PRODUCTIVITY OF WATER AND ECONOMIC BENEFIT ASSOCIATED WITH DEFICIT IRRIGATION SCHEDULING IN MAIZE

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Abstract

Deficit irrigation scheduling is one way in which farmers practicing irrigation farming can cope with the pressure that has been put on them to reduce water used for crop production in order to release water for other sectors. A field experiment was carried out at the Igurusi ya Zamani indigenous irrigation scheme in Mkoji Sub-catchment of the Great Ruaha River Basin in Tanzania, during the 2004 dry season, to investigate deficit irrigation scheduling protocols for maize for better productivity of water and economic benefit. The results showed that an irrigation scheduling protocol which entails skipping every other irrigation event at vegetative growth stage of the crop (crop establishment to tasseling initiation), and maintaining a regular 7-day irrigation interval at other growth stages, gave the highest productivity of water. For example, the productivity of water in terms of evapotranspiration ($PW_{(ETa)}$), and water applied ($PW_{(irrigation)}$), were 0.58kg/m^3 and 0.50kg/m^3, respectively. The crop yield from the scheduling protocol was not significantly different (P=95%) from what was obtained from the treatment that received regular irrigation at 7-day irrigation interval throughout the crop-growing season. The economic benefit calculated for the scheduling protocol (in terms of water and labour saved compared with the yield lost) amounted to about 20,000 Tsh/ha for large farms water users and about 15,000 Tsh/ha for small farms water users. It is recommended that further research work be carried to evaluate the performance of the scheduling protocol across irrigation cropping seasons

***Keywords**: Deficit irrigation scheduling, Evapotranspiration deficit, Crop yield, Water use, productivity of water, irrigation, Economic benefit*

Introduction

The chances of increasing crop production in the Sub-Sahara Africa through expansion of more area under cultivation in rain-fed agriculture are low. Apart from the fact that cultivable areas are dwindling *(Young, 1999),* unreliable rainfall, both in terms of distribution and amount, is a major limitation to how much can be realized through rain-fed agriculture in the region. Although, there seems to be better hope to increasing crop production under irrigated agriculture, the rapidly dwindling water resources and the growing increase in competition for water by non-agricultural sectors is now a course of concern to irrigation stakeholders.

Irrigated agriculture is under pressure to cut down the amount of water use for crop production and at the same time expected to produce more crops with less water. The need to minimize the amount of water used in irrigation is a common concession among stakeholders in water resource management. As a step towards achieving the objective of more crop per drop of water, there is the need for irrigators to begin to adopt the use of techniques and practices that regulated water application to crops and minimize needless waste. One of such practices is regulated deficit irrigation scheduling (DIS).

The objective of regulated deficit irrigation is to save water, labour, and in some cases energy, by subjecting crops to a period of moisture stress with minimal effects on yield. The water stress results in less evapotranspiration in plant due to closure of the stomata, reduced assimilation of carbon, and decreased biomass production (Smith and Kivumbi, 2002). When the water stress is not severe, the reduction of biomass production will have little adverse effect on ultimate yield and can lead to appreciable increase in productivity of water. But when the water stress is severe or occurs at the critical growth stages of a crop, deficit irrigation may only lead to drastic reduction in crop yield and a negative impact on productivity of water and economic returns.

The subject of deficit irrigation and the effect of moisture stress is widely reported in literature *(Jensen 1968, Doorenbos and Kassam, 1979, English, 1990, FAO, 2002)*. The effect of deficit irrigation for the same crop may vary with location as it very much depends on climate, which dictates the evaporative demand, and soil type, which dictates the available water for plant uptake. There is therefore a need for comprehensive assessment of DIS strategies for any location before recommendation and advice can be made on protocol to be adopted in an area. More importantly, the benefit associated with such scheduling need to be known and appreciated by farmers. Farmer do not practice irrigation scheduling because they have not be made to appreciate its essence in terms of economic benefit (*Westhuizen and Annandale, 1996)*, The primary objective of the work reported here was to study the consequence of some DIS protocols for maize in terms of productivity of water and to quantify the economic gain or otherwise, associated with the scheduling protocols.

Materials and Methods

The study area

Location

The experiment was carried out in one of the Tanzanian Ministry of Agriculture Training Institute (MATI) farms located in *Igurusi ya Zamani* Indigenous Irrigation Scheme, Igurusi, Mbeya Region. The irrigation scheme lies on latitude 8.33^o South and longitude 33.53^o East, at an altitude of 1100m to 1120m above sea level. The source of water for the scheme is the Lunwa River, which is one of the perennial rivers in Mkoji Sub-catchment of Great Ruaha River Basin. The Great Ruaha River basin is one of the four basins that make up the Rufiji River Basin. Figure 1 shows the map of Tanzania and the location of the Mkoji sub-catchment in the Rufiji River Basin. Figure 2 shows the Mkiji sbu-catchment and the location of the area where this study was carried out.

