WATER USE, PRODUCTIVITY, AND PROFITABILITY OF SMALL SCALE IRRIGATION SCHEMES IN GHANA'S UPPER EAST REGION

A Thesis

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Masters of Science

by

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ABSTRACT

The performance and profitability 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, daily soil moisture, and daily evaporation. Farmer cost inputs and harvest data were also recorded. Water availability contrasted significantly 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 had a Relative Water Supply of 5.7, compared to a value of 2.4 for the Weega system. The Relative Water Supply is the irrigation supply divided by the demand associated with the crops, cultural practices, and irrigated area. It was also concluded that the dissimilar water availabilities resulted in the evolution of very different irrigation methods and management structure. Where there was more water available (Tanga), management could afford to be relaxed and the irrigation inefficient. Where there was less water available (Weega), management was well structured and irrigation efficient. Furthermore, when analyzed at a high market price for crops grown, the Tanga system was half as profitable, in terms of total water used, as the Weega system. Also at a high market price, the Tanga system was 49% more profitable in terms of cultivated land area than the Weega system. The difference in profitability 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 profitability of water can be attributed to the varying irrigation methods and management structures, and ultimately to the contrasting water availability.

BIOGRAPHICAL SKETCH

The author was born in Princeton, West Virginia in 1980. In May of 2003, he completed his Bachelors of Science degree in Biological Systems Engineering at Virginia Polytechnic Institute and State University, with a concentration in Land and Water Resources. He began graduate studies in the Agricultural and Biological Engineering Field at Cornell University in August of 2003.

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The friendship, assistance, and good humor of Jens Liebe and Jan Friesen were a great relief and help during stressful times. I also extend deep gratitude to the people and farmers of the villages of Tanga, Weega, and Zebilla; for without their support and cooperation this project would not have happened.

Finally, I thank God and my family, for without these, nothing would have been possible.

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CHAPTER 1

INTRODUCTION

The average rate of irrigation development for the countries of sub-Saharan Africa from 1988 to 2000 was 43,600 ha/year (FAO, 2001). If this rate continues, then an additional 1 million hectares will be brought into irrigated production by the year 2025. While it is true that many large-scale irrigation systems have been constructed in this region in the past, their performance records indicate failure in regards to their anticipated benefit (Alam, 1991; Kortenhorst et al. 1989; Adams, 1992). As a result of the shortcomings of these large-scale systems, and with the expected continued growth of irrigation development, there is an increasing tendency to promote small-scale irrigation instead (Turner, 1994). The economics of these small-scale irrigation systems can also factor heavily in the livelihoods of those taking advantage of the systems (Vincent, 1994). Also, planners and irrigation engineers are often unaware that economic conditions and the likely performance of systems differ greatly from realities (Guijt and Thompson, 1994). For example, too many systems could lead to over-production, depress prices, and negatively affect the livelihoods of the farmers.

In general, reliable data on small-scale irrigation systems are lacking as few small systems have been technically monitored or have had their performance analyzed (Turner, 1994; Pearce, 1993; Morris and Thom, 1990). 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]. 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]. If more of these systems are to be built, then an investigation of the efficiency of different irrigation systems, in terms of water-use and different application scheme, is a necessary piece of information for planning.

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

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 water demand; and (2) to examine the profitability of the irrigation systems, in terms of water use and cultivated land area.

Two small irrigation systems, within a two kilometer 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 profitability of each system.

CHAPTER 2
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/year. Typically the area experiences a rainy season from late May to mid-October, and a dry season from November through early May. The annual mean temperature is 29 °C, with the annual mean maximum temperature being 34 °C. Millet, maize, and groundnuts, which compose the majority of the diet of the population, are the primary crops grown in upland areas during the wet season. Onions, tomatoes, and a few other 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 meters wide and from 5 to 20 meters long. The onions provide the largest income, while the various other crops provide supplemental food for the home or small profits at local markets.

