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Impact of Methods of Administering Growth-Stage Deficit Irrigation on Yield and Soil Water Balance of a Maize Crop (SAMAS TZEE)

H.E. Igbadun
Department of Agricultural Engineering, Ahmadu Bello University, P.M.B 1044, Zaria, Nigeria
[*Corresponding Author: Email: igbadun20@yahoo.com; ☎: +234(08964189575]

ABSRACT: Field experiments were conducted in 2009/10 and 2010/11 irrigation seasons at the Institute for Agricultural Research, Samaru Zaria, to assess the impact of two methods of administering Growth-stage deficit irrigation scheduling (GSDIS) on yield and soil water balance of an early maturing maize variety. The two methods include reducing water application depth at selected crop growth stages and skipping regular irrigation interval at selected crop growth stages. The test crop was SAMAS TZEE early maturing maize variety. Grain yield, biomass yield, harvest index, seasonal water applied, evapotranspiration and deep percolation and crop water productivity were determined. Grain and biomass yields ranged from 2.12 to 3.01 t/ha and 7.57 to 10.0t/ha, respectively, while seasonal evapotranspiration varied from 366 to 486.8 mm across the seasons. This study reveal that at vegetative growth stage of the maize crop, it is better to skip weekly irrigation (to irrigation every other week) and apply water to meet full water requirement than to maintain regular weekly irrigation but apply water at half water requirement. A grain filling to maturity stage, it is more advantageous to reduce irrigation water application by half water requirement than to skip weekly irrigation. Grain yield, biomass yield and seasonal evapotranspiration from such scheduling were not significantly different from that which received weekly irrigation throughout the crop growing season. Moreover, the productivity of water applied was higher while water loss to deep percolation was drastically reduced.

Keywords: Deficit irrigation scheduling, Economic net return, Maize crop, Irrigation water management

INTRODUCTION

Irrigated agriculture has continued to contend with the challenge of reducing water utilization at field level and freeing more water for other users in river basins. It is tasked with the responsibility of increasing water use efficiencies of crops by maximizing crop yield per water supply under limited water resources. One of the field practices that have been identified (Stegman *et al*., 1980) as a way of meeting this task is the Growth-stage deficit irrigation scheduling (GSDIS). GSDIS involves applying water less than crop water requirement at some growth stages considered less critical to moisture stress, and at other growth stages water is applied to meet full crop water requirement. This approach is different from the conventional deficit irrigation (DI) scheduling where water is applied short of the crop water requirement throughout the crop growing season.

The GSDIS can be administered in two ways. The first is by skipping regular irrigation event at selected growth stages, but apply water to meet crop water demand at each irrigation event. Pandey *et al*. (2000), Igbadun *et al.* (2005, 2006) and Ayana (2011) have studied deficit irrigation in maize crop using this approach. The second approach is to irrigate at regular interval (for example, 7-day) throughout the crop growing season, but apply water less than crop water requirement at selected growth stages of the crop, while at others irrigation meets full crop water demand. Both approaches have the potentials of minimizing the volume of water applied in the field when compared to the conventional irrigation method where a fixed frequency and fixed water application depths is observed throughout the crop growing season as commonly regularly practiced by farmers. Moreover, the GSDIS concept may also offer some additional advantages since there will be fewer irrigations in the season if the irrigation frequency is reduced; less man-hours on the field to irrigating a given area of land if water depth of application is reduced; a reduction in energy to lift water if pumping is involved; and the cost per liter of water used on the field will be reduced if water is to be paid for. But knowledge gaps remains as to whether the impact of the two methods of administering GSDIS on yield and soil water balance will be similar (both in form and magnitude) for a given crop in given location. The objectives of this study therefore, were to assess the impact of the two methods of administering GSDIS on grain and biomass yields of a maize crop, seasonal evapotranspiration, and the water productivity (with respect to water applied) to the field.