Figure 1: Location of Mkoji Sub-catchment within the Rufiji Basin in Tanzania (SWMRG, 2004)

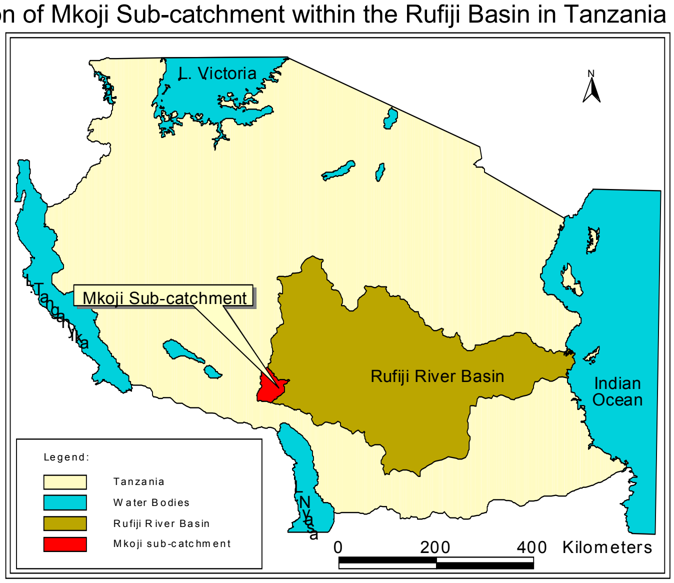
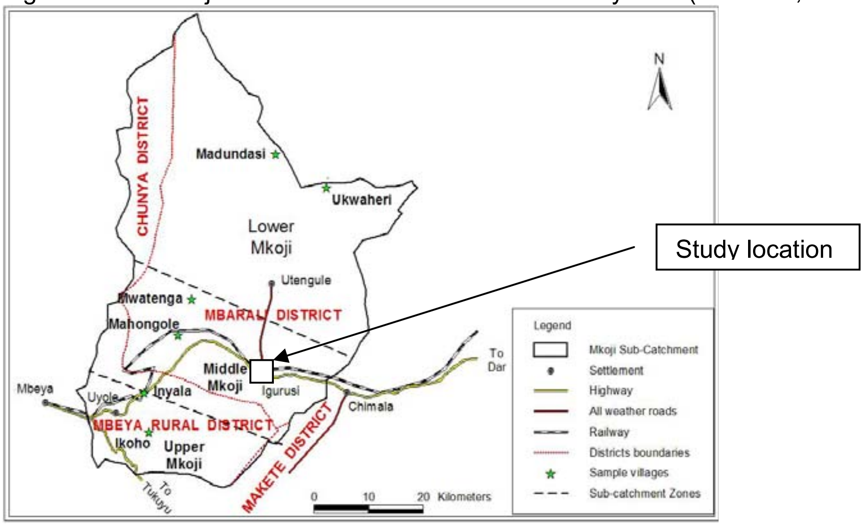


Figure 2: The Mkoji Sub-catchment zones and the study area (SWMRG, 2004)



Climate

The mean annual rainfall in the study area is about 800mm in the *wet years* and 450mm in the *dry years*. The rains fall between November and April. The area has a unimodal type of rainfall. The mean daily maximum and minimum temperature range from 28°C to 32°C and 9.5°C to 19.5°C, respectively. The highest values are recorded in October and November while the lowest values are experienced in June and July. The mean daily net solar radiation varies from 7.5 MJ/m^2/day to 12.3 MJ/m^2/day. The average annual evaporation is 1701mm. The total evaporation from July to October when dry season farming takes place is 640mm. The climate of the area, which is typical of Usangu Plain, favours the cultivation of cereals, legumes and vegetable under irrigation during the dry season.

Soil

The soils of the study area are typical of Usangu plain as described in *SWMRG (2004)*. The soil characteristic of the field where the experiment was laid is showed in Table 1. The soil textural class is sandy clay loam. The mean water holding capacity of the soil is 104 mm/m.