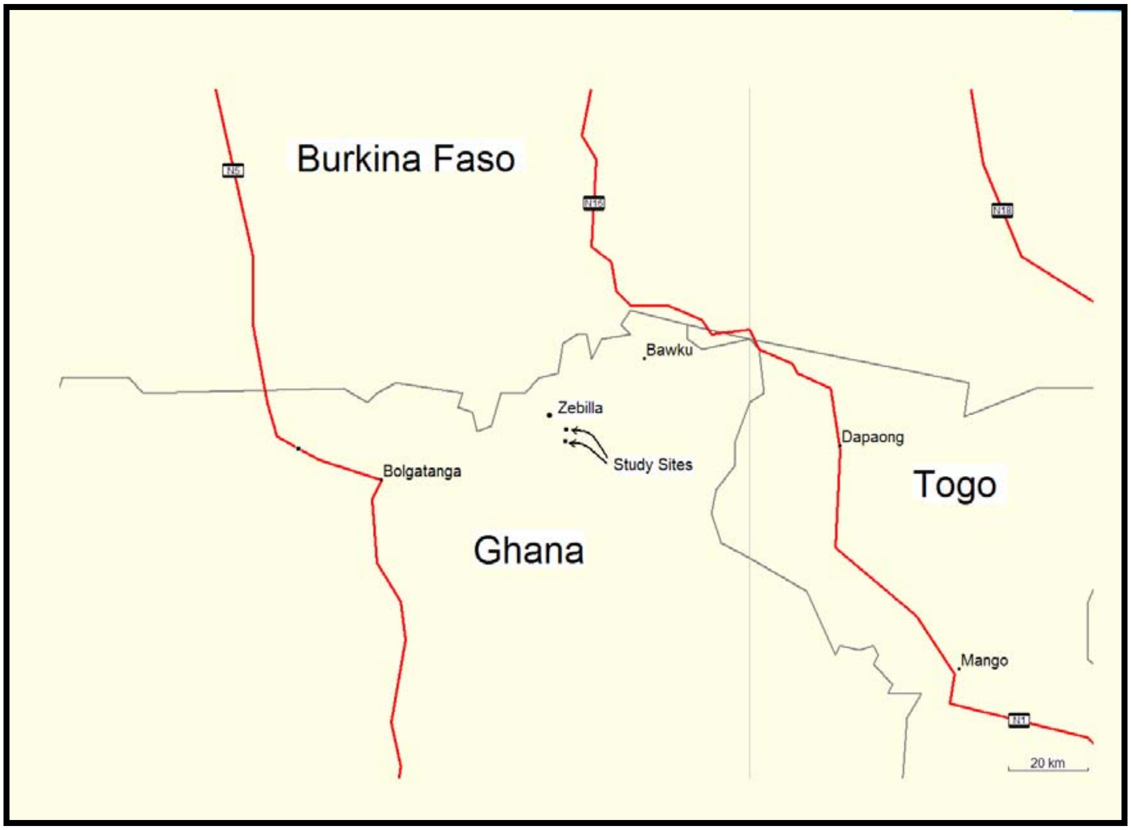

Figure 1: Study Site Location

The reservoir systems collect surface runoff during the wet season, and typically have enough storage that enough water remains at the end of the dry season to sufficiently water livestock and serve basic domestic needs. 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. 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.

Both crop selection and management tasks are performed by the farmers themselves and a farmer-comprised water-user's association. These water-user's associations elect a small number of officials to carry out fee collection and management decisions. All farmers cultivating a plot within the irrigation system are asked to pay a set fee, per plot, to the water user's association. These fees are saved to be used for canal repair and maintenance. As with the majority of small reservoirs in this region, these were built with the financial and technical assistance of a non-governmental organization.

Below the area irrigated by the canals, a small number of farmers have built mud walls and cultivated crops using the drainage water from the irrigation system. After the water passes through the canals, it fans out into a marshy area, where shallow wells can be dug. This 'wasted' water allows limited cultivation to be possible up to a kilometer 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, which is part of a cascading reservoir system, is 10.6 ha in surface area (Liebe, 2002) 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. The upper reservoir in this cascading system was used for irrigation until the release valves malfunctioned. The dam construction was administered by the non-governmental organization Action Aid, reportedly in the late 1980s. Two valves release water into two canals for an irrigation system below the dam. One of the valves leaks, and both canals show deterioration and only see limited maintenance. The two main canals distribute water to plots by means of turn-outs spaced along the length of the canals. These turn-outs 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 turn-out, the vast majority of irrigation is accomplished in the following way: circular basins (approx. 2 meters diameter, 1.5 meters deep) are dug in each farmer's enclosure, a trench is dug connecting the basin to the canal, water flows through the turn-out 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 two hours.

Farmer's plots are chosen in irregular shapes and sizes and spread across the area below the dam, with many areas that have potential to be cultivated left fallow (Figure 2). 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, stays saturated year-round from seepage from the dam and irrigation drainage.

There is a loose water-user's 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.

