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 to reduce water used for crop production in order to release more water for other sectors in need of water. 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 the irrigation scheduling protocol which entails skipping the regular irrigation event once after every other irrigation at vegetative crop growth stage gave the highest 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 from the treatment where the regular irrigation event was skipped every other irrigation at vegetative crop growth stage was not significantly different from that obtained from the treatment which received regular irrigation at 7-day irrigation intervals throughout the crop growing season. The volume of water saved was 1100m^3/ha. The economic benefit associated with the scheduling protocol (in terms of water and labour saved compared to yield loss) was about 12,300 Tsh/ha. A scheduling protocol which entails skipping every other irrigation at vegetative and at grain filling growth stages, but maintaining a regular 7-day irrigation frequency at flowering growth stage gave 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 that was under regular 7-day irrigation interval throughout the crop-growing season, the economic advantage was about 750 Tshs/ha. The volume of water saved was 2000 m^3/ha. These scheduling strategies are desirable and can be practiced in period of water scarcity, and the water saved can be released for other users.

Key words: Deficit irrigation scheduling, Evapotranspiration deficit, Crop yield, Water use, Productivity of water, Irrigation, Economic benefit.

Introduction

The chances of increasing crop production in Sub-Saharan Africa seem to lie much in irrigated agriculture, as unreliable rainfall, both in terms of distribution and amount, is a major limitation to agriculture in the region. But this hope is strongly challenged by the rapidly dwindling water resources of the region and the growing increase in competition for water by non-agricultural sectors. This challenge is a major cause 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 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 a need for irrigators to begin to adopt the use of techniques and practices that regulate water application to crops and minimize needless waste. One such practice is regulated deficit irrigation scheduling (DIS).

The objective of regulated deficit irrigation is to save water, labour, and in some cases energy, by withholding or skipping irrigation, or reducing the amount of water applied per irrigation. The practice leads to some degree of moisture stress on the crop and an effect on crop yield. The water stress results in less evapotranspiration in plants due to closure of the stomata, reduced assimilation of carbon and decreased biomass production (Smith and Kivumbi *et al*., 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, the reduction in yield may be so high that the benefit and returns for water will be reduced.

The subjects of deficit irrigation and the effect of moisture stress on crop production are widely reported in literature (Jensen, 1968, Hargreaves, 1975, Doorenbos and Kassam, 1979, English *et al.,* 1990, Howell, 1990, English and Raja, 1996, 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 protocols to be adopted in an area. More so, such assessment will generate results that can be used to convince farmers and other water resources stakeholders of the benefits associated with irrigation scheduling and the possible limits irrigators can go to in terms of reducing the amount of water used in crop production. 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 gains, or otherwise, associated with the scheduling protocols.

Materials and Methods

The study area

The experiment was carried out at 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 is at 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 the 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 Mkoji sub-catchment and the location of the area where this study was carried out.

Climate

Mean annual rainfall in the study area is about 800mm in wet years and 450mm in dry years. The rains fall between November and April. The area has a unimodal type of rainfall. The mean daily maximum and minimum temperatures range from 28^{o} to 32^{o}C and 9.5^{o} to 19.5^{o}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 vegetables 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 predominantly sandy clay loam. The mean water holding capacity of the soil is about 100 mm/m.

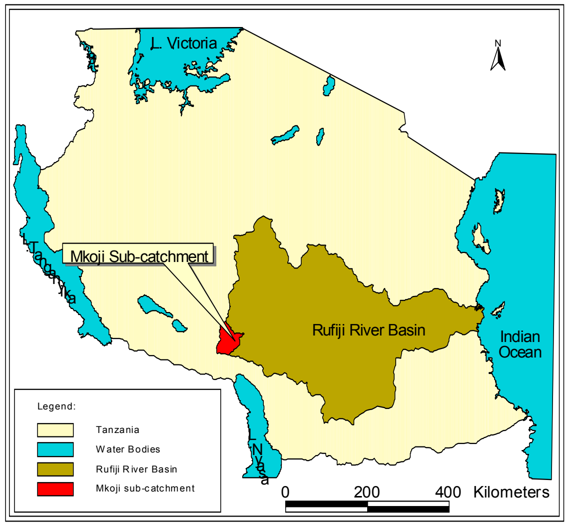

Figure 1: Location of Mkoji Sub-catchment within the Rufiji Basin in Tanzania (SWMRG, 2004)