Table 1. Soil properties of the experimental field

Soil Profile Depth	Moisture content at field capacity	Moisture content at wilting point	Soil bulk density	Organic Carbon	pH in H_2O	Clay	Silt	Sand	Text. Class
mm	m^3/m^3	m^3/m^3	g/cm^3	%		%	%	%	
0-150	0.282	0.097	1.44	1.34	6.39	19	18	64	Sandy loam
150-400	0.295	0.163	1.39	0.85	6.12	31	17	52	Sandy clay loam
400-700	0.305	0.226	1.45	0.39	6.28	33	22	45	Sandy clay loam
700-1000	0.278	0.212	1.38	0.46	6.56	36	19	45	Sandy clay

Land use

During the dry season, *Igurusi ya Zamani* Indigenous Irrigation Scheme is actively cultivated during the dry season. Maize is the lead crop cultivated under irrigation in the area, although crops like tomato, beans and Chinese cabbage are also actively cultivated. In the 2004 dry season, more than 105 plots ranging from 0.1ha to 0.8ha were cultivated with maize in the irrigation scheme by the indigenous farmers. Most farmers sell their produce as green maize, which fetch more money than dry grains. Harvesting the crop while it is still green reduces their labour of harvesting and processing of grains. It also gives them enough time and space to start rainy season cultivation. Farmers in the scheme operate a Water User's Association by which they manage the scheme especially in terms of maintaining the main and secondary canals; regulate the distribution of water and allocation of farmland to intended farmer in the scheme.

Experimental treatments description

The experiment consisted of 8 treatments, with frequency of irrigation as the only variable. Two frequencies: a 7-day and a 14-day irrigation frequency were used. A treatment that was used as reference to the other treatments was irrigated at 7-day interval through out the crop-growing season. The other treatments were varied by skipping the regular 7-day irrigation event after every other irrigation during the time span of a growth stage of the crop. Such act of skipping an irrigation event puts the affected treatment on a 14-day irrigation frequency until the growth stage is over. Three growth stages were considered. These were the crop establishment (24 Days after Planting, DaP,) to tasseling initiation (66 DaP), referred to as the vegetative stage in this study; the tasseling initiation to end of silking (66 to 94 DaP), which was the flowering stage; and grain filling to maturity (94 to126 DaP), which was the fruiting stage. Table 2 shows the treatment description.

Table 2. Description of the experimental treatments

Treatment label	Description
1	Regular irrigation carried out at 7-day interval throughout the crop growing season
2	Skipped every other regular irrigation at vegetative only, and irrigated at 7-day interval in other growth stages
3	Skipped every other regular irrigation at flowering only, and irrigated at 7-day interval in other growth stages
4	Skipped every other regular irrigation at fruiting only, and irrigated at 7-day interval in other growth stages.
5	Skipped every other regular irrigation at vegetative and flowering only, and irrigated at 7-day interval at fruiting growth stage.
6	Skipped every other regular irrigation at vegetative and fruiting only, and irrigated at 7-day interval at flowering growth stage.
7	Skipped every other regular irrigation at flowering and fruiting only, and irrigated at 7-day interval at vegetative growth stage.
8	Skipped every other regular irrigation throughout the crop growing

Based on the calculated crop water requirement for irrigated maize and the soil moisture retention characteristic of the study area, a design irrigation frequency for maize was calculated as: 11 days, 6 days and 8 days for the vegetative, flowering, and fruiting growth stages, respectively. It was therefore expected that by skipping the regular 7-day irrigation event in any treatment, crops would be subjected to some level of moisture stress before the next irrigation, due to the evapotranspiration deficit caused by limited soil moisture within the plant root zone. The 7-day irrigation frequency was used as the reference treatment since this was the schedule that is practiced for maize in the scheme and based on the water rotation formula operated by the WUA in the irrigation scheme.

The experimental treatments were laid in a randomized complete block design and each treatment except treatments1 and 8 was replicated three times. Treatment 1, which was receiving regular irrigation, and treatment 8 where irrigation was skipped once after every other irrigation, was replicated 6 times. This was done to provide three separate replicated plots for collecting samples for dry matter measurement.

Agronomic practices

The maize variety used for this experiment was TMV1-ST, which is a composite. It is one of the maize varieties commonly grown under irrigation in the study area. The interesting features of the maize variety which makes it preferred under irrigation is that it is stress tolerant, short growth duration (115-120 days) and is tolerant to maize streak disease (*Dr Lyimo, personal communication*).

Planting was done on 24 June 2004. Planting was done on flat basins of size 3.5 by 3.5 m^2. The crop was planted in rows at plant spacing of 75cm between row and 30cm between plants. Three seeds were planted per hole. Crop attained 100% germination six days after planting and was thinned to 1 plant per stand two weeks after planting. The plant population was 50,000 plants/ha.

Diammonium phosphate (DAP) fertilizer was applied at the rate of 60 kg of potassium/ha at planting by placing the fertilizer 6-8cm away from the hole where the seeds were placed. Top-dressing was carried out at five weeks after planting with Urea fertilizer. The total Nitrogen applied from the two fertilizer applications was 120 kg N/ha. The Southern Highland Research Institute, Uyole, recommended this level of fertilizer for maize in the study area. Weeding was done four times before harvesting. *Celecron* insecticide was sprayed two times to control stem borers.