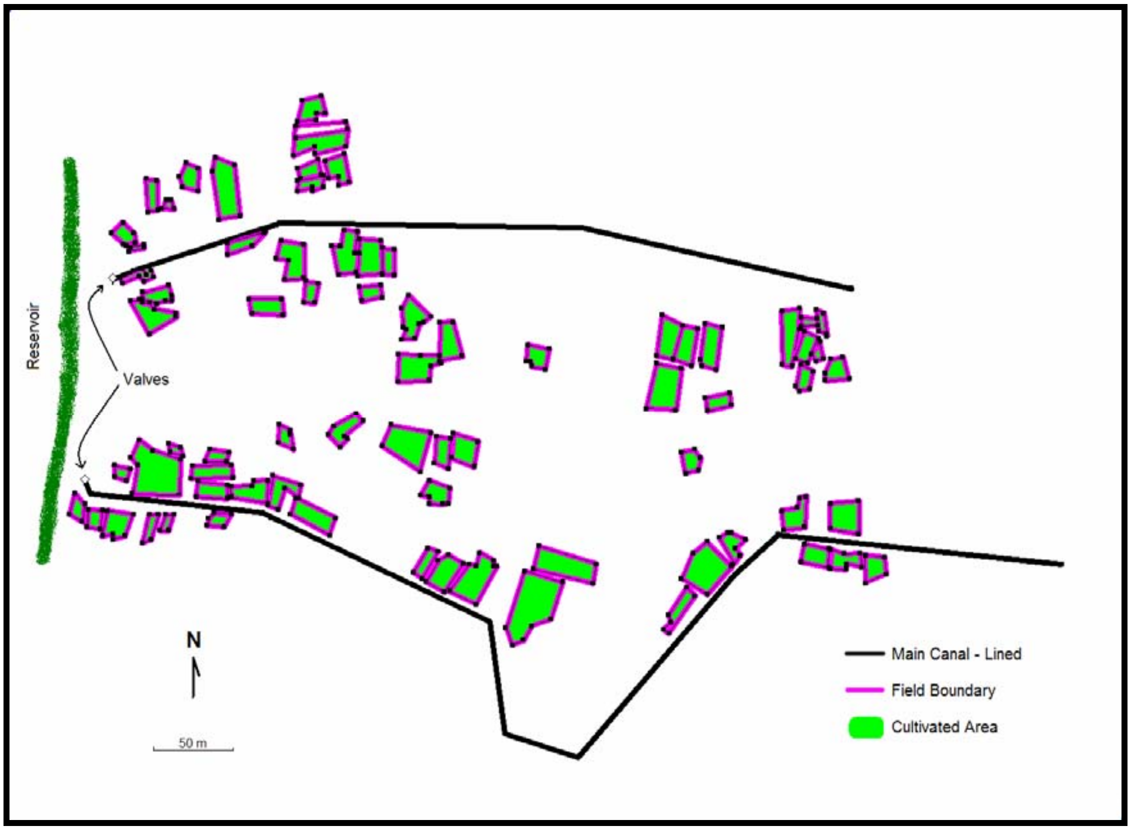

Figure 2: Tanga System Layout

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, 2002), 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 by the Red Cross, reportedly in the mid 1980s. 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 an irrigation system below the dam. The two main canals distribute water to plots by means of turn-outs spaced along the length of the canals. These turn-outs can be plugged with mud or rocks if farmers do not want to irrigate their fields, and opened if irrigation water is needed. At this study site, a turn-out can service many farmers' fields; therefore, farmers also control water by using earthen barriers across the turn-out 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 turn-out into a turn-out 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 hours.

Farmer's plots are chosen in fairly regular shapes and sizes and spread across the area below the dam, occupying most all areas that have potential to 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, stays saturated year-round from seepage from the dam and irrigation drainage.

There is a well formed water-user's 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 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 un-guarded plots. When a breech occurs, it results in a rush to harvest, whether the onions are mature or not.

Figure 3: Weega System Layout

CHAPTER 3

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. During the study period, daily visits and observations were made at both study sites.

Hydrologic data were collected daily at each of the sites. 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, of the capacitance type, were placed in each of the stilling wells. Individual stage height measurements were recorded in one minute intervals. Judging from daily observations, it can be stated with confidence that submergence of the flumes did not occur. This being the case, a discharge error of less than 2% can be expected for all measured flow rates.

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 initial cost 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 amount of profit received from the sale of this additional crop. 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.

Soil moisture was also measured at the Weega Reservoir study site. Measurements were taken in clusters of five in each of six areas, the head, middle, and tail of each main canal. These measurements were performed twice every day, directly before and directly after irrigation. Plots for measurement were chosen at random within each section, and measurement points within the plots were selected to be surrounded by onion plants.

A Class A evaporation pan was placed in the irrigated area below each reservoir, and at a location greater 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 relative water supply 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)

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

where *RWS* = Relative Water Supply; *S* = supply of irrigation water (cm); and *D* = demand of irrigation system (cm). The supply of irrigation water is described by the expression

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

where *P* = rainfall (cm); *Gr* = groundwater contribution (cm); and I_s = water released from reservoir during sample period (cm). In this case, there was no rainfall, so *P* = 0. The groundwater contribution, *Gr*, is assumed to be negligible in the irrigated areas. Equation (2) can now be reduced to

$$S = I_s \tag{3}$$

I_s was 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.

The demand of the irrigation system is described by the expression,

$$D = ET_c \tag{4}$$

where ET_c = evapotranspiration from the crops (cm), otherwise known as consumptive use. ET_c was calculated using the method described in the FAO Crop Evapotranspiration publication (1998). Weather data were inserted into the proper FAO equation to calculate an evaporation pan coefficient. This pan coefficient was then multiplied by the average weekly evaporation rate to obtain the reference crop evapotranspiration. The crop coefficient was then multiplied by this reference crop evapotranspiration to obtain ET_c. The same nine week sample period (Jan. 15 – Mar. 18) was used when determining the ET_c value. Only a mid-season crop coefficient was used to calculate the ET_c due to the fact that this nine week period occurred during the middle of the growing season. Unless standing water is present, or leaching is performed for salinity control, seepage and percolation losses are not included in the water requirement for the production of a vegetable or upland crop unless. Neither of these conditions occurred at either of the study sites. Although it would be very difficult to prevent percolation losses in earthen trenches, the water lost is not essential for crop growth, and therefore is not included in the demand. Substituting the new expressions for supply and demand, *RWS* can now be described by the expression

$$RWS = I_s / ET_c \qquad (5)$$

<u>Calculation of Profitability</u>

The profitability of each of the study sites was determined using two different methods. The first method determined the profitability based on profit per volume of water released from the reservoir

$$P_w = p / I_t \tag{6}$$

where P_w = profitability of water released ($/$m^3$); p = sum of profits of all farmers at reservoir ($); and I_t = total volume of water released from reservoir (m^3). Individual farmer's profits were determined using the difference between the total cost of inputs 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. The low price (≈ $8.60) was common during April, the medium price (≈ $17.20) was common through May, and the high price (≈ $43.01) was likely in the following months if onions could be stored effectively.

The second method determined profitability based on profit per area of cultivated land

$$P_L = p / A \tag{7}$$

where P_L = profitability of land area ($/ha); and A = land area under cultivation (ha). This profitability was also calculated using three different potential incomes based on the same three market prices of onions used for P_W.

CHAPTER 4

RESULTS AND DISCUSSION

Evaporation Data

Table 1: Average Evaporation Rates

Location of Pan	Average Evaporation Rate, mm/day
Tanga Reservoir	7.1
Weega Reservoir	7.5
Desert	10.2

The average evaporation rates for the three Class A evaporation pans are displayed in Table 1. 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 43.7% higher than the rate from the Tanga pan, and 36.0% 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 by extending the width of the boundary layer; therefore, effectively lowering the evaporation rate from the Tanga pan.