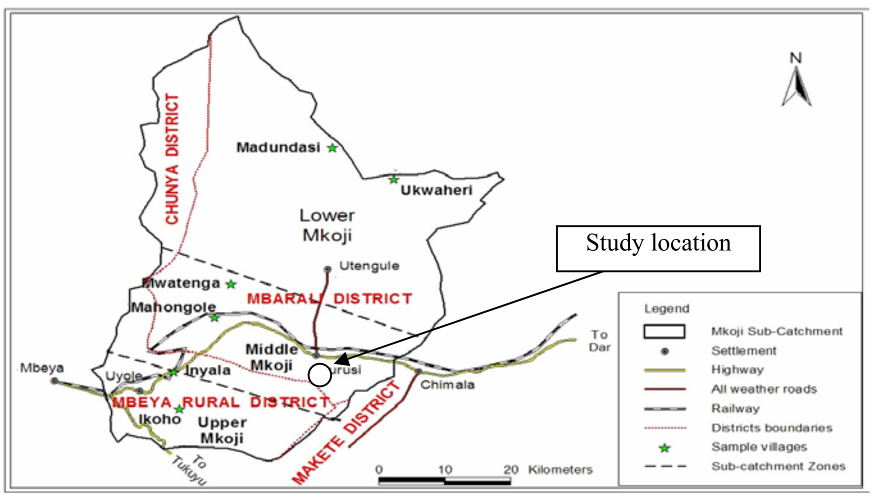

Figure 2. The Mkoji Sub-catchment zones and the study area (SWMRG, 2004)

Table 1. Soil properties of the experimental field

Soil Profile Depth Mm	Moisture content at field capacity m^3/m^3	Moisture content at wilting point m^3/m^3	Soil bulk density g/cm^3	Organic Carbon %	pH in H_2O	Clay %	Silt %	Sand %	Text. Class
0-150	0.262	0.127	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

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 indigenous farmers. Most farmers sell their produce as green maize, which fetches more money than dry grain. Harvesting the crop while it is still green reduces their labour of harvesting and processing grain. It also gives them enough time and space to start rainy season cultivation. Farmers in the scheme operate a Water Users' Association by which they manage the scheme especially in terms of maintaining the main and secondary canals, and regulate the distribution of water and allocation of farmland to intended farmers in the scheme.

Experimental treatment description

The experiment consisted of 8 treatments. The treatments were based on skipping the regular irrigation event at some growth stages of the crop. The regular irrigation event was at intervals of 7 days. The 7-day frequency of irrigation was used in order to conform to the weekly rotational irrigation schedule practiced for maize in the study area. The treatment, which received regular irrigation throughout the crop-growing season, was therefore used as a reference to other treatments. By skipping a regular irrigation event in a treatment in one or more growth stages, the crop in that treatment received a 14-day irrigation frequency throughout the duration of the growth stages. 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 grain filling stage. Table 2 shows the treatment description.

The design irrigation frequency for maize was calculated based on the crop water requirement for irrigated maize and the soil moisture retention characteristic of the study area. The design irrigation frequencies for the vegetative, flowering, and fruiting growth stages were 11 days, 6 days and 8 days respectively. It was therefore expected that by skipping the regular 7-day irrigation event in any treatment, crops would be subjected to some degree of moisture stress before the next irrigation, due to the evapotranspiration deficit caused by limited soil moisture within the plant root zone.