Irrigation was by gravity and a average discharge of 4 litres/sec was diverted into the experimental field from a tertiary canal. This discharge was allowed to flow into each basin at a time. An average time of 2.5 minutes was used to apply the desired depth of water into each plot. The point of water entrance into each plot was constructed with brick and the floor lined to avoid erosion. In order to measure the depth of water applied to each plot, a graduated staff gauge was placed beside the brick. Each staff gauge was calibrated using a cutthroat flume. With the aid of a calculator and a stopwatch, the flow discharge into each plot and the time required to apply the desired depth of water was immediately calculated as soon as water is introduced into the plot. Water was allowed into the plot for the time calculated. A sheet metal plate was used to close the entrance to stop water from entering the plots.

The depths of water applied at each irrigation event include: 30mm depth of water from planting to end of the first stress-cycle of the vegetative growth stage (5th week after planting); 40mm depth of water during the other two stress-cycles of the vegetative growth stage (6th-9th week after planting); and 50 mm depth of water during the flowering and fruiting growth stages, respectively. However 40mm depth was applied at the last irrigation (16th week after planting). A pre-planting irrigation was done at 30mm depth of water 3 days before planting. These depths of water applied were based on weekly sum of the daily reference evapotranspiration for the study area. The daily reference evapotranspiration was calculated using the FAO-Penman-Monteith Model. The weekly sums were rounded up to the nearest round figure. Irrigation was withdrawn on 16 October 2004.

The crop matured for harvest on 28 October 2004, at 126 DaP, but was left on the field to dry until 11 November 2004 when it was harvested by cutting the aboveground biomass. After cutting, the crop was left on the field for one week for further drying before weighing and removing the maize from the stalks. The maize was dried in the open sun for 5 days; threshed and weighed. The grain moisture content at threshing was determined in the laboratory and was found to be about 13%.

Data collection and analysis

Soil moisture content

Soil moisture content was monitored throughout the crop-growing season using a ML1 Theta Probe. Soil moisture content was measured at 2 days after an irrigation event, and just before the next irrigation (7th day) in all the treatments. The two periods were termed *wet* and *dry measurements.* When irrigation was skipped in any treatment, soil moisture content was measured 2 days, 7 days and 9 days after irrigation, and just before the next irrigation event (14th day). The 7 and 9 days coincided with the dry and wet measurements of the treatments under regular irrigation frequency. Moisture measurements were made at 8cm, 30cm, 55cm and 80cm depth below the soil surface. The measurements taken at these depths were considered to represent soil profile depths of 0-15cm, 15-40cm, 40-70cm, and 70-100cm, respectively. Three pieces of 7.6cm diameter PVC pipes were installed to the depth of 30cm, 55cm and 80cm, respectively, in each plot to provide access to insert the theta probe into the soil to the depths of measurement. A hand hole was used to open up the soil surface to the depth of 8cm to insert the probe into the soil for the top profile measurement. A special handle was constructed to hold and lower the probe to the profile depths through the access pipe. The theta probe gives soil moisture content reading in volumetric ratio. The difference between two successive moisture measurements was taken to be crop water use (evapotranspiration) based on the water budget method of estimating actual crop evapotranspiration (James, 1988). It was assumed that deep percolation within the root zone was negligible 2 days after irrigation. There was no runoff as the bunds of the basins were built to accommodate the volume of water applied.

Crop growth parameters

Crop growth was monitored throughout the crop-growing season. Plant height of ten tagged plants were measured using a tape rule. The leaf area index was measured using the Accupar Ceptometer. Dry matter yield was also determined from treatments 1 and 8 by cutting aboveground biomass of the crop from an area of 1.8m^2 in the replicated plots tagged for that purpose. These plots were different from those in which soil moisture measurements were been taken. The cut matters were dried in an oven for 72 hours at 65^{o}C and weighed. The final dry matter and grain yield were measured at final harvest. Only the results of grain yields are given in this report.

