimeters				Microsystems			
System Code[1]	**Reservoir A**	**Reservoir B**	**Reservoir C**	**Tubewell D**	**Pumpset E**	**Pumpset F**	**Manual G**	**Manual H**
Cost of Water C^w (FCFA/m^3)	2	4	4	9	27	37	68	65
Irrigation Efficiency, EFF (%)[1,1]	72	138[2]	97	50	70	110[2]	123[2]	92
Distribution Labor, L_d (h/m^3)	0.07	0.07	0.02	0.01	0.16	0.14	0.45	0.48
Production Benefit, Pw (FCFA/m^3)	48	42	28	21	114	84	110	98

[1]Refer to Table 1 and 2.

[2]Efficiency values greater than 100% suggest that crop water requirements for maximum yield were not met. At perimeter B, high pre-season storage losses were incurred in the wide, shallow reservoir due to evaporation, which resulted in an unanticipated water shortage. Farmers irrigated lower-valued maize sparingly (as opposed to the higher-valued onions) before the reservoir went dry prematurely. In a typical year, the dry season EFF value is usually about 80% at perimeter B. For this reason, the 138% EFF value is not included in Figure 3.

where,

P_w = production benefit per unit quantity of water, FCFA/m^3

Y = crop yield, kg/ha

M = crop market value, FCFA/kg

This measure is similar to water use efficiency (WUE), an agronomic term used to describe productivity per unit of water (Howell et al., 1990), and to the economic term, average value product (Ellis, 1988). Although variations of this measure are used extensively in the evaluation of irrigation production, particularly within developing regions, some discretion should be used in its interpretation. This is particularly true in humid regions where yields may be related to factors other than water. However, its application is more useful in arid regions where irrigation water is a scarce resource and each unit of water added can be more directly related to a unit yield increase (Howell et al., 1990; Rao, 1993; Sally and Abernathy, 1994). In the context of the eight case studies, most farmers operate within a subsistence-level economy and access to other external inputs (such as fertilizers and new seed varieties) is limited. As a result, variations in non-water inputs among the different systems tends to be limited. Discrepancies from market fluctuation are minimized since all systems are located within the same country and comparisons are limited to the same growing season (the dry season).

Results And Discussion

Table 3 details water costs and system performance parameters for the eight irrigation systems. Water costs to the farmers (C_w) is comparatively low in the reservoir perimeters. Farmer water costs are only 5% to 10% of production benefit (P_w) from these perimeters. The cost of water to manual lift microsystems is much higher both in absolute cost and relative to the value of production. The cost of water to the manual-lift microsystems was 65 and 68 FCFA/m^3 which represents over 60% of the production benefit.

The cost of water data in Table 3 are disaggregate in Figure 1 to illustrate the higher cost of energy, labor, and other fixed costs in the microsystems as compared to the perimeters. The figure also shows that farmers in the river and tubewell perimeters (C and D) must pay both pumping costs and a land tax. The reasons that the tubewell (D) energy costs are higher than those for the river (C) perimeter include a higher pumping head and a higher unit cost for electricity. The average cost of electricity to the tubewell perimeter was 42 FCFA/kWh and about 36 FCFA/kWh in the river

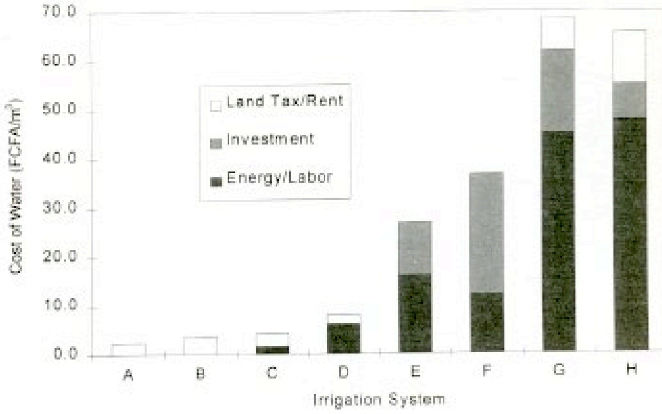

Figure 1. Farmer costs for irrigation water

perimeter. In the case of the tubewell perimeter, energy came from diesel-fueled generators while the river perimeter received electricity purchased from neighboring Nigeria, both electrical sources of which are sponsored by the state. There is a major difference in cost between energy generation in Niger and that which is imported (approximately 70 FCFA/kWh and 17 FCFA/kWh, respectively, before the FCFA devaluation). This issue as related to Nigerien perimeters is discussed in some detail by Kohler (1987). The higher land tax for the tubewell (D) perimeter is in part due to the high costs of maintaining the multiple submersible pumps (which includes parts, replacement pumps, a team of technicians and their transport) as compared to fewer, but higher capacity pumps at the river perimeter (C).

