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WATER USE AND PRODUCTIVITY OF TWO SMALL RESERVOIR IRRIGATION SCHEMES IN GHANA'S UPPER EAST REGION†

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ABSTRACT

To examine the impact of small reservoir irrigation development in Africa, the performance and productivity of two small reservoirs and irrigation schemes in the Upper East Region of Ghana were investigated in this study. Hydrologic data measured included daily irrigation volumes and daily evaporation. Farmer cost inputs, excluding labor, and harvest data were also recorded. There was a strong contrast in water availability between the two systems, the Tanga system having a higher amount of available water than did the Weega system. The concept of relative water supply was used to confirm this disparity; Tanga was an inefficient system with a relative water supply of 5.7, compared to a value of 2.4 for the efficient Weega system. It was also concluded that the dissimilar water availabilities resulted in the evolution of very different irrigation methods and coincided with different management structures. Where there was more water available per unit land (Tanga), management was relaxed and the irrigation inefficient. Where there was less water available per unit land (Weega), management was well structured and irrigation efficient. The productivity of water (US$ m^{-3}) of the Tanga system was half that of the Weega system, when analyzed at a high market price for crops grown. In terms of productivity of cultivated land (US$ ha^{-1}), however, the Tanga system was 49% more productive than the Weega system. The difference in the productivity of land is primarily a result of increased farmer cash inputs in the Tanga system as compared to the Weega system. The difference in the productivity of water can be attributed to the varying irrigation methods and management structures, and ultimately to the contrasting water availability. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: irrigation; water management; international development; small reservoirs

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RÉSUMÉ

L'impact du développement de petits réservoirs d'irrigation en Afriques est étudié en analysant la performance et le bénéfice économique de deux petits réservoirs avec de différents schèmes d'utilisation dans une région au nord-est du Ghana. Les données hydrologiques utilisées dans cette étude comprennent les volumes journaliers d'irrigation, ainsi que des mesures journaliers d'évaporation. En outre les coûts des investissements des agriculteurs ainsi que des données de récoltes ont été enregistrés. La quantité d'eau disponible était considérablement différente dans les deux systèmes: les ressources en eau du système de Tanga étaient nettement supérieures par rapport à celles du système de Weega. Le concept de l'approvisionnement relatif en eau a été utilisé pour démontrer cette disparité:

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†Utilisation d'eau, productivité et gain économique de deux petits réservoirs avec de différents schèmes d'irrigation de au nord-est de Ghana.

Tanga avait un système inefficace avec un taux d'approvisionnement relatif en eau de 5.7 comparé à un taux de 2.4 du système efficace de Weega. Il a été conclu que les différences au niveau de la disponibilité d'eau sont à la base d'une évolution de méthodes et s'accordent avec de concepts de gestion d'irrigation très contrastés. Quand il y avait plus d'eau disponible par unité de surface (Tanga), la gestion était peu organisée et l'irrigation moins efficace. Par contre, quand les ressources en eau étaient limitées (Weega) la gestion était bien structurée et l'irrigation très efficace. En termes d'eau les agriculteurs de Tanga recevaient seulement la moitié du bénéfice économique des agriculteurs de Weega quand le prix du marché était élevé pour les produits récoltés. Par contre, en termes de surface cultivée, les agriculteurs de Tanga faisaient 49% plus de profit par rapport aux agriculteurs de Weega. La différence du bénéfice économique de la terre cultivé est principalement une conséquence des investissements élevés des agriculteurs dans le système de Tanga comparé au système de Weega. La différence du bénéfice économique de l'eau peut être attribuée aux variations des méthodes d'irrigation et des structures de gestion et donc finalement aux disponibilités en eau très contrastées.

MOTS CLÉS: irrigation; gestion des ressources en eau; développement international; petit réservoirs

INTRODUCTION

The average rate of irrigation development for the countries of sub-Saharan Africa from 1988 to 2000 was 43 600 ha yr^{-1} (FAO, 2001). If this rate continues, an additional 1 million ha will be brought into irrigated production by the year 2025. Programs to achieve the UN millennium goals will increase availability of funding for irrigation projects that would improve food production and security. The World Bank estimates that water infrastructure investments on the order of $180 billion per year are needed until 2025. While it is true that large-scale irrigation systems have been constructed in this region, their performance records indicate failure in regard to their anticipated benefit (Alam, 1991; Kortenhorst *et al*., 1989; Adams, 1992). As a result of the shortcomings of these large-scale systems, small-scale irrigation was subsequently advocated (Turner, 1994; Vincent, 1994). Although recent focus has turned towards management and performance improvement, new small-scale irrigation projects continue to be promoted (SRP, 2006; FAO, 2001). Vincent (2003) recognizes the importance of these small, sometimes marginal, farmers in water management strategies and calls for a new approach that recognizes their importance.