Productivity of water and economic benefit calculation

The productivity of Water with reference to evapotranspiration ($PW_{(ETa)}$) was expressed as:

$$PW_{(ETa)} = \text{crop yield (kg)/ crop water use (m}^3\text{)}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

The productivity of Water with reference to irrigation water applied ($PW_{(irrigation)}$) was expressed as:

$$PW_{(irrigation)} = \text{crop yield (kg) / irrigation water applied (m}^3\text{)}\ldots\ldots\ldots\ldots \text{(2)}$$

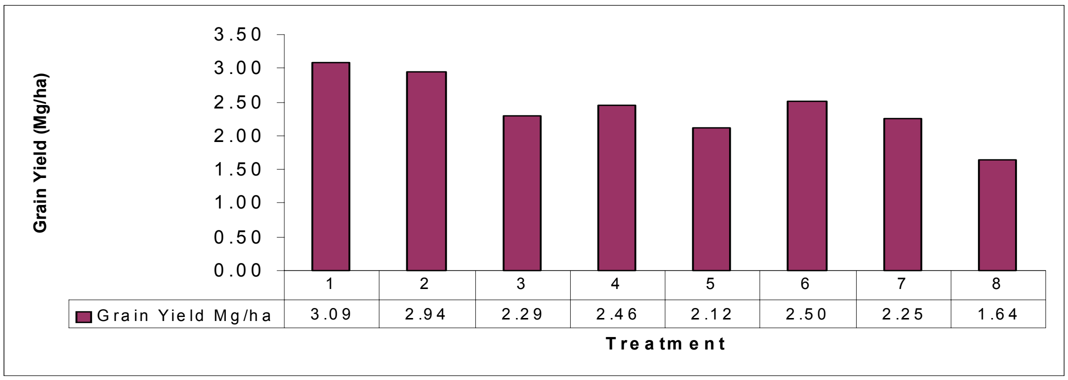
Economic benefit with respect to the scheduling protocols was calculation as the difference between the revenue lost due to yield decrease as a result of the deficit irrigation schedule and the sum of the cost of labour for irrigation gained and the water saved by skipping the irrigation event. A farm gate price of 1200 Tanzanian Shilling (Tsh)/20kg of maize was used in the calculation of revenue lost due to yield decrease. The cost of labour to irrigate an hectare was estimated at 6000 Tshs per irrigation based on a man-day labour cost of 1500 Tshs. 4 people were projected to effectively irrigate an hectare within 6 hours of water supply. Although, farmers in the study area have not started paying for water (they only pay a token of 1000-2000 Tshs to their association based on farm size once a season either as membership due, or for coming to the scheme to farm), an attempt was made to put a price per cubic metre of water used in order to calculate the economic benefit of water saved. A price of 50 Tshs per 10m^3 for small farm size (about 1 ha) and 100 Tshs per 10m^3 for large farm size (above 1 ha) was assumed. The value for domestic water in the area was estimated as 1000 Tshs/m^3 (SWMRG, 2004). It was assumed that if large farms water users pay the domestic water price and the small farms water users pay half of that price, it will be a fair consideration. This was based on the premise that large farms use more water. They should therefore be made to pay more for water so as to encourage them to schedule irrigation.

Results and Discussion

Crop yield

Figure 1 shows the grain yield of maize for the different treatments. The reference treatment, (Treatment 1), which was irrigated at 7-day interval throughout the crop growing season had the highest grain yield of 3.09 Mg/ha. Treatment 8 in which an irrigation event is skipped after every other irrigation throughout the crop-growing season had the lowest yield of 1.64 Mg/ha. The yield from the reference treatment was about the lower range of the estimated potential yield level for cereals in the Sub-Sahara Africa, given as 3-5 Mg/ha *(Barron, 2004).* However, it was less than the 3.8 Mg/ha potential yield level simulated for maize in Machakos district, Kenya, using a crop growth simulation model (Barron, 2004). The yield from treatment 8 was lower than the average grain yield of irrigated maize from farmers' field in the study area, which is given as 1.78 Mg/ha *(SWMRG, 2004).*

Fig. 1. Grain yield of maize cultivated under deficit irrigation scheduling



A statistical comparison of the grain yields of the treatment showed that there was a significant difference among the yields at statistical level of significance of 95%. The mean ranking at *LSD=0.05* showed that treatment 1 was not statistically different from treatment 2, but the two treatments were significantly different from the others. The yield from treatment 4 and 6 were also not statistically different for each other, but were different from the other treatments. The percentage yield loss among the treatments when compared with the reference treatment varied from 4.8% in treatment 2 to 46% in treatment 8 (Table 3). The yield loss in treatment 2 was only 4.8% (approximately 50 kg/ha). The lack of significant difference between treatments 1 and 2 suggests that the regular 7-day irrigation interval can be skipped once after every other irrigation throughout the vegetative growth stage of the crop with very minimal loss of yield. The implication is that farmers in the study area may afford to miss regular irrigation schedule every other week during the vegetative growth stage of the maize crop.