The component of energy and labor is the largest of the total water costs for the microsystems. In all but one of the microsystems, energy/labor ranks as the highest component. It was only in the early 1980's that small pumps were introduced into the irrigation sub-sector in any significant numbers. Virtually all new pumps are purchased by farmers already using traditional water lifting methods to irrigate, and since the mid 1980's this changeover of technologies has particularly accelerated. In the late 1970's, the number of chadouf systems along the Komodougou basin in eastern Niger numbered in the 1000's. Today hardly one chadouf for every 50 to 100 pumps can be found in the area. Comparison of the energy/labor component between the two pumpset microsystems (E and F) and the two manual-lift microsystems (G and H) explain the incentive for such changeover. Not only does changing to a pump greatly reduce costs, but it also frees up labor which can then be used to either increase farm production or invested in other pursuits requiring local household labor. Since production values of the pumpset and manual microsystems are similar, it is not surprising given the lower cost to lift and distribute water that farmers are moving rapidly into pump systems.

A switch from a manual-lifting microsystem to a small pump microsystem does not represent a lessening of the farmer's control over water or farm management. While a change from a microsystem to a perimeter parcel would mean a reduction in water costs to farmers, it would also represent a significant loss to the farmer of individual control of irrigation scheduling and cropping practices. This is because irrigation scheduling and cropping practices, in the perimeters, are system-level decisions made by the farmer community (i.e., the cooperative) in joint collaboration with ONAHA.

As shown in Table 3 the irrigation efficiencies (EFF) of all systems except those using tubewells are very high. In fact, five of the systems have efficiency values close to or exceeding 100%. This suggests that water is a scarce resource as compared to other cropping inputs and, therefore, is seen by farmers as quite valuable. In the tubewell perimeter (D), irrigation efficiency was only 50%, indicating that the tubewell water as received by farmers may not be valued as highly as in the other systems.

The production benefit on the perimeters requiring water to be lifted is 30% to 50% less than the reservoir perimeters (A and B) and only about a quarter of the value of production from the microsystems. The comparatively low value production benefit from these perimeters is a result of field crops rather than vegetables being grown. The choice of low-value crops for these perimeters may be the result of farmer perception of unreliable water delivery or factors unrelated to the irrigation service.

Production levels per unit volume of water (P_w) along with corresponding costs to the farmer for bringing water to the field (C_w) for each system are shown in Figure 2. The cost and benefit of a unit of water differ significantly between microsystems and perimeter systems. The difference (or margin) between production benefit and water cost are greatest for pumpset microsystems (E and F) and least for perimeter systems (A to D). The lowest margins among all the systems studied are found in the two perimeters (C and D) which incur energy costs for pumping. Comparisons between pumpset microsystems (E and F) and manual microsystems (G and H) are similar to those found by Baba (1993) in his study of crop production within manual and small pump systems in northern Nigeria.

Figure 3 compares cost of water (C_w) to the irrigation efficiency (EFF). The limited number of systems included in the case studies precludes the possibility of establishing that the slope of the linear regression in Figure 3 is statistically different from zero, but the implication is that the higher the cost of getting water to the farmer, the better it is managed within the parcel. This tendency among farmers to manage irrigation water more efficiently when water is costly and/or scarce (or the tendency to use water in