In general, reliable data on small reservoir irrigation systems are lacking as few small systems of this type have been monitored and their performance analyzed (Liebe *et al*., 2005). Of the majority of systems that have been investigated, the focus has primarily been on Asia (e.g. Yoder and Martin, 1990; Ambler, 1994; Vermillion, 1998; Sur *et al*., 1999). Furthermore, of the few systems that have been investigated in Africa, quantitative performance data on small reservoir crop production is extremely limited (e.g. Mugabe *et al*., 2003; Norman *et al*., 2000). That a significant number of these small reservoir systems are functioning suboptimally and/or are falling into disrepair indicates that there is room for improvement in planning, operation, and maintenance (SRP, 2006). Since more of these systems are being built, an investigation of the efficiency of different irrigation systems, in terms of water use and application, is important. Studies of this type will also be essential if Vincent (2003) is correct in suggesting that at the core of new designs in water management lies a smallholder hydrology perspective.

This paper provides one of the first examinations of the performance and productivity of small reservoir irrigation systems in West Africa. There are over 160 of these small reservoirs in the Upper East Region of Ghana alone (van de Giesen *et al*., 2002; Liebe *et al*., 2005), and thousands are spread across the whole of West Africa. These reservoirs provide a source of water for livestock watering, domestic use, irrigation, fish production, brick making, and a number of other beneficial uses. Without these reservoirs and irrigation systems, many farmers would be forced to travel from their homes to labor elsewhere, especially in the dry season.

Two small irrigation systems, within a 2 km distance, were studied in the Upper East Region of Ghana. Although both of the systems were managed by farmers holding parcels within the irrigated areas, the management styles differed greatly. The system performance was evaluated by comparing the relative water supply (RWS) and productivity of each system.

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The objectives of this study were to (1) evaluate the performance and efficiency of the irrigation systems by quantifying the amount of water used for irrigation and comparing it to crop water demand; and (2) to examine the productivity of the irrigation systems, defined here as the net income (excluding labor costs) received from crops grown per volume of water released or per area of cultivated land. The data presented are of broader interest than the local planning and management of these systems. Given the dearth of data concerning productivity and efficiency of these village-level schemes, this study provides a first look at strengths and weaknesses of these systems. With the continued donor support for investments in small-scale African irrigation, and increasing interest in multi-purpose systems, both planners and engineers have a clear need for this type of information. The results presented show that from a technical perspective, even at the better managed scheme, there is plenty of room for improvement. Planners developing new reservoirs should be simultaneously developing strategies to improve the management of the irrigation systems and work to fully exploit the value of the complementary uses of the reservoirs to the communities they serve.

STUDY SITE DESCRIPTIONS

Overview

Two surface catchment reservoirs in Ghana's Upper East Region were selected for the study (Figure 1). The average annual rainfall in this area is approximately 1100 mm yr^{-1}. Typically the rainy season is from late May to mid-October, and a dry season from November through early May. The annual mean temperature is 29°C and the annual mean maximum temperature 34°C. Millet, maize, and groundnuts, which compose the bulk of the diet of the population, are the primary crops grown in upland areas during the wet season. Onions, tomatoes, and a few other

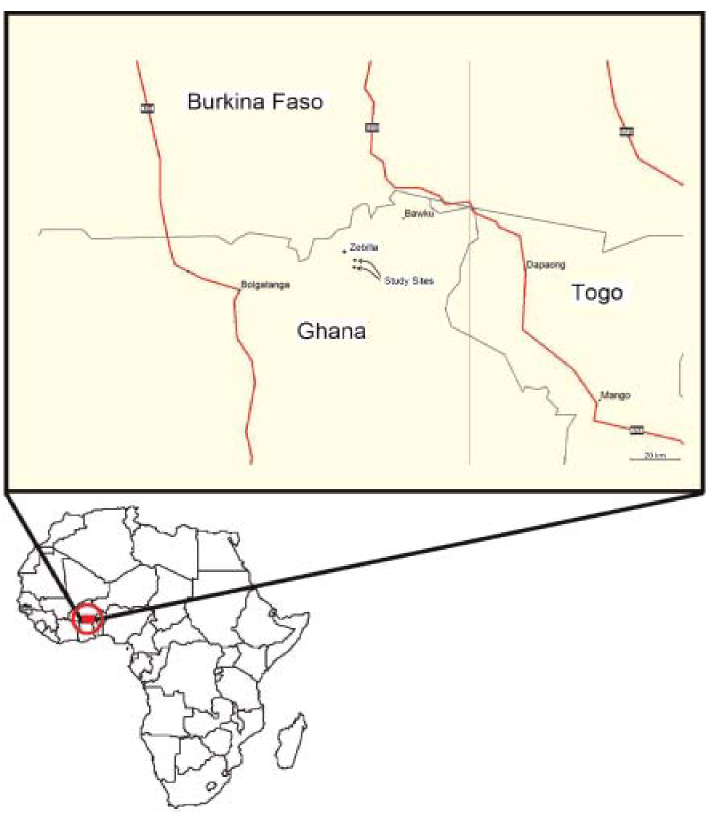

Figure 1. Study site location. This figure is available in colour online at www.interscience.wiley.com/journal/ird

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vegetables, such as okra and leaf vegetables for soups, are grown during the dry season in the irrigated areas. At both study sites, onions are the primary crop and are typically transplanted in early January and take three months to mature. They are grown in beds approximately 1.5 m wide and from 5 to 20 m long. Produce brokers traveling to the reservoirs, or local villages and towns, provide the primary market for crops. Market access is not problematic if brokers come directly to the reservoirs, and is often solved by use of donkey carts if crops need further transport. The onions provide the largest income, while the various other crops provide supplemental food for the home or small income at local markets.