A comparison of the grain yields from the treatments in which the regular irrigation event was skipped after every other irrigation (7-day irrigation interval) at one crop growth stage (treatment 2, 3, and 4), and those that experienced *irrigation-skip* at any two growth stages (treatment 5, 6, and 7) showed that treatment 5, which experienced skipping of irrigation at vegetative and flowering growth stage recorded the least yield of 2.12 Mg/ha. Treatment 3, which experienced irrigation-skip at the flowering growth stage only also had a low yield of 2.29 Mg/ha, while treatment 2 where the crop experienced *irrigation-skip* at the vegetative growth stage only, recorded the highest yield of 2.94 Mg/ha. Treatment 6 which experienced the *irrigation-skip* at vegetative and grain filling growth stage had a higher yield than the other treatments, except treatment 2.

The results showed that the flowering growth stage was most vulnerable to the irrigation scheduling, and suggests that the flowering growth stage was more critical to moisture stress for irrigated maize. These results agree with findings reported by Doorenbos and Kassam (1979) and *Stegman (1982*). However *Stone et. al. (2001)* observed that there was no crop growth stage that was particularly sensitive to moisture stress in sweet corn, but yield components changed with timing of deficit, in New Zealand. The finding in this experiment suggest that the grain yield of the crop was much dependent on the growth stage at which moisture stress occur, and not necessarily the number of stages the stress occur. When stress occurred at a very critical growth stage of the crop, grain yield loss was significantly high (as in treatment 3). But when moisture stress occurred at other stages that are less critical, and the crop is adequately irrigated at the critical growth stage, yield lost was fairly low (as in treatment 6)

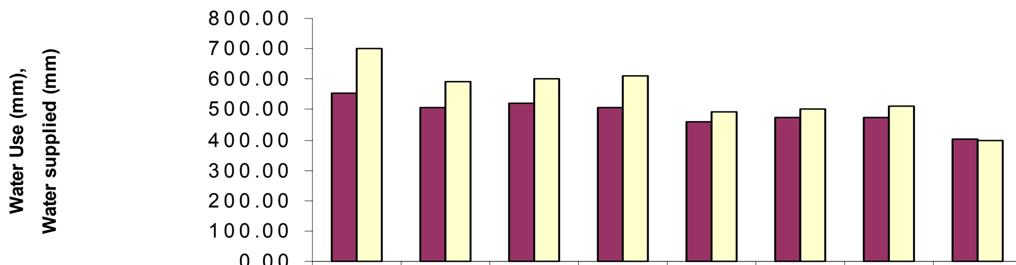
Table 3. Evapotranspiration deficit, yield lost and economic benefit associated with the deficit irrigation scheduling protocol.

Treatment	No. of Irrig. Skp	Vol. of water Saved	ET deficit	Yield Lost	Labour Gained	Water Saved	Water Saved	Total Saved	Total Saved	Rev. Lost	Diffr'nce	Diffr'nce	Rmk
		m^3	%	%	@ 6000 Tsh/ha	@ 50 Tsh/10 m^3	@ 100 Tsh/10 m^3	Tsh (SH)	Tsh (LH)	@ 1200 Tsh/20kg	Tsh (SH)	Tsh (LH)	
1		-	-	-	-	-	-	-	-	-	-	-	-
2	3	1100	7.97	4.80	18000	5500	11000	23500	29000	8888.89	14611.11	20111.11	Gain
3	2	1000	5.89	25.93	12000	5000	10000	17000	22000	48000	-31000	-26000	Lost
4	2	900	8.73	20.44	12000	4500	9000	16500	21000	37841.27	-21341.3	-16841.3	Lost
5	5	2100	16.72	31.14	30000	10500	21000	40500	51000	57650.79	-17150.8	-6650.79	Lost
6	5	2000	14.00	18.93	30000	10000	20000	40000	50000	35047.62	4952.381	14952.38	Gain
7	4	1900	14.72	27.11	24000	9500	19000	33500	43000	50190.48	-16690.5	-7190.48	Lost
8	7	3000	27.22	46.91	42000	15000	30000	57000	72000	86857.14	-29857.1	-14857.1	Lost