Table 2. Description of the experimental treatments

Treatment label	Description
1	Irrigation at regular intervals throughout the crop-growing season (Reference treatment).
2	Skipped every other regular irrigation event at vegetative only, but observed regular irrigation at other growth stages
3	Skipped every other regular irrigation event at flowering only, but observed regular irrigation at other growth stages
4	Skipped every other regular irrigation event at grain filling only, but observed regular irrigation at other growth stages.
5	Skipped every other regular irrigation event at vegetative and flowering only, but observed regular irrigation at fruiting growth stage.
6	Skipped every other regular irrigation event at vegetative and grain filling only, but observed regular irrigation at flowering growth stage.
7	Skipped every other regular irrigation event at flowering and grain filling only, but observed regular irrigation at vegetative growth stage.
8	Skipped every other regular irrigation event at vegetative, flowering and grain filling growth stages

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

Agronomic operations

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 this maize variety which makes it preferred under irrigation is that it is stress tolerant, of 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 rows and 30cm between plants. Three seeds were planted per hole. The crop attained 100% germination six days after planting and was thinned to 1 plant per stand two weeks after planting. The plant population was about 44450 plants/ha. Diammonium phosphate (DAP) fertilizer was applied at the rate of 60 kg/ha of P_2O_5 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 amount of nitrogen applied from the two fertilizer applications was 120 kg N/ha. The Southern Highland Research Institute, Uyole, recommends 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. The crop matured for harvest at about 126 days after planting, 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 cob maize from the stalks. The maize was dried in the open sun for 5 days, then threshed and weighed. The grain moisture content at threshing was determined in the laboratory and was found to be about 13%.

Irrigation

Irrigation was by gravity, and an average discharge of 4 litres/sec was diverted into the experimental field from a tertiary canal. This discharge was allowed to flow into one 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 was 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 the pre-planting irrigation 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 50mm depth of water during the flowering and fruiting growth stages. 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 sums of the daily reference evapotranspiration for the study area. The daily reference evapotranspiration was calculated using the FAO-Penman-Monteith method (Allen *et al., 1998*). The weekly sums were rounded up to the nearest round figures. The total number of irrigation events varied from 10 in treatment 8 in which regular irrigation was skipped every other irrigation in the three crop growth stages, to 17 in treatment 1 which experienced regular irrigation throughout the crop growing season. Table 3 shows the depth of water applied during irrigation. Irrigation was withdrawn on 16 October 2004.

Data collection and analysis

Soil moisture content

Soil moisture content was monitored throughout the crop-growing season using an 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 8, 30, 55 and 80cm depth below the soil surface. The measurements taken at these depths were considered to represent soil profile depths of 0-15, 15-40, 40-70, and 70-100cm, respectively. Three pieces of 7.6cm diameter PVC pipes were installed to the depth of 30, 55 and 80cm in each plot to provide access to insert the theta probe into the soil to the depths of measurement. A hand hoe 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 crop water use, also referred to as actual crop evapotranspiration (ETa), was calculated based on the soil moisture depletion studies method, (Michael, 1999) given as.

$$WU = \overset{n}{\underset{i=1}{?}} (VMC_{1i} - VMC_{2i}).\ D_i \qquad (1)$$

Where: WU =Crop water use (actual crop evapotranspiration) from the root zone for successive sampling periods or within one irrigation cycle (mm).

VMC_{1i} = Volumetric moisture content at the time of the first sampling in the i^{th} layer.

VMC_{2i} =Volumetric moisture content at the time of the second sampling in the i^{th} layer.
D_i = depth of the i^{th} layer of the soil (mm).
n = number of soil layers sampled in the root zone depth D.
The seasonal crop water use (seasonal evapotranspiration) (mm) was obtained as:

SWU = ? WU (2)

The seasonal evapotranspiration deficit (SET_d), with respect to the reference treatment, was expressed as:

$SET_d = 1-(SWU_o/SWU_r)$ (3)

Where: SWU_o = Seasonal evapotranspiration from the other treatments.
SWU_r = Seasonal evapotranspiration from the reference treatment.

Crop growth parameters

Crop growth was monitored throughout the crop-growing season. Plant heights 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 being taken. The harvested shoots were dried in an oven for 72 hours at 65^oC to constant weight. The final dry matter and grain yield were measured at final harvest. Only the results of grain yields are given in this report.