These small irrigation systems are common in the region and beyond. Their existence is directly linked to the need for a source of dry season income. Farmers utilizing these systems commonly reported that without the opportunity for income the reservoirs provided, they would have left their families and seasonally migrated to the southern regions of the country in order to earn income. Although the impact of this seasonal labor migration on sending areas remains in contention among researchers (Hampshire and Randall, 1999), the income production the reservoir irrigation systems can facilitate has the potential to positively impact livelihoods.

The reservoir systems collect surface runoff during the wet season, and typically there is enough water remaining at the end of the dry season to water livestock and serve domestic needs. Reservoir water levels varied between approximately 2 and 3 m for both systems during the dry season studied. The reservoirs also typically fill to a level so that overflow is released through an emergency spillway located at each reservoir. Water is delivered from the reservoir to the cropped area by a concrete lined, and at one study site, partially lined, open canal system. These canals are filled by operating two adjustable valves controlling two outlets from each reservoir. Single canal capacities ranged between 0.05 and 0.09 $m^3 s^{-1}$. Some discharges were as low as 0.02 $m^3 s^{-1}$, but were more often near capacity. Irrigation is performed by a trench system or a basin and bucket system, both described in detail in the reservoir sections. Trench and basin forming, bed preparation, and cultivation, are all performed manually with short hoe-like tools. Limited regression agriculture occurs at one reservoir, but is insignificant in terms of water use when compared to downstream cultivation.

Both crop selection and management tasks are performed by the farmers themselves and a small water users' association. These water users' associations are comprised almost entirely of farmers and, in addition to management tasks, also serve the purpose of collecting fees to be used for canal repair and maintenance. All farmers cultivating a plot within the irrigation system are asked to pay a set fee, per plot, to the water users' association. This fee is also to be paid if the plot is left fallow and they wish to retain cultivation rights. Although the collected fees are saved in a bank account belonging to the association, legal recognition of the association is uncertain. As with the majority of small reservoirs in this region, these were built with the financial and technical assistance of a non-governmental organization.

Downstream of the area irrigated by the canals, a small number of farmers have built mud walls and cultivate crops reusing the drainage water from the irrigation system. This irrigation is performed by digging shallow wells and carrying water to small fields adjacent to the marshy area. This ''wasted'' water therefore allows limited cultivation to be possible up to 1 km below the end of the canal system. This marshy area also allows for a diverse population of birds and aquatic vegetation.

Tanga system

The Tanga reservoir is 10.6 ha in surface area (Liebe *et al*., 2005), has an estimated storage volume of 25 ha-m, a water-level variation of 2.1 m during the period of observation, and the total area under cultivation is 1.6 ha. During the study period, 73 farmers maintained plots at this study site. This reservoir is located near the main junction at the market in the village of Tanga. Tanga is located approximately 4.5 km south of the town of Zebilla, in the Bawku West District of the Upper East Region (10.912 N, 0.442 W (WGS 84)). Upstream from the reservoir is a smaller reservoir that cascades into the Tanga reservoir. This upper reservoir in the cascading system was used for irrigation until the release valves malfunctioned. The Tanga dam construction was administered and financed by Action Aid, reportedly in the late 1980s, using some community labor for canal construction. Ownership of land is historically disputed, but plots are generally recognized as the property of those initially claiming them during the adoption of the irrigation system farming (van Kinderen, 2006). Two valves release water into two canals for the irrigation

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Figure 2. Tanga system layout. This figure is available in colour online at www.interscience.wiley.com/journal/ird

system below the dam. One of the valves leaks, and both canals show deterioration and see only limited maintenance. The two main canals distribute water to plots by means of turnouts spaced along the length of the canals. These turnouts can be plugged with mud or rocks if a farmer does not want to irrigate his or her fields and opened if irrigation water is needed.

Once the water passes through a turnout, the vast majority of irrigation is accomplished in the following way: circular basins (approx. 2 m diameter, 1.5 m deep) are dug in each farmer's enclosure, a trench is dug connecting the basin to the canal, water flows through the turnout and fills the basin while the valves are open, the farmer transfers the water from the basin to the crop with a bucket or calabash. Irrigation water is typically released in the evenings, every day, for approximately 2 h.

Farmers' plots are irregular in shape and size and are scattered across the area below the dam, with many areas that have potential to be cultivated left fallow (Figure 2). The majority of these areas are left fallow in the dry season because their owners wish to cultivate in the wet season and the inability to arrange mutually acceptable agreements for others to cultivate in the dry season (van Kinderen, 2006). The average farmer's plot size at this study site was 0.022 ha. The strip of land extending away from the dam, and at the lowest point between the canals, serves as a small drainage waterway for any seepage from the dam and irrigation drainage.

There is a loose water users' association in place at this dam, with the fee for a plot being relatively inexpensive (≈ $1.08). The farmers build their own mud walls surrounding each individual plot to prevent animals from entering the cultivated areas.