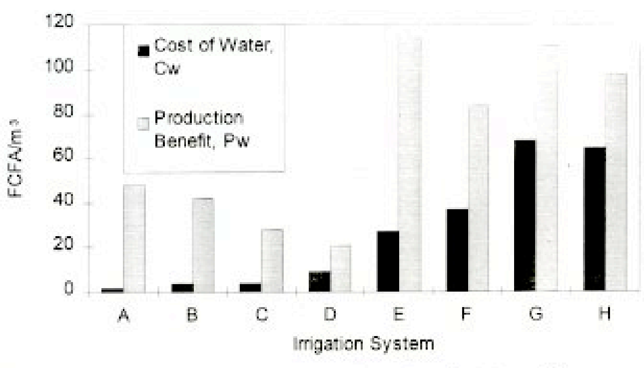

Figure 2. Farmer water cost and production benefit

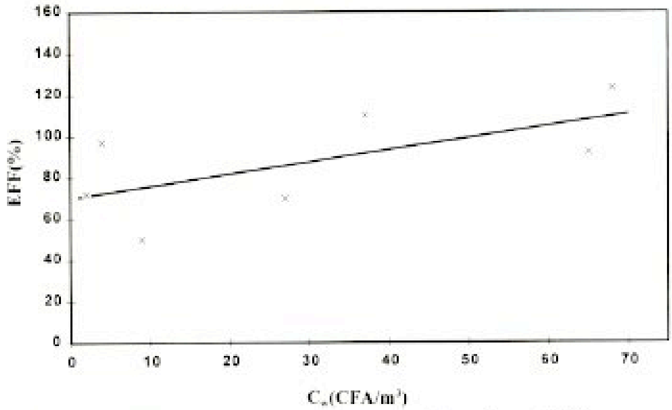

Figure 3. Farmer water cost versus irrigation efficiency

excess when access to it is unrestricted and/or without direct cost) has been observed before (e.g., Schram and Gonzales, 1976; Young, 1986; Small and Carruthers, 1991; Norman, 1991). Both the price of water (if incurred) and availability (or scarcity) of water may affect the farmer's perception of its value (which involves both direct and indirect costs). Among perimeters, Keller (1986) argues that increasing water scarcity by rationing provides greater incentive for efficient water use than by increasing existing high prices.

The implication from Figure 3 is reinforced by the relationship between labor allocated by the farmer for field-level water distribution and the cost of water. There is an increasing commitment to time spent on field water distribution as one moves from the larger perimeters, to pump microsystems, to manual systems. These groupings of system types are clearly depicted in Figure 4 (compare with Table 3). In their well-known study of farm size and productivity, Berry and Cline (1979) argue that there is an inverse relationship between farm size and unit area yields, because the small-farm sector makes better use of its available land by applying higher levels of household labor input per unit area of land. Other technical (though less relevant) reasons for this inverse relationship have been explored by others (Ellis, 1988).

The majority of microsystem farmers using small pumpsets were in the past users of manual-lift microsystems. By moving to fuel-powered pumping,

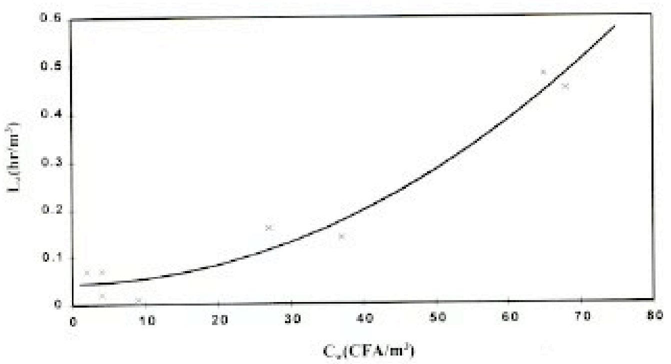

Figure 4. Farmer water cost versus water distribution labor

farmers have thus had access to higher and more stable flow rates, and reduced labor for field water distribution by some 60%. Thus, water has been exchanged for labor. From a survey of 70 pump users in the Komodougou Valley, 80% had increased their system size by 50% to 100% after switching from manual lifting (Hart, 1986). Thus, most farmers choose to reinvest the extra labor freed-up from switching technologies back into the irrigated microsystem, rather than investing it in other household/farming activities.

Many wells (lined and unlined) on which small, motorized pumpsets are used do not have yields equal to the pumps' capacities. Thus, the great majority of pump users throttle-down their pumps well below optimal pumping efficiency, thus reducing fuel efficiency and increasing cost per unit volume of water pumped. Most of these pumps are designed to operate at optimal system efficiency with a total head of about 22 m, and most effectively when the suction head component of the total head is minimized. According to manufacturers' specifications, approximately 10% of the output is lost at 2.8 m suction head, 30% at 6 m, and the flow usually ceases completely at around 8 m. Most of the pumps observed in the study areas are used with 2 to 6 m of suction head (see Table 2). At these suction heads, the pumps operate more effectively when throttled to about 3.5 to 4.0 L/s, rather than the actual observed flow rates of 1.5 to 2.0 L/s. Thus, even greater improvements in energy costs could be had if pumps were operated at optimal speeds and if they were better matched to the lift. To do this, and to avoid excessive starting and stopping, wells with better yields might be necessary.