Seasonal crop water use and water applied

Figure 2 shows the seasonal crop water use (crop evapotranspiration) and water applied to the crop for each treatment. The results show that crop water use and water applied in the reference treatment were higher than the other treatments, while the lowest was observed in treatment 8. There was no statistical difference among the seasonal water use of treatments 2, 4, 5, 6, and 7. Table 3 shows the seasonal evapotranspiration deficit that resulted from skipping the regular 7-day irrigation frequency event in some treatments, and the volume of water saved. The seasonal evapotranspiration deficit varied from 5.9% in treatment 3 to 27.2% in treatment 8. Seasonal water saved varied from 900m^3/ha in treatment 4 to 3000m^3/ha in treatment 8. A comparison of water use among the treatments that experienced *irrigation-skip* in only one growth stage (treatments 2, 3, and 4) indicated that though the season evapotranspiration deficit in treatment 3 was less than the other treatments, its impact on yield was more severe. Yield lost in treatment 3 was 25.9%, compared to 4.8% and 20.4% in treatment 2 and 4, respectively. A comparison of the impact of the evapotranspiration deficit in treatments 5, 6, and 7, which experienced *irrigation-skip* at any two growth stages also indicated that treatment 5 and 7 which were irrigated at 14-day irrigation frequency at vegetative stage and grain filling stage, respectively recorded a yield lost of 31% and 27%, respectively. These values were higher than in treatment 6, which was 18.9%. These results further buttressed the fact that the flowering growth stage was most critical in terms of moisture stress for irrigated maize in the study area.

Fig.2. Crop water use (crop evapotranspiration) and irrigation water applied



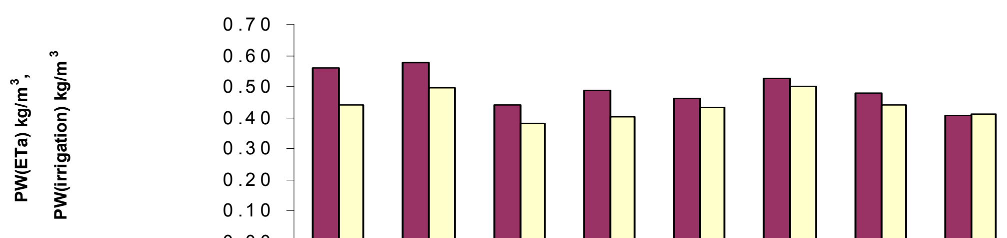
	1	2	3	4	5	6	7	8
ETa mm	552.91	508.86	520.32	504.62	460.49	475.49	471.53	402.42
Water applied mm	700	590	600	610	490	500	510	400

treatment

Productivity of water and economic benefit

Figure 3 shows the physical Productivity of Water (PW) in terms of evapotranspiration and irrigation water applied, for each treatment. Treatment 2 recorded the highest PW in terms of evapotranspiration ($PW_{(ETa)}$), while treatment 3 recorded the lowest valve. Treatment 2 and 6 recorded the highest PW in terms of water applied ($PW_{(irrigation)}$), while treatment 8 recorded the lowest value. The highest value of 0.58kg/m^3 $PW_{(ETa)}$ recorded in treatments 2 was 10% lower than the average potential PW(ETa) for maize calculated as 0.68kg/m^3. This potential estimate was based on an average potential yield of 4.0Mg/ha for maize (using the potential yield of cereal in the Sub- Sahara Africa (Barron, 2004) as a base), and a crop water requirement of 600mm/season for the study area. The lowest value for $PW_{(ETa)}$ and $PW_{(irrigation)}$ from the experiment were 0.41kg/m^3 and 0.38 kg/m^3. These were higher than values obtained in farmers field for the same item in the study area, being 0.34 kg/m^3 and 0.23 kg/m^3 respectively, *(SWMRG, 2004).*

Fig. 3. Productivity of Water (PW) with reference to evapotranspiration and water supplied



	1	2	3	4	5	6	7	8
PW (ETa) kg/m3	0.56	0.58	0.44	0.49	0.46	0.53	0.48	0.41
PW (Irrig.) kg/m3	0.44	0.50	0.38	0.40	0.43	0.50	0.44	0.41