Weega system

The Weega reservoir, which is a stand-alone system not connected to other reservoirs, has a surface area of 11.9 ha (Liebe *et al.*, 2005), an estimated storage volume of 22 ha-m, a water-level variation of 3.1 m during the period of observation, and the total area under cultivation is 6.0 ha. It is located 3 km south of the Tanga reservoir and 7.5 km south of Zebilla, near the small village of Weega. During the study period, 241 farmers maintained plots at this study site. The dam construction was administered and financed by the Red Cross, reportedly in the mid-1980s, utilizing small fees and some community labor for construction. Land is officially owned by the community, and plots are ''borrowed'' by farmers for a yearly fee (van Kinderen, 2006). The canals (lined and unlined) are maintained fairly well, and are both extended using hand-dug earthen canals. Two valves release water into as many canals for the irrigation system below the dam. The two main canals distribute water to plots by means of turnouts spaced along the length of the canals. These turnouts are plugged with mud or rocks if farmers do not want to irrigate their fields, and opened if irrigation water is needed. A turnout can service many farmers' fields;

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Figure 3. Weega system layout. This figure is available in colour online at www.interscience.wiley.com/journal/ird

therefore, farmers also control water by using earthen barriers across the turnout trenches to direct water onto their individual plots.

The irrigation method at this study site is quite different from the method at the first reservoir. Irrigation water is directed through a turnout into a turnout trench, and then diverted by the earthen barriers onto a plot and into small trenches that are dug in-between each individual bed. The water is then thrown/splashed up onto the beds by a farmer with a piece of calabash. This results in a great deal of water not being used and flowing to the middle of the irrigated area, where it forms a drainage stream exiting the fields. Irrigation releases are fairly regular, and occur daily in the evenings for approximately 3 h. Farmers are also present during this time to splash irrigation water onto their crops.

Farmers' plots are chosen in fairly regular shapes and sizes and spread across the area below the dam, occupying most of the area that can potentially be cultivated (Figure 3). The average farmer's plot size at this study site was 0.025 ha. The strip of land extending away from the dam, and at the lowest point between the canals, serves as a small drainage waterway for any seepage from the dam and irrigation drainage.

There is a well-formed water users'association in place at this dam, with the fee for a plot being relatively inexpensive for men (≈ $1.08), and cheaper for women (≈ $0.86) who are part of the women's group that lobbied the Red Cross for the construction of the dam. The fees are deposited in a bank account and are to be used when maintenance or repairs are needed. The farmers all work together and build a single mud wall around the entire irrigated area. This works well when all the farmers are still tending to their onions; however, when some farmers harvest, animals can break the wall adjacent to the now empty plot, and then the animals have access to all unguarded plots. When a breach occurs, it results in a rush to harvest, whether the onions are mature or not.

METHODOLOGY

Field data acquisition

The study was conducted during the dry season and while crops were being cultivated, from late December 2004 to late April 2005. Daily visits and observations were made at both study sites.

Hydrologic data were collected daily at each site. The flow rates of water released for irrigation were recorded for the season at both reservoirs. The aforementioned irrigation system design required the construction of four flow monitoring stations, one for each main canal. Long-throated flumes and stilling wells were installed at the head of each main canal. The flumes and stilling wells were constructed *in situ*, using concrete and plastic and metal pipe. Automatic water level recorder devices were placed in each of the stilling wells. Individual stage height

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measurements were recorded at 1 min intervals. Judging from daily observations, it can be stated with confidence that submergence of the flumes did not occur.

Socioeconomic data were also collected. A survey, with the assistance of an enumerator, was conducted during the harvest period at each reservoir. All farmers from both study sites participated in the survey. They were asked the cost for the season of seeds, fertilizer, pesticides, and plot ''rental'', as well as the amount of onions harvested, recorded in number of standard sacks. If the farmers grew any other crops, they were also asked the net income received from the sale of this additional crop, excluding labor costs. When a farmer harvested and the survey had been completed, an area measurement of the corresponding plot was also performed. This resulted in area measurements for the entire cropped area below each reservoir. The individual plots and canals were also mapped in relation to one another.

A Class A evaporation pan was placed in the irrigated area below each reservoir, and at a location more than 0.5 km upwind of both reservoirs. Small areas for the pans were rented from farmers in the irrigated area; these farmers also helped to prevent disturbance by animals or humans. Water levels were recorded daily and water additions were made when needed, approximately every other day.

Calculation of relative water supply (RWS)

Relative water supply (RWS) is used for comparison of the efficiency of irrigation systems. Actual RWS at the field level is defined as the supply of irrigation water divided by the demand associated with the crops actually grown, with the cultural practices actually used, and for the actual irrigated area (Levine, 1999):

$$\mathrm{RWS} = S/D \tag{1}$$

where RWS = relative water supply; S = supply of irrigation water (cm), and D = demand of the irrigation system (cm).

The supply of irrigation water, since the water table remains constant, can be described by the expression

$$S = P + I_s \tag{2}$$

where P = rainfall (cm) and I_s = water released from reservoir during sample period (cm). In this case, there was no rainfall, so $P = 0$.

The demand of the irrigation system, where salinization is not a problem, is described by the expression

$$D = ET_c \tag{3}$$

where ET_c = evapotranspiration from the crops (cm), otherwise known as consumptive use. Conveyance losses are not included when calculating demand at the field level.