Table 2: Weekly Recorded Weather Data and Pan Coefficient

	Week								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
R.H. (%)	31	31	30	26	28	46	36	37	54
Windspeed (m/s)	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

Table 3: Weekly Recorded Average Evaporation Rates

	Rate, mm/day								
Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
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

To obtain evapotranspiration rates, the FAO method (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 2). Once the pan coefficient was obtained, it was multiplied by the average recorded evaporation rate for the week (Table 3), resulting in the reference crop evapotranspiration (Table 4). This reference crop evapotranspiration was then multiplied by the mid-season crop coefficient (1.05 for onions) to obtain the evapotranspiration rates in Table 5. These values can then be used for determining crop water demand.

Table 4: Weekly Reference Crop Evapotranspiration

	Rate, mm/day								
Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
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

Table 5: Calculated Evapotranspiration Rates

	Rate, mm/day								
Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
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

Soil Moisture

The following four figures display the soil moisture data recorded from plots irrigated by the two main canals in the Weega system. Figure 4 and 6 show the soil moisture before irrigation and Figure 5 and 7 show the soil moisture directly following irrigation[1]. In general, the soil moisture in the plots at the tail end of the canal is lower than the soil moisture in the plots in the middle and at the head of the canal. Figure 8 and Figure 9 display the change in the soil moisture between measurements performed directly before irrigation and those performed directly after irrigation[1]. No consistent significant difference in moisture changes between the head and the tail of the system can be deduced from these recorded data. The moisture changes are too variable to state with confidence a consistent trend.

Even though moisture differences do exist along the irrigation system, application rates can not be implicated in these discrepancies. Farmers toward the head of the canals were repeatedly instructed by water-user association leaders not to open their turnouts until farmers toward the tail end of the canal had sufficient time to water their crops. It can be speculated that these management measures helped ensure all farmers received an equal water allocation. One possible reason for the differences in head to tail soil moistures may be soil type differences, as soils towards the tail of the system were consistently more sandy than those soils located at the head of the system.

[1] Missing data on 2/7, 2/12, 2/13, 2/20, 2/21, and 2/28-3/4 due to equipment tampering