The yield loss with respect to the reference treatment was the difference between the yields obtained from the reference treatment and the other treatments. The loss in yield was expected to be as a result of the moisture stress occasioned by skipping irrigations.

Productivity of water calculation

The productivity of water with reference to evapotranspiration (PW(ETa)) was expressed as:
PW(ETa) = crop yield (kg)/ SWU (m3) (4)
The productivity of water with reference to irrigation water applied (PW(irrigation)) was expressed as:
PW (irrigation) = crop yield (kg) /Volume of irrigation water applied (m3) (5)

Table 3. Depth of water applied during irrigation (mm)

	Irrigation event																		
Growth stage				Vegetative						Flowering				Grain filling					
Treat-ment label	Pre-planting Irrigation	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total No of irrigat-ion events	Total water applied
1	30	30	30	30	30	40	40	40	40	50	50	50	50	50	50	50	40	17	700
2	30	30	30	30	X	40	X	40	X	50	50	50	50	50	50	50	40	14	590
3	30	30	30	30	30	40	40	40	40	50	X	50	X	50	50	50	40	15	600
4	30	30	30	30	30	40	40	40	40	50	50	50	50	50	X	50	X	15	610
5	30	30	30	30	X	40	X	40	X	50	X	50	X	50	50	50	40	12	490
6	30	30	30	30	X	40	X	40	X	50	50	50	50	50	X	50	X	13	500
7	30	30	30	30	30	40	40	40	40	50	X	50	X	50	X	50	X	13	510
8	30	30	30	30	X	40	X	40	X	50	X	50	X	50	X	50	X	10	400

X = irrigation event skipped

Economic returns associated with the scheduling protocols

The economic return from the scheduling protocols was calculated as the difference between the sum of the cost of labour for irrigation and the cost of water that was saved by skipping irrigation events, and the revenue lost due to yield decrease resulting from the scheduling protocol. This was expressed as:

$$ER = (g * LB + c * WS) - p * YL \qquad (6)$$

Where: ER = Economic returns
LB= Labour saved from skipped irrigation events
WS = Volume of water saved per ha
YL = Yield loss per ha
c = unit price per m^3 of water
p= unit price per kg of grain yield
g= unit cost of labour per irrigation per ha

The farm-gate price for maize grain was 1200 Tanzanian Shilling (Tshs)/20kg in the study area. *(Exchange rate: 1000 Tshs= $1; rate as at 2004)*. The cost of labour to irrigate a hectare was estimated at 6000 Tshs per irrigation based on a man-day labour cost of 1500 Tshs. It was projected that 4 people will effectively irrigate a hectare within 8 hours of water supply with a discharge of 17.5 l/sec at water application depth of 50mm.

The indigenous irrigation farmers in the study area do not make direct payment for water used in their farms. They pay a token of 1000-2000 Tshs to their association based on farm size per season as membership due, (for maintaining the main canal and the intake). According to the farmers, it is the water Users' Association leaders that 'settle' the water fees with River Basin Management Officers. The problems associated with settlement have been reported by van Koppen *et al.* (2004). A survey of the willingness of farmers in the study area to pay for irrigation water (according to the farmers: "*on the condition that the water will be delivered to our fields according to the rotation schedule, and we do not need to go and fight or spend the nights on the field hunting for water*") shows that farmers are willing to pay 20,000 Tshs for water to irrigate a 1 ha field. This amount translates to about 290 Tshs/100m^3 for a volume of 7000 m^3 per season applied in the reference treatment. What the farmers are willing to pay for irrigation water is about 0.3% of what they are willing to pay for domestic water in the study area, being 1000 Tsh/m^3 as reported in SWMRG (2004).

Results and Discussion

Crop yield

The grain yield for the different treatments is presented in Table 1. The reference treatment, (Treatment 1), which was irrigated at 7-day intervals throughout the crop growing season had the highest grain yield of 3.09 t/ha. Treatment 8, in which an irrigation event was skipped at every other irrigation in the three growth stages had the lowest yield of 1.64 t/ha. The yield from the reference treatment was higher than the average grain yield of irrigated maize from farmers' fields in the study area, which is given as 1.78 t/ha (SWMRG, 2004). The grain yield from treatment 8 was lower than the average yield of irrigated maize in the area.