Both S and D were calculated weekly during a nine-week sample period. This nine-week period (January 15 through March 18) was used because this was the period when the greatest density of crops was growing at the study sites, due to late plantings and early harvests.

Calculation of productivity

The productivity of each of the study sites was determined using two different methods. The first determined the productivity based on net income per volume of water released from the reservoir

$$P_w = p/I_t \tag{4}$$

where P_w = productivity of water released (\$ m^{-3}); p = sum of net income of all farmers at the reservoir (\$); and I_t = total volume of water released from the reservoir (m^3). Individual farmer's net incomes were determined using the difference between the total cost of inputs, excluding labor, and the potential income received from harvested produce. These potential incomes were based on three different market prices of onions: a low, medium, and high price. These prices were quoted by the farmers during the socioeconomic surveys, and are given in price per standard grain sack. The low price (≈ \$8.60) was common during April, the medium price (≈ \$17.20) common

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Table I. Average evaporation rates

Location of pan	Average evaporation rate (mm day^{-1})
Tanga reservoir	7.1
Weega reservoir	7.5
Desert (non-irrigated area)	10.2

through May, and the high price (≈ \$43.01) was likely in the following months if onions could be stored effectively. Cost of onion storage is neglected as harvest volumes typically allow onions to be easily stored in one's home.

The second method determined productivity based on net income (as defined above) per area of cultivated land

$$P_L = p/A \tag{5}$$

where P_L = productivity of land area (\$ ha^{-1}); and A = land area under cultivation (ha). This productivity was also calculated using three different potential incomes, based on the same three market prices of onions used for P_W.

RESULTS AND DISCUSSION

Evaporation data

The average evaporation rates for the three Class A evaporation pans are displayed in Table I. These average evaporation rates were ascertained by dividing the sum of the measured evaporation rates by the total number of days when measurements were performed. The average evaporation rate from the ''Desert'' pan is 44% higher than the rate from the Tanga pan, and 36% higher than the rate from the Weega pan. Due to the lack of irrigated vegetation or open water adjacent to the ''Desert'' pan, it can be conjectured that the higher evaporation rate is due to the ''oasis effect''. If this is the case, it is assumed that the irrigated crops surrounding the evaporation pans at the reservoirs reduce the respective evaporation rates.

The average evaporation rate from the Weega pan was 5.6% higher than the evaporation from the Tanga pan. Although there was more irrigated area upwind of the Weega pan, many mud walls surrounded individual plots at the Tanga site, including the plot that the evaporation plan was placed in. It is reasonable to speculate that these mud walls reduced the wind's effect on evaporation.

To obtain evapotranspiration rates, the FAO method (Allen *et al.*, 1998) was employed. This method required weekly averages of relative humidity and wind speed, collected from a local weather station. These data were then used, with the distance of irrigated area upwind of the pan (500 m for both sites), and the proper equation from the FAO handbook, to calculate the evaporation pan coefficient (Table II). Once the pan coefficient was obtained, it was multiplied by the average recorded evaporation rate for the week, resulting in the reference crop evapotranspiration. This reference crop evapotranspiration was then multiplied by the mid-season crop coefficient (1.05 for onions) to obtain the final evapotranspiration rates (Table II). These values were used for determining crop water demand.

Farmers' costs

Table III shows a breakdown and total cost of crop inputs, excluding labor, and subsequent yields per area cultivated for each study site. All other costs are composed of plot fees and water user association fees, and the fertilizer costs include both nitrogen and ammonia additions (≈ \$1 kg^{-1}). Tanga experienced 60% better crop yields per hectare than Weega. Tanga farmers also invested 78% more cash in crop inputs than did Weega farmers. This difference in input cost is due primarily to a significantly higher fertilizer investment, followed by a higher pesticide investment, and thirdly, a higher seed input. Per hectare, Tanga farmers spent 110% more on fertilizer, 67% more on pesticide, and 52% more on seeds than did Weega farmers. All other costs per hectare were very similar between the two systems. A possible explanation for why the Tanga farmers invested more in crop inputs is the increased security in returns gained by building and maintaining individual walls around plots. This practice

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Table II. Weekly evaporation and weather data (mm day^{-1})

Week	1	2	3	4	5	6	7	8	9
RH (%)	31	31	30	26	28	46	36	37	54
Windspeed (m s^{-1})	6	5	5	7	7	5	5	5	4
Pan coefficient	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.7	0.7
Recorded average evaporation rates									
Tanga	6.0	5.4	6.4	8.3	7.5	7.4	7.6	7.7	7.6
Weega	7.7	5.7	8.0	8.6	8.1	8.0	8.6	7.8	7.7
Reference crop evaporation									
Tanga	3.7	3.5	4.0	4.6	4.3	5.1	4.9	5.1	5.5
Weega	4.8	3.7	5.0	4.8	4.7	5.6	5.5	5.1	5.6
Calculated evapotranspiration rates									
Tanga	3.9	3.7	4.2	4.8	4.5	5.4	5.1	5.3	5.8
Weega	5.0	3.8	5.2	5.0	4.9	5.9	5.8	5.4	5.9

Table III. Input cost and yield

Reservoir	Fertilizer ($ ha^{-1})	Pesticide ($ ha^{-1})	Seed ($ ha^{-1})	All other costs ($ ha^{-1})	Total cost ($ ha^{-1})	Yield (sacks ha^{-1})
Tanga	961	80	599	48	1687	85
Weega	457	48	393	47	946	53

eliminated reliance on others to maintain a common wall, hence establishing independence and sole responsibility for the prevention of livestock damage, a significant cause of crop failure.