MATERIALS AND METHODS

Location of Study

Field trials were carried out during the 2009/10 and 2010/11 irrigation seasons at the Samaru Irrigation Field of the Institute for Agricultural Research (I.A.R), Ahmadu Bello University, Zaria, Nigeria. Zaria lies on latitude 7°35'N, longitude 11°11'E and altitude 686 m above mean sea level, within the Northern guinea savannah ecological zone. The climate can be described as semi-arid, with three distinct seasons: the hot dry season which spans from March to May; warm rainy season from June to early October; and the cool dry season which spans from November to February. Irrigation activities in the study area run from November to May. The weather data for the crop growing seasons are presented in Tables 1 and 2. The soils of the study location have been classified as alfisol (Odunze, 1998). The 0-50 cm profile depth of the experimental site was loamy while the 50-100 cm depth was clay loam. The total available water (TAW) was 116 mm/m.

Table 1: Weather data of the study location during the 2010 crop growing season

Parameter	**Month**			
	February	**March**	**April**	**May**
Maximum Temperature (°C)	37.2	37.8	39.2	35.4
Minimum Temperature (°C)	17.2	21.2	23.2	23.1
Relative humidity (%)	11	19	38	68
Wind speed (km/d)	156.6	167.9	131.6	176
Sunshine hour (hr)	9.4	9	8.6	8.9
Reference Evapotranspiration (ETo mm/d)	5.7	6.7	7.2	7.7

Table 2: Weather data of the study location during the 2011 crop growing season

Parameter	**Month**			
	February	**March**	**April**	**May**
Maximum Temperature (°C)	36.3	39.2	38.1	35.4
Minimum Temperature (°C)	18.1	20.2	22.6	22.3
Relative humidity (%)	20	13	29	65
Wind speed (km/d)	131.9	163.5	184.9	208.5
Sunshine hour (hr)	7.4	7.2	6.6	7.1
Reference Evapotranspiration (ETo mm/d)	5.7	6.8	7.8	7.3

Experimental treatment description

The field experiment in each season consisted of seven (7) treatments comprising a conventional scheduling method and three treatments each of the two methods of administering GSDIS. The conventional scheduling treatment, referred to as CSC in this study, was irrigated at 7-day interval throughout the crop growing season. The water applied during each irrigation event was the weekly total of the daily reference evapotranspiration (WRET) (rounded up to whole number). The treatments based on reduction of water application depths at selected crop growth stages were referred to as RWAD while those of which regular irrigation interval were being skipped at selected growth stages were referred to as SKII. Skipping the regular irrigation interval means irrigating such treatment after every other week (i.e.14-day interval). Table 3 shows further description of the experimental treatments. The 7-day irrigation interval observed in the study was based on schedule of water allocation in the research field. However, it was observed to be adequate for a maize crop without going into moisture stress even at peak consumptive use based on the total available water and the atmospheric evaporative demand of the study location. The crop growth stages at which the treatments were imposed were: vegetative (15-42 days after planting, DAP), flowering (tasseling to silking, 43-63 DAP), and grain filling to physiological maturity stages (64-95 DAP), based on observation of crop growth and development on the field.

Experimental Layout and Agronomic Practices

In each season, the experiment was laid in a randomized complete block design and the treatments were replicated three times. The size of the experimental field in each season was 20 m by 40 m. The field was divided into three blocks and the blocks were divided to check basins of 3 m long by 3.5 m wide. Each check basin was made into six furrows of 3 m long and 0.75 m wide. The furrows were made within the basins to allow for hill-planting as against planting on the flat. The basins were separated by a space of 0.75 m creating a buffer to reduce lateral movement of water across the plots. The experimental blocks were 1.5 m apart separated by a walkway and a furrow ditch which convey water to the experimental plots. The check basins allow all water applied to each plot to infiltrate without runoff.

In 2009/10 season, the maize crop was planted on 23rd February, 2010 while in 2010/11 season, planting was done on 10th February, 2011. In both seasons, a plant spacing of 25 cm between plants and 75 cm between rows were used giving a plant population of was 53,333 plants/ha. The planting was done on one side of the furrows. In 2009/10 season, weeding was carried out thrice, at 2, 5 and 8 weeks after planting. In 2010/11 season however, weeding was carried out twice, at 3 and 6 weeks after planting since weed proliferation on the experimental field was less. Compound Fertilizer (NPK 15:15:15) was at the rate of 60 KgN/ha at three weeks after planting applied as basal dose and Urea fertilizer was used for topdressing at 6 weeks after planting at a rate of 60 kgN/ha. The fertilizer was applied after weeding. The total N applied was 120 kg/ha as recommended by the Institute for Agricultural Research, Samaru, Zaria. The fertilizers were applied after weeding on each occasion. There was no pests or diseases incidence.