There also appears to be an upper flow rate limit above which microsystem farmers are unwilling to run their pumps. Interviews indicate concerns with earthen channels and basins needing frequent repairs or being washed out due to high flow rates. Additionally, higher flows mean increased labor input for pre-season land-leveling of larger field basins necessary to accommodate greater flow rates, and an increase in field labor during irrigations necessary to manage the flow for field distribution. Depending on the field layout and crop type, if the flow is too high, a second person is necessary to help divide and manage the distribution among basins at flow rates manageable by one person (Norman and Gandah, 1990).

Within the perimeters, farmers generally increase field level turnout flow rates from a system design rate of 5 to 6 L/s to flow rates of 9 to 13 L/s. Fields allocated to farmers in perimeters tend to be significantly larger than traditional microsystems. Previous studies indicate that, rather than intensively managing smaller holdings within perimeters, farmers tend to cultivate and irrigate larger holdings, but less intensively. They also substitute higher field level flow rates, and in some cases more water in general, for labor. Thus, since most households are limited in available labor or in labor which they are willing to commit to irrigated production, the larger the area the more water must be exchanged for limited labor (Norman, 1988).

Microsystem farmers have far greater individual control over water management, particularly in terms of scheduling than do perimeter farmers. Although perimeter farmers may exercise some control over the flow rate and total volume of water applied during each irrigation, scheduling of irrigation is not an individual decision. Microsystems, while incurring higher unit costs for production, have the advantage of more control when their crops are grown. They are thus better able to take advantage of the market by scheduling harvests at more opportune times and to intensify cultivation due to direct control of timing between irrigations. By contrast, average irrigation frequencies among the reservoir perimeter parcels ranged from 6 to 11 days, whereas among the four microsystems irrigation frequencies ranged from 3 to 5 days.

In the perimeter system, charges levied on the farmers do not include individual or group charges based on water use. Rather, costs (including energy costs) are levied equally among all users on the basis of area served. For most perimeters in the Sahel this is the predominant method used for establishing water charges. This approach fails to establish a direct link between water use and costs so that farmer incentives to manage water efficiently are absent (Moris and Thom, 1990). Particularly in systems where the energy component of total water costs is considerable, there is little incentive for an individual farmer or a sub-unit of farmers (such as those who share a common tubewell) to conserve water. One of the principal constraints to charging farmers for the actual water used is the added responsibility for monitoring that would be placed on ONAHA, which already faces both personnel and financial resource constraints. The ONAHA is looking for ways to lower *redevance* rates but as long as parcel abandonment rates and debt rates are not high, this measure may not be best taken until taxation on an actual water use basis can be implemented.

Figure 2 shows that the tubewell perimeter (D) has the higher water cost (C_w) and the lowest marginal return between C_w and production value per unit volume of water (P_w) of all the systems. Among the four perimeters studied, the tubewell system also has the highest parcel abandonment rate (approximately 6%) and the highest debt rate for *redevance* payment among parcel holders. While each of the other perimeters has some debt problems among parcel holders, they each have waiting lists for farmers desiring access to parcels. The tubewell perimeter indicates that at a direct farmer cost of 10 FCFA/m^3 some farmers are at the point where continuation of farming is problematic.

Microsystem farmers, who can obtain a return of 80 to 100 FCFA for each cubic meter of water used, appear to be willing to pay at least 20 to 35 FCFA/m^3 when using pumps and cultivating areas larger than what they were able to do when lifting manually. Farmers using manual-lifting methods to irrigate are willing to incur a cost of at least 65 to 70 FCFA/m^3. Both the willingness of farmers to incur these costs and their ability to maintain such production return rates is very likely a result of their ability to control all aspects of system management. A number of projects presently under implementation in Niger envisage newly developed microsystem activities in which 2 to 4 farmers will be induced to share a common water source (in most cases a shallow tubewell and submersible pump)(IBRD/FAO, 1990). Unless the cost to the individual for water can be reduced to well below what is paid for by an individual pump user, problems may arise in finding sufficient incentive for the farmers to coordinate and maintain participation in such projects.