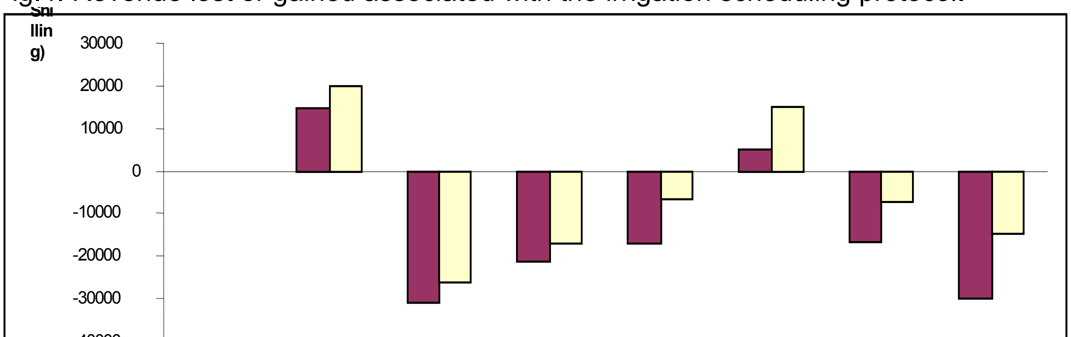
Treatment

The PW values are indicators of the quantity of crop yield produced from every cubic metre of water use or applied to the crop on the field. This means that in treatment 2, 58kg/ha of maize was produced from every 100m^3 of water use by the plant, and 50kg/ha of maize was produced from every 100m^3 of water applied to the crop. In treatment 6, 53kg/ha of maize was produced from every 100m^3 of water use by the plant, and 50kg/ha of maize was produced from every 100m^3 of water applied to the crop. The crop production attained for a cubic metre of water use in treatment 2 was 2% higher than that obtained in treatment 1. The crop production obtained for every cubic metre of water applied for the same treatment (2) was 6% higher than that obtained in treatment 1. A comparison of treatment 6 with 5 and 7 where the crop experienced *irrigation-skip* in two growth stages indicated that the crop production obtained for every cubic water use in treatment 6 was 5% and 7% greater than that obtained in treatment 5 and 7, respectively. The schedule in Treatment 6 should be more desirable than that in treatments 5 and 7.

Table 3 shows the economic benefit associated with the deficit irrigation scheduling protocols. A total of 17 irrigations, including pre-planting irrigation was made in the reference treatment for the cropping season. The skipping of irrigation event at the vegetative stage in treatment 2 reduced the total number of irrigation events in the treatment to 14. Thus, 3 regular irrigation events were skipped in treatment 2; 5 regular irrigation events each were skipped in treatments 5 and 6, respectively, and 7 irrigation events were skipped in treatment 8. As a result of skipping irrigation, water and labour required to irrigate was saved. The volume of water saved ranged from 900m^3/ha in treatment 4 to 3000m^3 in treatment 8. Based on the prices for water assumed in this study, the cost of water saved ranged from 5500 Tshs to 15,000 Tshs/ha for small farms (SF) and 11000 Tshs to 30,000 Tshs/ha for large farms (LF) water users. The value of the labour gained ranged from 12,000 Tshs in treatments 3 and 4 to 42,000 Tshs in treatment 8. The total revenue saved from water and labour ranged from 16,500 Tshs to 57,000Tsh/ha for the small farms and from 21000 to 72,000Tsh for the large farms water users.

Based on the farmer's gate price for the farm produce, the revenue lost as a result of yield reduction, with respect to the reference treatment ranged from approximately 9000 Tsh in treatment 2 to 87000 Tsh in treatment 8. The difference between revenue lost and gained is shown in fig.4. Only treatment 2 and 6 made gains, both at SF and LF level, although the gain in treatment 6 at SF was marginal. The gains recorded in large farms were higher than in small farms. This is principally due to the fact that the price of water prescribed for the SF was half that of the large farms. The gains or losses reported here should be understood to mean what the farmer gained or lost when he follows the deficit irrigation scheduling protocol. It is not the gross or net economic returns in producing the crop.

Fig.4. Revenue lost or gained associated with the irrigation scheduling protocol.



	1	2	3	4	5	6	7	8
SH		14611.11	-31000	-21341.3	-17150.8	4952.381	-16690.5	-29857.1
LH		20111.11	-26000	-16841.3	-6650.79	14952.38	-7190.48	-14857.1

Conclusions and recommendation

Irrigation scheduling protocol which entails skipping irrigation event once after every other irrigation at vegetative crop growth stage gave the best productivity of water in terms of evapotranspiration ($PW_{(ETa)}$),and water applied ($PW_{(irrigation)}$), being 0.58kg/m^3 and 0.50kg/m^3, respectively. The crop yield based on the scheduling protocol was not significantly different from that obtained from the treatment which received regular irrigation at 7-day irrigation interval. The economic benefit associated with the scheduling protocol (in terms of water and labour saved compared with yield lost) amounted to about 20,000 Tsh/ha for large farms water users and about 15,000 Tsh for small farms water users.

A scheduling protocol which entails skipping every other irrigation at vegetative and at fruiting, but maintaining a regular 7-day irrigation frequency achieved a $PW_{(ETa)}$ of 0.53kg/m^3, and a $PW_{(irrigation)}$ of 0.50kg/m^3. Although the yield loss was as high as 19% with reference to the treatment under 7-day irrigation interval, the cost of water and labour saved resulted to an economic benefit of about 15,000 Tsh/ha in large farms water users and a marginal value of about 5000 Tsh in small farms water users. In period of serious water scarcity, this irrigation scheduling protocol can be practiced in the study area in order to release water for other users.

It is recommended that further research work be carried to evaluate the performance of the scheduling protocol across irrigation cropping seasons.

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