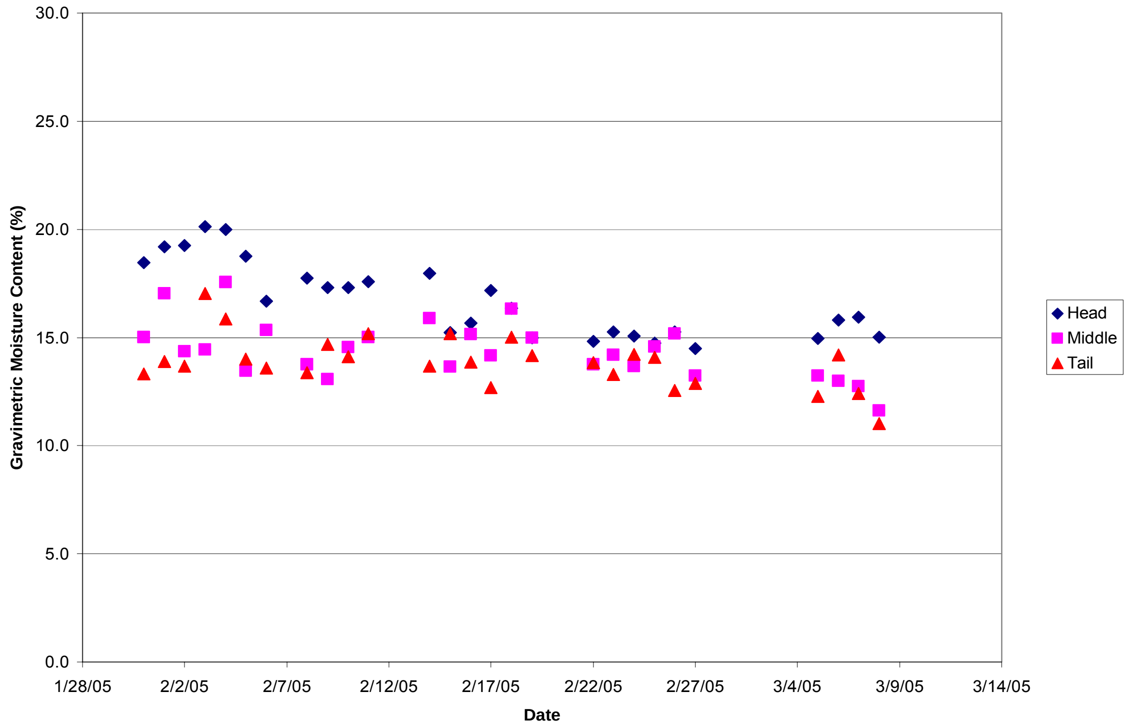

Figure 4: Soil Moisture before Irrigation - Weega Canal A

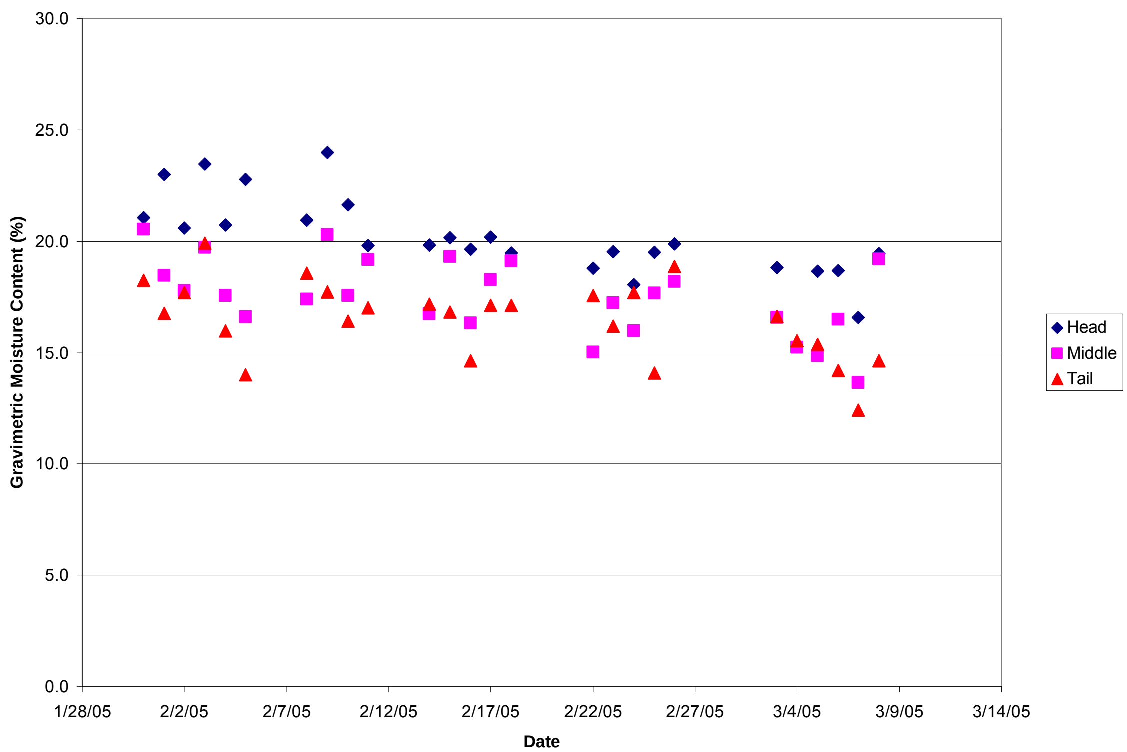

Figure 5: Soil Moisture after Irrigation - Weega Canal A

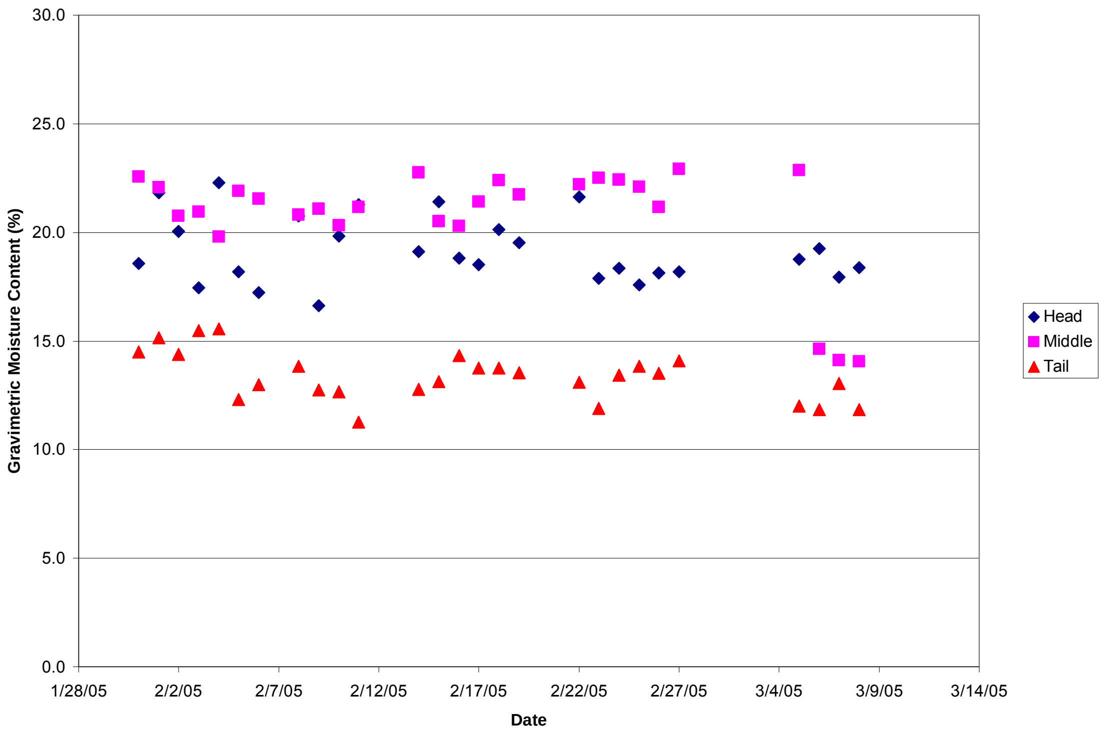

Figure 6: Soil Moisture before Irrigation - Weega Canal B

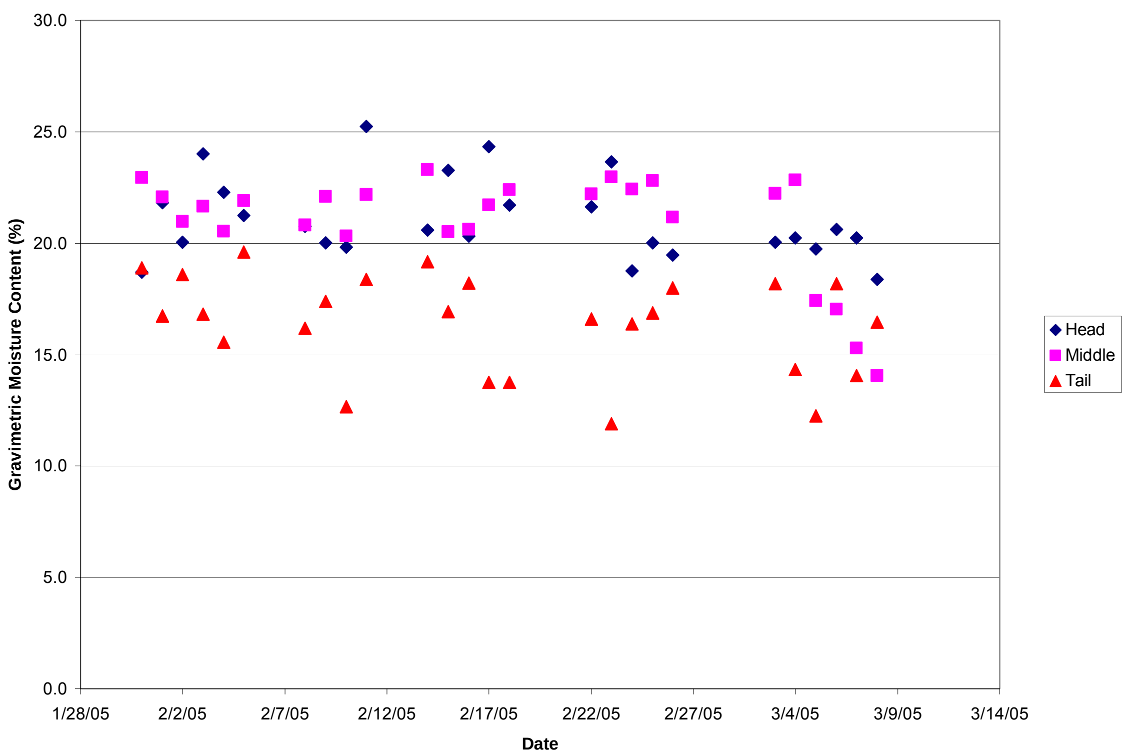

Figure 7: Soil Moisture after Irrigation - Weega Canal B

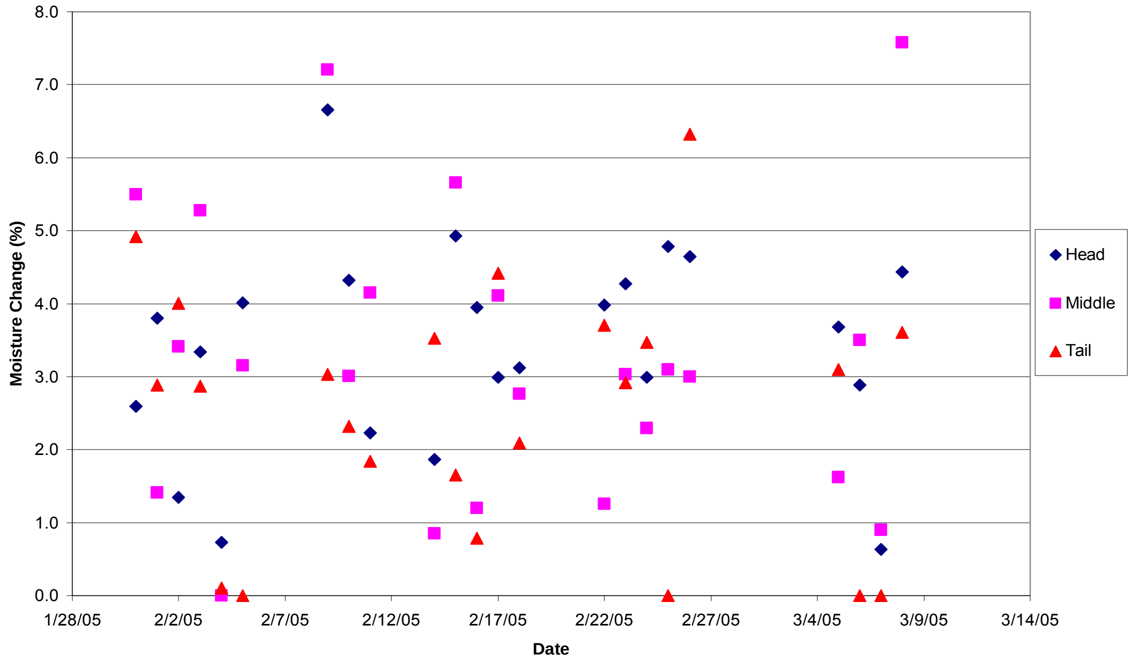

Figure 8: Soil Moisture Change during Irrigation - Weega Canal A

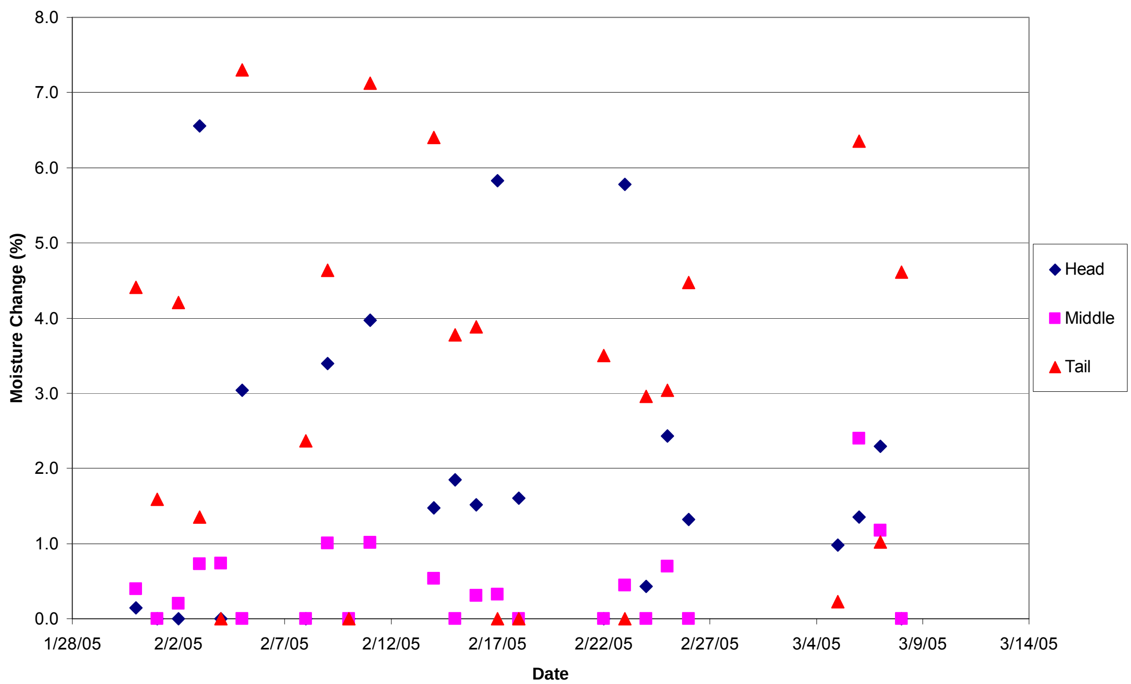

Figure 9: Soil Moisture Change during Irrigation - Weega Canal B

Farmer Cost

Table 6: Input Cost and Yield

Reservoir	Input Cost ($/ha)	Yield (sacks/ha)
Tanga	1687	85
Weega	946	53

Table 7: Cost Breakdown

Reservoir	Fertilizer Cost ($/ha)	Pesticide Cost ($/ha)	Seed Cost ($/ha)	All Other Costs ($/ha)
Tanga	961	80	599	48
Weega	457	48	393	47

Table 6 shows the cost of crop inputs and subsequent yields per area cultivated for each study site. 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. Table 7 shows a breakdown of farmer costs into fertilizer, pesticide, seeds, and all other costs. 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). 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.

Water Distribution, Use, and Availability

Table 8 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.

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. Judging from this information, it can be speculated that the difference in the values between the two canals at the Tanga system is a result of the relaxed management structure.

Table 8: Irrigated Areas

	Area under Cultivation (ha)	**Total Water Released for Season (m^3)**	**Water Released per Area Irrigated (m^3/ha)**
Tanga Canal A	0.8629	34121	39542