Table 4. Grain yield of maize cultivated under deficit irrigation scheduling

Treatment label	Grain yield (t/ha)	Yield loss (t/ha)	Percent Yield loss
1	3.09 a^+		
2	2.94 a	0.15	4.8
3	2.29 c	0.80	25.9
4	2.46 b	0.63	20.4
5	2.12 d	0.97	31.1
6	2.50 b	0.59	18.9
7	2.25 c	0.84	27.1
8	1.64 d	1.45	46.9

+ Grain yields with the same alphabet are not statistically different (P= 0.05)

A statistical comparison of the grain yields of the treatment showed that there were statistical differences among the yields (P = 0.05). The mean ranking based on the Duncan Multiple Range Test showed that the yield of the reference treatment was not statistically different from that of treatment 2, but the two treatments were significantly different from the others. The yield from treatments 4 and 6 were also not statistically different. The percentage yield losses of the treatments with respect to the reference treatment varied from 4.8% in treatment 2 to 46.9% in treatment 8.

The non-significant difference between yields of treatments 1 and 2 suggests that the scheduling protocol for treatment 2 where the regular 7-day irrigation interval was skipped once every other irrigation throughout the vegetative growth stage of the crop can be practiced in place of the protocol in treatment 1 without any significant loss in yield. This means farmers in the study area can afford to miss their regular irrigation schedule every other week during the vegetative growth stage of the maize crop.

A comparison of grain yields from treatments in which every other regular irrigation event was skipped 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 t/ha. Treatment 3, which experienced *irrigation-skip* at the flowering growth stage only also had a low yield of 2.29 t/ha, while treatment 2 where the crop experienced *irrigation-skip* at the vegetative growth stage only, recorded the highest yield of 2.94 t/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 show that the flowering growth stage was most vulnerable to 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 in New Zealand that there was no crop growth stage that was particularly sensitive to moisture stress in sweetcorn, but yield components changed with timing of deficit. The findings in this experiment suggest that the grain yield of the crop was more dependent on the growth stage at which moisture stress occurs, and not necessarily on the number of stages at which the stress occurs. 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 was adequately irrigated at the critical growth stage, yield lost was fairly low (as in treatment 6).

Seasonal crop water use and water applied

Table 5 shows the seasonal crop water use (crop evapotranspiration), seasonal evapotranspiration deficit and water applied to the crop for each treatment. The difference between seasonal crop water use in the reference treatment and the other treatments is also shown in the table. The seasonal crop water use and irrigation water applied in the reference treatment were higher than the other treatments. The least values were recorded in treatment 8. There were no statistical differences among the seasonal water use of treatments 2, 4, 5, 6, and 7. 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 the impact of the seasonal evapotranspiration deficits (SET_d) among the treatments that experienced *irrigation-skip* in only one growth stage (treatments 2, 3, and 4) indicated that though the SET_d 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 (see Table 4). A comparison of the impact of the SET_d 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 recorded a yield loss 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.

Table 5. Seasonal crop water use (crop evapotranspiration) and irrigation water applied

Treatment label	Seasonal crop water use (mm)	Season difference in crop water use (mm)	Seasonal ET_d (%)	Seasonal water applied (mm)	Volume of water saved (m^3/ha)
1	552.9 a+		-	700	-
2	508.9 c	44.0	7.97	590	1100
3	520.3 b	32.6	5.89	600	1000
4	504.7 c	48.2	8.73	610	900
5	460.5 c	92.4	16.72	490	2100
6	475.5 c	77.4	14.00	500	2000
7	471.5 c	81.4	14.72	510	1900
8	402.4 d	150.5	27.22	400	3000

+ Seasonal crop water-use with the same alphabet are not statistically different at 0.05 level of significance

Table 5 also shows the volume of water saved as a result of skipping regular irrigation events in the treatments. A total of 17 irrigation events including pre-planting irrigation were made in the reference treatment for the cropping season. The skipping of irrigation events 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 (see Table 3). As a result of skipping irrigation, the volume of water saved ranged from 900m^3/ha in treatment 4 to 3000m^3/ha in treatment 8.