Water distribution, use, and availability

Table IV shows the total area irrigated by each canal and each reservoir. The total volume of irrigation water for the entire season, as well as total volume per land area, is also shown. The total water released per land area irrigated is 2.9 times greater at the Tanga reservoir than it is at the Weega reservoir. This higher availability of water is hypothesized to be the primary cause of a less efficient irrigation method and a more relaxed management structure. As a result of increased management at the Weega system, there was also an increased labor input. As management increased, so did the time and effort the farmers and water user association officials put into ensuring that released water was used efficiently. Furthermore, farmers at the Tanga system were not required to invest as much labor in management or irrigation method to ensure that crops received ample water.

Table IV. Irrigated areas

	Area under cultivation (ha)	Total water released for season (m^3)	Water released per area irrigated (m^3 ha^{-1})
Tanga canal A	0.8629	34 121	39 542
Tanga canal B	0.7591	19 245	25 352
Weega canal A	2.8824	32 373	11 231
Weega canal B	3.1245	35 895	11 488
Tanga total	1.6220	53 366	32 901
Weega total	6.0069	68 268	11 365

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Table V. Total supply, demand, and average RWS for sample period

Reservoir	Supply (cm)	Demand (cm)	RWS
Tanga	171.3	30.0	5.7
Weega	79.4	32.9	2.4

The water released per area irrigated is very similar between the two canals at the Weega system, but the values for the two canals at the Tanga system are grossly different. This difference is a symptom of the relaxed management structure.

Relative water supply

The cumulative supply and demand, and the RWS of both reservoirs for the entire nine-week sample period, are shown in Table V. Both systems have average RWS values approximately equal to, or greater than, a value of 2.5. Levine (1999) indicates that, for systems with an RWS value of 2.5 or greater, water stress will generally not be an important factor affecting irrigation performance. This generality held true at both study sites, as daily observations confirmed that water stress was not a common problem. The RWS values for each of the nine weeks during the sample period are shown in Figure 4. Each week consists of seven days of measurements; the first week starting on January 15, and week number nine ending on March 18. The Tanga system maintains an RWS value that is greater than the Weega system, often by a magnitude of 2 or more.

At the Tanga site, which has a relatively high RWS, the high water availability allows the farmers to choose a less efficient irrigation method. It can be speculated that the basin and bucket irrigation method was chosen because water scarcity was not an issue, and there was no incentive to choose a more efficient method.

The higher water availability at the Tanga site, validated by a higher RWS, coincided with a weaker management system. It can also be observed that the Tanga system's RWS value fluctuates considerably; this also helps confirm the assertion that the management at the Tanga system is relatively weak. The water supply volumes, in relation to demand, vary drastically at the Tanga system, a result of relaxed management, while the supply values for the Weega system remain relatively consistent in relation to demand throughout the season (Table VI).

It is reasonable to state that if the available water at the Tanga system was reduced, or the cropped area increased, the farmers could be forced to improve their management structure, switch to the trench irrigation method, or both.

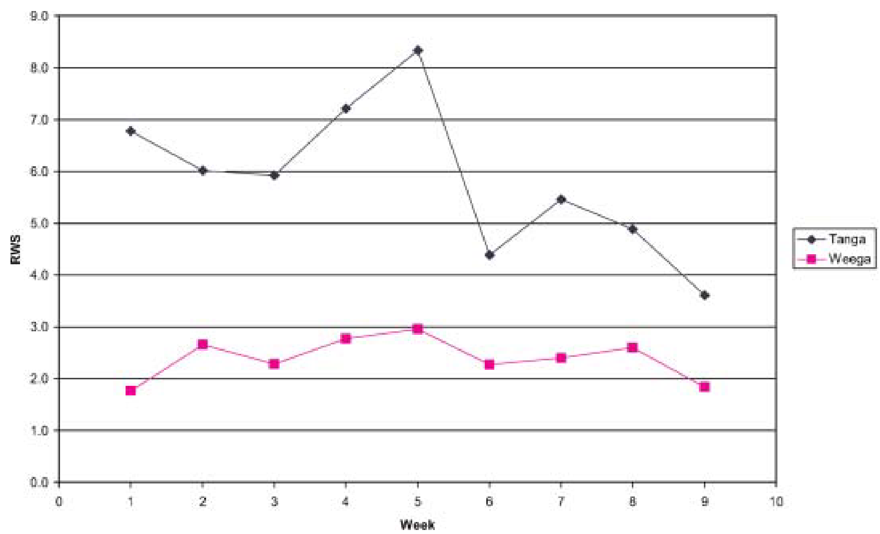

Figure 4. RWS values for nine weeks starting Jan. 15 and ending Mar. 18. This figure is available in colour online at www.interscience.wiley.com/journal/ird

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Table VI. Supply and demand for nine weeks (cm)