Tanga Canal B	0.7591	19245	25352
Weega Canal A	2.8824	32373	11231
Weega Canal B	3.1245	35895	11488
Tanga Total	1.6220	53366	32901
Weega Total	6.0069	68268	11365

Relative Water Supply

Table 9: 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 cumulative supply and demand, and the RWS of both reservoirs for the entire nine week sample period, are shown in Table 9. Both the 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 average RWS value of the Tanga system for the sample period is greater than twice the RWS value of the Weega system. The RWS values for each of the nine weeks during the sample period are shown in Figure 10. 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 basin and bucket system results in more water being released, in relation to crop demand, than in the trench system to satisfy farmer's needs. At the Weega site, where the RWS is much lower, the farmers employ the less water-demanding trench system. Although the trench system is ultimately a more efficient irrigation method, it was observed that the labor input was generally much higher for farmers using this system. During a trench system irrigation, farmers worked intently and moved quickly around their plots, attempting to make use of all available water. In contrast, during a basin and bucket system irrigation, farmers would stand idle while their basin slowly filled and then carry water to their crops at their leisure.

The higher water availability at the Tanga site, validated by a higher RWS, also resulted in a weaker management system. As an example, the opening and closing of the canals at the Tanga system was not always performed by the caretaker. Farmers wanting water would sometimes open