According to Lowenberg-DeBoer (1991) and Lowenberg-DeBoer et. al. (1994), there is evidence from Niger that patterns relating to the adoption of new agricultural technologies seem to be consistent with what would be expected in a high capital cost area. The tendency is that farmers invest significant capital in a new technology (such as a concrete-lined well or gasoline-powered pumpset) only if immediate, high returns are anticipated, usually within the first crop season. Long-term sustainability, in such a case, may be of secondary concern to the farmer. This study emphasizes the immediate cost to the farmer for gaining access to irrigation water, and the effect of that cost on the way in which he manages that water within his farm. The real effect, if any, of the opportunity cost of invested capital on farmer performance during the irrigation season is unclear. Some recent economic studies of systems similar to those covered in this study do not include opportunity costs in comparative evaluations (e.g., Baba, 1993). As mentioned earlier, the assumption has been made in this study that the forgone opportunity of the investments has little immediate effect on farmer performance related to water management. When opportunity costs are included in the assessment of water cost (equation 1), only C_w values for microsystems will change. In perimeters, farmers assume no initial investment costs and the only variable costs related to accessing irrigation water are energy/pumping costs associated with perimeters C and D. However, no real opportunity costs are involved since energy/pumping costs are included in the seasonal *redevance* which is paid by the farmer *following* each crop season at harvest. Among microsystems, opportunity costs are derived from the initial investments in water lifting technologies and wells, and for the on-going energy or labor cost for water lifting. The unit cost of water (C_w) among manual-lift systems (G and H) increases only marginally when opportunity costs are considered, as seen in Table 4. The increase in C_w is much more significant for pumpset systems (E and F), primarily as a result of the high initial investment required for fuel-powered pumps and lined wells. The significantly increased differential between pumpset systems E and F, as noted before and after opportunity costs are included, is primarily due to the higher pump and well costs of system F resulting from a lower water table (compare pumping heads in Table 2).

Conclusions

Government-administered irrigation perimeters provide the lowest cost per unit volume of water to farmers. The cost of water in the small-scale, manual-lift microsystems is an order of magnitude greater than for the larger perimeters. However, because the volume of production for microsystems is two to four times that of the perimeters, the margin above water costs tends to be higher for the microsystems. The pump-lift microsystems are the most cost-effective for farmers, and moving from manual-lift to pump production levels per unit volume of water used.

As the cost of water increased, farmers invested more time at the field-level in water distribution. The flow rate in manual lift microsystems was so low that a great deal more labor was needed to field apply water than for the other systems. The flow rate from motorized pumps was three to five times that of manual

TABLE 4

Unit cost of irrigation water, C_w, including and excluding opportunity costs

	Microsystems			
System[1] Code	Pumpset E	Pumpset F	Manual G	Manual H
Cw, excluding opportunity costs (FCFA/m^3)	27	37	68	65
Cw, including opportunity costs (FCFA/m^3)	52	101	73	76

[1] Refer to Table 2.

lift pumps allowing for greater ease of water application. Perimeter farmers spent far less time distributing water in the field than microsystem farmers. In general, perimeter farmers had preferred flow rates into their fields and their cropping systems required less intensive water management.

One of the principal differences between perimeters and microsystems is that the energy cost per unit volume of water used by the farmer is incurred directly by the individual when in a microsystem; whereas all farmers within the same perimeter system incur the same cost, based on perimeter-wide averages. Thus, for perimeter farmers there is no individual incentive to conserve water and reduce overall costs. The fact that microsystem irrigators are directly liable for the cost of each cubic meter of water used may explain, at least in part, better performance in the microsystems in terms of irrigation efficiency and overall system production.

Experience in the microsystems suggests that a means should be sought by which parcel holders or groups of parcel holders in perimeters incur directly the cost of water they use. Where feasible, this action should be coupled with a policy which both encourages parcel level intensification of irrigated production and seeks the means by which farmers may exercise more direct control over access to and timing of water deliveries.

In microsystems, ways should be sought to reduce the energy/labor component of water costs without significantly reducing the farmer's control over the management of his system. Small mechanical pumps better matched to local pumping conditions and to field application techniques would improve microsystem productivity.

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