Table 3: Experimental treatment description

Scheduling concept	Treatment label	Treatment Description
CSC	$V7_{100\%}$ $F7_{100\%}$ $G7_{100\%}$	Irrigation interval was 7 days in vegetative (V), flowering (F) and grain filling (G) growth stages. Water applied was 100 % of WRET in all the growth stages
SKII	$V14_{100\%}$ $F7_{100\%}$ $G7_{100\%}$	Irrigation interval was 14 days in vegetative (V), 7 days in flowering (F) and grain filling (G) growth stages. Water applied was 100 % of WRET in all the growth stages.
	$V7_{100\%}$ $F14_{100\%}$ $G7_{100\%}$	Irrigation interval was 14 days in flowering (F), 7 days in vegetative (V) and grain filling (G) growth stages. Water applied was 100 % of WRET in all the growth stages.
	$V7_{100\%}$ $F7_{100\%}$ $G14_{100\%}$	Irrigation interval was 14 days in grain filling (G), 7 days in vegetative (V) and flowering (F) growth stages. Water applied was 100 % of WRET in all the growth stages.
RWAD	$V7_{50\%}$ $F7_{100\%}$ $G7_{100\%}$	Irrigation interval was 7 days throughout the crop growing season. Water applied at Vegetative stage 50 % of WRET and 100 % of WRET at flowering and grain filling stages.
	$V7_{100\%}$ $F7_{50\%}$ $G7_{100\%}$	Irrigation interval was 7 days throughout the crop growing season. Water applied at Vegetative stage 50 % of WRET and 100 % of WRET at flowering and grain filling stages.
	$V7_{100\%}$ $F7_{100\%}$ $G7_{50\%}$	Irrigation interval was 7 days throughout the crop growing season. Water applied at Vegetative stage 50 % of WRET and 100 % of WRET at flowering and grain filling stages.

Water Application

The system of irrigation for both seasons was surface. Water was admitted into the experimental plots through some calibrated orifices installed in each plot. The average flow rate into each plot was 2.3 l/s. The time allowed for water to go into each plot was based on the depth of water applied, having known the plot size and the flow rate into the plots. The depth of water applied per irrigation event was the average weekly reference evapotranspiration (ETo) (rounded to whole number). Tables 4 and 5 detailed the water applied per irrigation event. A pre-planting water application depth of 30 mm was applied three days before planting while 20 mm depth of water was applied on weekly basis for two weeks during the crop establishment stage before treatment were imposed. In both seasons, rainfalls were recorded during the grain filling to maturity growth stage. The total rainfall depths were considered as effective since check basin were used, and were therefore recorded as part of the total water applied. As a result of the rainfall on May 10th in 2009/10 season, the regular weekly irrigation which would have been carried out on 11th (77 days after planting) was withheld since the rainfall depth, which was 49.5 mm, was about the depth of water that would have been applied through irrigation, which was 50 mm. However, the treatments where irrigation would have been skipped for that week ($V7_{100\%}$ $F7_{100\%}$ $G14_{100\%}$) and that which water application depth would have been reduced by 50 % ($V7_{100\%}$ $F7_{100\%}$ $G7_{50\%}$) received full water application depth through rainfall.

Soil Moisture Measurement

The soil moisture contents of the experimental plots were monitored throughout the crop growing season using calibrated gypsum blocks in both seasons. Four gypsum blocks were installed in each experimental plot at 15, 40, 60 and 85 cm soil profile depths to monitor soil moisture changes at 0-25, 25-50, 50-75 and 75-100 cm depths. Soil moisture resistances were measured using a Auto-range digital Multmeter (MechTech MAS345) two days after every irrigation and just before the next irrigation. The resistances measured were related to gravimetric soil moisture content using the gypsum-moisture content calibration curve developed for the sets of gypsum blocks used.