Productivity of water

The results of the productivity of water (PW) in terms of evapotranspiration and irrigation water applied are shown in Table 6. Treatment 2 recorded the highest PW in terms of evapotranspiration ($PW_{(ETa)}$), while treatment 3 recorded the lowest value. In terms of irrigation water applied, treatments 2 and 6 recorded the highest $PW_{(irrigation)}$ while treatment 8 recorded the lowest value. The peak values of $PW_{(ETa)}$ and $PW_{(irrigation)}$ from the experiment were 0.58kg/m^3 and 0.50 kg/m^3, respectively. These values were 41.4% and 54.0% higher than the average $PW_{(ETa)}$ and $PW_{(irrigation)}$ respectively, obtained in farmers' fields for the study area. The average values $PW_{(ETa)}$ and $PW_{(irrigation)}$ from the farmers' fields reported by SWMRG (2004) were 0.34 kg/m^3 and 0.23 kg/m^3 respectively.

Table 6. Productivity of Water (PW) in terms of evapotranspiration and water applied

Treatment label	$PW_{(ETa)}$	$PW_{(irrigation)}$
1	0.56	0.44
2	0.58	0.50
3	0.44	0.38
4	0.49	0.40
5	0.46	0.43
6	0.53	0.50
7	0.48	0.44
8	0.41	0.41

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

Economic returns associated with the scheduling protocol

Table 7 shows the economic returns from the irrigation scheduling protocols. The value of water saved ranged from 2610 Tshs to 8700 Tshs/ha in the cropping season. The cost of the labour saved by skipping irrigation ranged from 12,000 Tshs in treatments 3 and 4 to 42,000 Tshs/ha in treatment 8, in the cropping season. The total revenue saved from water and labour was between from 14,610 Tshs to 50,700 Tsh/ha. Based on the farmers' 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 Tshs in treatment 2 to 87000 Tshs in treatment 8. The difference between revenue lost or gained is shown in the table.

Only treatments 2 and 6 had positive returns, although the return in treatment 6 was marginal. The gains or losses reported here should be understood to mean what the farmer gained or lost when he followed the deficit irrigation scheduling protocol. It is not necessarily the gross or net economic returns in producing the crop.

Table 7. Revenue loss or gained associated with the irrigation scheduling protocol.

Treat-ment label	Cost of labour gained @ 6000 Tsh/irrigation	Cost of water saved @ the rate of 290 Tsh/100m^3	Total revenue saved (Col. 2+3)	Cost of the grain yield loss @ the rate of 1200Tsh/20kg	Revenue loss or gained (Col. 4 – 5)	Remark
1	-	-	-	-	-	
2	18000	3190	21190	8888.90	12301.11	Gain
3	12000	2900	14900	48000.00	-33100	Lost
4	12000	2610	14610	37841.27	-23231.3	Lost
5	30000	6090	36090	57650.79	-21560.8	Lost
6	30000	5800	35800	35047.62	752.381	Gain
7	24000	5510	29510	50190.48	-20680.5	Lost
8	42000	8700	50700	86857.14	-36157.1	Lost

Conclusions and recommendation

Deficit Irrigation scheduling protocols for irrigated maize were investigated at *Igurusi ya Zamani* indigenous irrigation scheme. The irrigation scheduling protocol which entails skipping every other regular irrigation event at vegetative crop growth stage gave the highest 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 from the scheduling protocol was not significantly different from that obtained from a treatment which received regular irrigation at 7-day irrigation intervals throughout the crop growing season, as practiced by the farmer in the area. The volume of water saved was 1100m^3/ha. The economic return associated with the scheduling protocol (in terms of water and labour saved compared with yield loss) was about 12,300 Tsh/ha. This scheduling strategy is desirable. However there is a need to evaluate these scheduling strategies across irrigation seasons before a conclusive recommendation.

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