Week	1	2	3	4	5	6	7	8	9
Demand									
Tanga	2.7	2.6	2.9	3.4	3.2	3.8	3.6	3.7	4.1
Weega	3.5	2.7	3.7	3.5	3.4	4.1	4.1	3.8	4.1
Supply									
Tanga	18.5	15.4	17.4	24.4	26.5	16.5	19.7	18.2	14.7
Weega	6.2	7.1	8.4	9.8	10.1	9.4	9.8	9.8	7.6

Table VII. Productivity of land

Reservoir	Net income per cultivated land area (US$ ha^{-1})		
	Low market price	Medium market price	High market price
Tanga	−857.96	−93.83	+2198.53
Weega	−441.72	+37.57	+1475.45

Productivity

The productivity of each reservoir is shown below in Tables VII and VIII, in terms of net income per cultivated area and per volume of irrigation water released, respectively. These values were calculated for three different market prices of onions; a low price, medium price, and a high price. For this study, labor inputs were not measured and are not included in costs. In general, no outside labor is hired; therefore, net income is essentially a return on farmer investments, excluding labor.

Based on the productivity of land, the Tanga system is less productive than the Weega system until a high market price can be achieved; however, at a medium market price, the Tanga system still experiences a loss, while the Weega system experiences an insignificant productivity. At the high market price, the Tanga system is 49% more productive than the Weega system. This difference in productivity of land can be considered in conjunction with the farmer costs (Table III) and the absence of water stress affecting crop growth. As water stress is not a limiting factor, the increased productivity of land is due primarily to the increased fertilizer, pesticide, and seed inputs, and not irrigation technique or management.

Based on the productivity of released water, the Tanga system is less productive than the Weega system, except at a low market price, when both experience a loss. At a high market price, the Weega system is almost twice as productive as the Tanga system. This relatively high productivity of water is a result of the trench irrigation technique and improved management structure in place at the Tanga study site. Furthermore, as the irrigation method and management structure are results of the overall water availability, the higher productivity of water is therefore ultimately a result of this lower water availability.

Using either measure of productivity, during this study year the systems are not significantly productive, or rather experience a loss, at a low or medium market price. Although these data offer a general range of productivities, they are likely to differ from year to year. Disease, drought, and input costs all will have an effect. Continued monitoring is advisable to more accurately determine the long-term productivity of these small reservoir systems.

Table VIII. Productivity of water

Reservoir	Net income per volume of water released (US$ m^{-3})		
	Low market price	Medium market price	High market price
Tanga	−0.03	+0.00	+0.07
Weega	−0.04	+0.00	+0.13

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Well-designed storage facilities for onions are likely to increase net incomes, as they allow onions to be kept and sold in the wet season, when market prices are higher. It is also possible that the construction of more small reservoirs could adversely affect the productivities of these systems. If the supply of dry-season cash crops increases, prices could conceivably drop to the point where positive net incomes could be attained, even from well-stored onions.

CONCLUSION

Small reservoir irrigation projects in West Africa are important to the livelihoods of those who utilize these systems. The study and understanding of these small reservoirs are essential for the continued agricultural development of the region. The managerial, operational, and environmental factors associated with these systems are all necessary tools to aid in creating a more accurate characterization of their productivity.

The high RWS values of both study sites indicate that water stress was not likely to be a significant factor affecting crop production. The significantly higher water availability of the Tanga system coincided with a much more relaxed management structure than at the Weega system. The higher water availability of the Tanga system also resulted in the selection/evolution of a much less efficient irrigation method (basin and bucket) than is employed in the Weega system (trench). This higher water availability is confirmed by a much higher RWS in the Tanga system. If the water availability of either system was to be reduced and yields remain consistent, the management structure would be forced to improve, the irrigation method would have to change, or both. It can also be assumed that if a decrease in water availability were to occur, this would be reflected in a lower RWS.

Data also suggest that the differences in yields and productivities of land are a result of markedly higher inputs (seeds, fertilizer, and pesticide) per hectare. Although the management structure was weaker at one study site than the other, it cannot be implicated in differences of productivities of land. If water stress were to become a factor in crop production, it is expected that management would become a very important factor in the productivity of the irrigation system. The productivity of water data suggest that a stronger management structure and the trench method of irrigation result in a more economical use of irrigation water when compared to the bucket and basin system. It can also be surmised that ultimately the higher productivity of water at the Weega system is due to lower water availability.

Further study of these systems is called for to more accurately determine their long-term economic benefit to the farmers using them. This continued monitoring would also add to the currently limited knowledge of small reservoir irrigation systems and help indicate what effect the construction of more systems would have on the produce markets and the livelihoods of farmers. Rockstrom (2000), in a review of selected aspects of similar water-harvesting methods, advises that a systems approach be used when developing rural water management approaches. This includes, but is not limited to, biophysical parameters, linkages between the agroecological system, rural society, production, and markets (Rockstrom, 2000). The upscaling of this type of system could have widely varying impacts on different communities, depending on various local parameters (e.g. social structure and hydrology). If similar future projects are to be successful at improving livelihoods, planning will need to incorporate a multitude of factors. This multifaceted approach to planning is perhaps made more evident by the differing performances of these two similar systems.