The calibration curve was expressed as:

$$GMC = 536.17 * RS^{-0.394} \qquad (1)$$

where, GMC is gravimetric moisture content (% dry weight basis), RS is electrical resistance in ohm (Ω)

It was anticipated that free drainage would have ceased and the soil moisture content attained field capacity two days after irrigation since the soils of the experimental field was medium textured. The soil moisture contents measured on the field two days after irrigation were within ± 5% that obtained as field capacity in the laboratory using pressure plate apparatus.

Crop Harvesting

The crop attained physiological maturity 85 and 84 days after planting in 2009/10 and 2010/11 seasons, respectively, and irrigation was withdrawn thereafter to allow for drying of the crop. The last irrigation was carried out on 18th May, 2010 and 3rd May for the 2009/10 and 2010/11 seasons, respectively. Soil moisture monitoring was also stopped two weeks after the last irrigation, and the crop was harvested a week later. In both seasons, harvesting was done by cutting the above the ground dry matter of the entire experimental plot. The harvest (crop biomass) were carefully labeled and conveyed to the laboratory where they were air-dried for three weeks until the biomass was fully dried and the maize grain had attained 13.5 % moisture content. The dry matters were then weighed, and the maize cobs were threshed and weighed. The reason why the crop was not allowed to fully dry on the field was because of the onset of rains.

Computation of Soil Water Balance Components

The seasonal soil water balance was expressed as:

$$I + P = ET + R + Dp \pm \Delta S..........(2)$$

where, I is seasonal irrigation applied; P is rainfall depth; ET is evapotranspiration; R is runoff; Dp is deep percolation, and ΔS is change in soil moisture storage between the beginning and end of season. All values are in mm.

Since check basins were used, there were no runoffs from the plots. The seasonal irrigation amount was the sum total of the weekly water application depths. The seasonal evapotranspiration was the sum total of the weekly estimates. The weekly evapotranspiration were estimated from the soil moisture content measurements made two days after irrigation and just before the next irrigation using Eq.3, given as (Michael, 1999):

$$ET = \frac{\sum_{i=1}^{n} \left(GMC_{1i} - GMC_{2i}\right) * A_{si} * D_i}{t} \qquad (3)$$

where, ET is average daily evapotranspiration between successive soil moisture content sampling periods (mm/day); GMC_{1i} is gravimetric soil moisture content (g/g) at the time of first sampling in the i^{th} soil layer; GMC_{2i} is gravimetric soil moisture content (g/g) at the time of second sampling in the i^{th} layer; A_{si} is bulk density of the i^{th} layer; D_i is depth of i^{th} layer (mm); n is number of soil layers sampled in the root zone depth D, and 't' is number of days between successive soil moisture content sampling.

The evapotranspiration for a week was therefore the product of the daily crop evapotranspiration between successive soil moisture content sampling and the number of days in the week. The seasonal ET was the summation of the weekly ET. The seasonal deep percolation was taken as the difference between the seasonal water input (rainfall and irrigation) and seasonal evapotranspiration. Δ**S** was assumed negligible since the soil was relatively dry at harvesting.

Computation of Water Productivity

The productivity of the seasonal water applied (PSW) were computed with respect to biomass and grain yields, expressed as:

$$PSW_{(Biomass)} = \frac{\text{Biomass yield (kg)}}{\text{Seasonal water applied (m}^3\text{)}} \qquad (4)$$

$$PSW_{(grain\ yield)} = \frac{\text{Grain yield (kg)}}{\text{Seasonal water applied (m}^3\text{)}} \qquad (5)$$