when they desired, finding the valve key near the head of the canal. This has resulted in massive canal failure and water wastage, due to the failure to close the release valve at the end of the day. The management and organizational structure at the Weega system was strong, and the opening and closing of the canals was only performed by the caretaker and was fairly punctual. In the latter part of the growing season, the volume of water in the Weega reservoir was becoming low enough to evoke farmer concern that the water would drop below normal end-of-season levels if irrigation continued on a daily schedule. As a result, the leaders of the water user's association dictated that water would only be released on an every-other-day schedule. This schedule was also adhered to rigidly by the caretaker. In comparison, a much higher percentage of total storage remained in the Tanga reservoir toward the end of the cropping season; therefore, there was no perceived cause to strengthen management.

During week five at the Tanga system, a canal was inadvertently left open throughout the night. During week six, also at the Tanga system, there was a day when no irrigation was performed. This day of no irrigation, and the night-long opening the week before, is reflected in the difference of 3.9 in the RWS value between weeks five and six. 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 10).

The higher RWS value of the Tanga system verifies the assertion that, as a result of higher water availability, the management structure was weaker and the chosen irrigation method was less efficient. It is reasonable to state that if the available water at the Tanga system was reduced, or the cropped area was increased, the farmers could be forced to improve their management structure, switch to the trench irrigation method, or both.