As stated before, the collected figures may serve as a first guide for further planning and construction of small reservoirs. Both systems show low levels of productiveness and low resource use efficiencies, which can probably be expected throughout the region until more pressure on irrigated land arises. The West African savanna is dotted with thousands of these small systems and construction of new ones continues today. It is remarkable that the traditional financial and technical analysis presented here shows such low returns on water and labor. Indirectly, the low pressure on irrigated land is an indication that the returns are indeed low and that irrigated agriculture would be abandoned if the opportunity costs for labor in the dry season were not as low as they are. Even after allowing for interannual availability and measurement uncertainties, it is reasonable to speculate that the relatively high capital investments (dam, intakes, lined canals) can never be amortized through returns from the irrigation schemes alone. For future planning, it is important that realistic low return figures are used for irrigation. Given the continued enthusiasm among donors and rural populations for the construction of small reservoirs, it is likely that the

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complementary uses of these multipurpose systems, such as improved household water supply, fishing, stock watering, and brick making, are actually of great importance and should be also be investigated in future studies.

Perhaps the most important insight is that even between two very comparable systems of similar size, set in the same socioeconomic and physical environments, large differences are found in water and land profitability. Having recognized this, further study is called for to investigate the social and institutional reasons for these differences.

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REFERENCES

Adams WM. 1992. *Wasting the Rain: Rivers, People, and Planning in Africa*. University of Minnesota Press: Minneapolis, Minn.

Alam M. 1991. Problems and potential of irrigated agriculture in sub-Saharan Africa. *Journal of Irrigation and Drainage Engineering, ASCE* **117**(2): 155–172.

Allen RG, Pereira LS, Raes D, Smith M. 1998. Crop evapotranspiration: guidelines for computing crop water requirements. Irrigation and Drainage Paper No. 56, FAO, Rome.

Ambler J. 1994. Small-scale surface irrigation in Asia: technologies, institutions and emerging issues. *Land Use Policy* **11**(4): 262–274.

FAO. 2001. *Smallholder Irrigation Technology: Prospects for Sub-Saharan Africa*. International Programme for Technology and Research in Irrigation and Drainage, Knowledge Synthesis Report No. 3, Rome.

Hampshire KR, Randall SC. 1999. Seasonal labour migration strategies in the Sahel: coping with poverty or optimizing security? *International Journal of Population Geography* **5**: 367–385.

Kortenhorst LF, van Steekelenburg PNG, Sprey LH. 1989. Prospects and problems of irrigation development in Sahelian and sub-Saharan Africa. *Irrigation and Drainage Systems* **3**: 13–45.

Levine G. 1999. *Understanding Irrigation Behavior: Relative Water Supply as an Explanatory Variable*. International Water Management Institute IWMI Serie Latinoamerica: Mexico.

Liebe JR, van de Giesen N, Andreini M. 2005. Estimation of small reservoir storage capacities in a semi-arid environment. A case study in the Upper East Region of Ghana. *Physics and Chemistry of the Earth* **30**: 448–454. DOI:10.1016/j.pce.2005.06.011.

Mugabe FT, Hodnett MG, Senzanje A. 2003. Opportunities for increasing productive water use from dam water: a case study from semi-arid Zimbabwe. *Agricultural Water Management* **62**: 149–163.

Norman WR, Walter MT, Walter MF, Brooks ES. 2000. Water distribution management in small West African canal systems. *Journal of Irrigation and Drainage Engineering, ASCE* **126**(5): 304–313.

Rockstrom J. 2000. Water resources management in smallholder farms in Eastern and Southern Africa: overview. *Physics and Chemistry of the Earth (B)* **25**(3): 275–283.

Small Reservoirs Project (SRP). 2006. [web document] www.smallreservoirsproject.org

Sur HS, Bhardwaj A, Jindal PK. 1999. Some hydrological parameters for the design and operation of small earthen dams in lower Shiwaliks of northern India. *Agricultural Water Management* **42**(1): 111–121.

Turner B. 1994. Small-scale irrigation in developing countries. *Land Use Policy* **11**(4): 251–261.

van de Giesen N, Kunstmann H, Jung G, Liebe J, Andreini M, Vlek PLG. 2002. The GLOWA Volta Project: integrated assessment of feedback mechanisms between climate, landuse, and hydrology. In *Climatic Change: Implications for the Hydrological Cycle and for Water Management*, Beniston M (ed.). Advances in Global Change Research vol. 10. Kluwer Academic Publishers: Dordrecht; 151–171.

van Kinderen I. 2006. Social capital in rural dry season farming communities and its effect on the use and implementation of small water reservoirs. MS thesis. Technical University of Delft. The Netherlands.

Vermillion DL. 1998. Impacts of irrigation management transfer: results from IIMI's research. *International Network in Participating Irrigation Management* **7**: 1–21.

Vincent L. 1994. Lost chances and new futures: interventions and institutions in small-scale irrigation. *Land Use Policy* **11**(4): 309–322.

Vincent L. 2003. Towards a smallholder hydrology for equitable and sustainable water management. *Natural Resources Forum* **27**: 108–116.

Yoder R, Martin ED. 1990. Farmer-managed irrigation systems in Nepal. In *Management of Farm Irrigation Systems*, Hoffman GJ, Howell TA, Solomon KH (eds). ASAE: St. Joseph, Mich; 961–968.