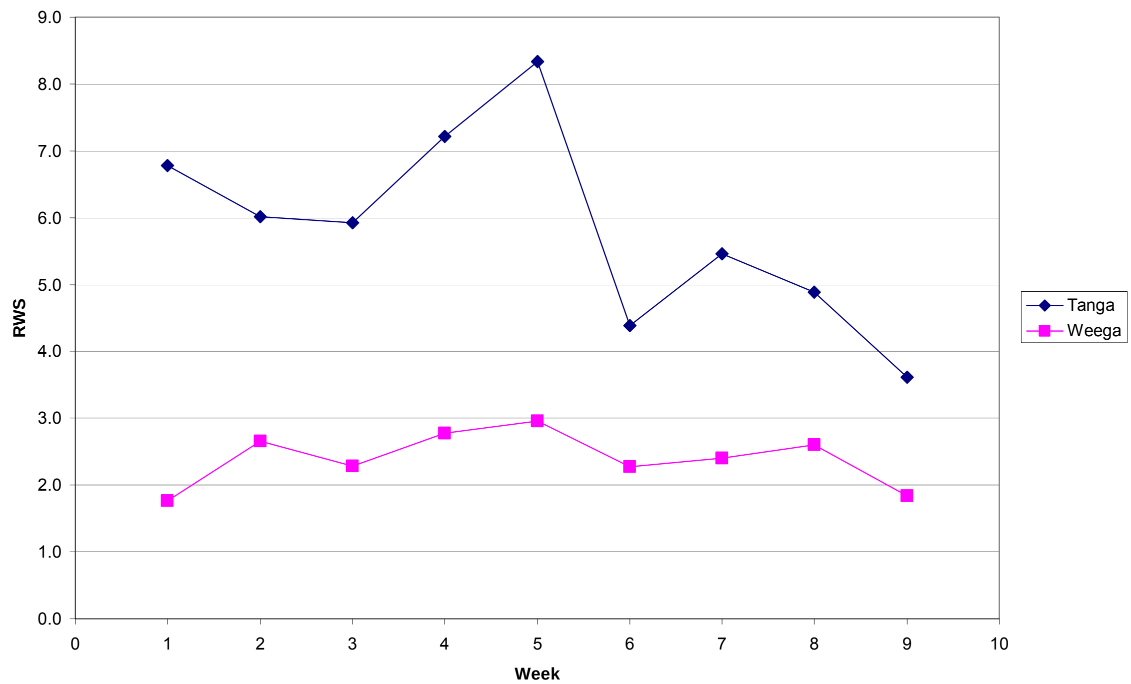

Figure 10: RWS for Nine Weeks Starting Jan. 15 and Ending Mar. 18

Table 10: 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

Profitability

The profitability of each reservoir is shown below in Table 11 and Table 12, in terms of profit per cultivated area and profit 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.

Table 11: Profitability of Land

Reservoir	**Profit (+) or Loss (-) per Cultivated Land Area ($/ha)**			
	Market Price	Low	Medium	High
Tanga		-857.96	-93.83	+2198.53
Weega		-441.72	+37.57	+1475.45

Based on the profitability of land, the Tanga system is less profitable 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 profit. At the high market price, the Tanga system is 49% more profitable than the Weega system. This difference in profit per cultivated land can be considered in conjunction with the farmer costs (Table 6) and the absence of water stress affecting crop growth. As water stress is not a limiting factor, it can be speculated that the increased profit per cultivated land is due primarily to the increased fertilizer, pesticide, and seed inputs, and not irrigation technique or management.

Table 12: Profitability of Water

Reservoir	**Profit (+) or Loss (-) per Volume of Water Released ($/m³)**			
	Market Price	Low	Medium	High
Tanga		-0.03	+0.00	+0.07
Weega		-0.04	+0.00	+0.13

Based on the profitability of released water, the Tanga system is less profitable 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 profitable as the Tanga system. It can be conjectured that this relatively high profit per volume 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 profitability of water is therefore ultimately a result of this lower water availibility.

Using either measure of profitability, during this study year the systems do not experience a significant profit, or rather experience a loss, at a low or medium market price. Although these data offer a general range of profits, they are likely to differ from year to year. Disease, drought, and input costs all have an effect on the profit. Continued monitoring is advisable to more accurately determine the long-term profitability of these small-reservoir systems. Well-designed storage facilities for onions are likely to increase profits, 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 profitability of these systems. If the supply of dry-season cash crops increases, prices could conceivably drop below the point where profits could be attained, even from well-stored onions.

CHAPTER 5

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 is 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 and profitability.

The high RWS values of both the 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 resulted in 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 at 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. The Tanga system could feasibly adopt a management structure and irrigation method similar to the Weega system if this decrease in water availability were to occur. 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 profitability 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 profitability 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 profitability 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 profitability 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 profitability. This continued monitoring would also add to the currently limited knowledge base and help indicate what effect the construction of more systems would have on the produce markets and the livelihoods of farmers.

Although differences in soil moisture between the head and tail of the system do exist in this system, water allocation rates cannot be implicated. In general, farmers at the tail of the irrigation system receive equal water as those at the head of the irrigation system. If the system were to expand, increased management would be critical to ensure that all farmers received equal water allocations.

It can also be hypothesized that irrigation systems transected by many mud walls will experience a lower crop evapotranspiration rate than those systems that are not. This reduced rate is attributed to the wind-breaking effect of the walls.

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