Table 4: Irrigation Water applied in each treatment in 2009/10 season

	Establishment (0-14 DAP)			Vegetative (15-42 DAP)				Flowering (43-63)			Grain filling- Maturity (64-95)					
Date of Irrigation	21-Feb	02-Feb	09-Mar	16-Mar	23-Mar	30-Mar	06-Apr	13-Apr	20-Apr	27-Apr	04-May	06-May	10-May	11-May	12-May	18-May
Days after planting	Pre-planting	7	14	21	28	35	42	49	56	63	70	72*	76*	77**	78*	84
Treatment	Irrigation water applied															
$V7_{,100\%}$ $F7_{,100\%}$ $G7_{,100\%}$	30	20	30	30	30	40	40	40	50	50	50	24	49.5	0	10.2	50
$V14_{,100\%}$ $F7_{,100\%}$ $G7_{,100\%}$	30	20	30	30	0	30	0	40	50	50	50	24	49.5	0	10.2	50
$V7_{,100\%}$ $F14_{,100\%}$ $G7_{,100\%}$	30	20	30	30	30	40	40	0	50	0	50	24	49.5	0	10.2	50
$V7_{,100\%}$ $F7_{,100\%}$ $G14_{,100\%}$	30	20	30	30	30	40	40	40	50	50	0	24	49.5	0	10.2	0
$V7_{,50\%}$ $F7_{,100\%}$ $G7_{,100\%}$	30	20	30	15	15	20	20	50	50	50	50	24	49.5	0	10.2	50
$V7_{,100\%}$ $F7_{,50\%}$ $G7_{,100\%}$	30	20	30	30	30	40	40	25	25	25	50	24	49.5	0	10.2	50
$V7_{,100\%}$ $F7_{,100\%}$ $G7_{,50\%}$	30	20	30	30	30	40	40	40	50	50	25	24	49.5	0	10.2	25

* = Rainfall depth

** = Irrigation was skipped for all treatment because of rainfall the previous day

Table 5: Irrigation Water applied in each treatment in 2010/11 season

	Establishment			Vegetative (15-42 DAP)				Flowering (43-63)			Grain filling- Maturity (64-95)				
Date of Irrigation	08-Feb	15-Feb	22-Feb	01-Mar	08-Mar	15-Mar	22-Mar	29-Mar	05-Apr	12-Apr	19-Apr	26-Apr	28-Apr	03-May	09-May
Days after planting	Pre-planting	7	14	21	28	35	42	49	56	63	70	77	79*	84	90*
Treatment	Irrigation water applied														
$V7_{,100\%}\ F7_{,100\%}\ G7_{,100\%}$	30	20	20	30	30	40	40	40	50	50	50	50	18.5	50	36.5
$V14_{,100\%}\ F7_{,100\%}\ G7_{,100\%}$	30	20	20	0	30	0	40	40	50	50	50	50	18.5	50	36.5
$V7_{,100\%}\ F14_{,100\%}\ G7_{,100\%}$	30	20	20	30	30	40	40	0	50	0	50	50	18.5	50	36.5
$V7_{,100\%}\ F7_{,100\%}\ G14_{,100\%}$	30	20	20	30	30	40	40	40	50	50	0	50	18.5	0	36.5
$V7_{,50\%}\ F7_{,100\%}\ G7_{,100\%}$	30	20	20	15	15	20	20	40	50	50	50	50	18.5	50	36.5
$V7_{,100\%}\ F7_{,50\%}\ G7_{,100\%}$	30	20	20	30	30	40	40	20	25	25	50	50	18.5	50	36.5
$V7_{,100\%}\ F7_{,100\%}\ G7_{,50\%}$	30	20	20	30	30	40	40	40	50	50	25	25	18.5	25	36.5

* = Rainfall depth
** = Irrigation was skipped for all treatment because of rainfall the previous day

RESULTS AND DISCUSSION

Crop Yield

Table 6 shows the grain yield (GY), biomass yield (BY) and the harvest index (HI) of the maize crop for the two seasons. The grain yield varied from 2.01 to 2.91 t/ha and biomass yield varied from 6.25 to 10.1 t/ha in 2009/10 season, while in 2010/11 season, grain yield ranged from 2.17 to 3.01 t/ha and biomass yield ranged from 7.57 to 9.52 t/ha. There was no significant difference between the yields of the two seasons. The harvest index ranged from 0.28 to 0.31 and 0.28 to 0.32 in 2009/10 and 2010/11 seasons, respectively. The lowest values in the grain and biomass yield range occurred in one of the RWAD treatments where water was applied at 50% of WRET at vegetative growth stage ($V7_{50\%}$ $F7_{100\%}$ $G7_{100\%}$), while the highest grain and biomass yield were recorded in the CSC treatment ($V7_{100\%}$ $F7_{100\%}$ $G7_{100\%}$) in both seasons. Although the grain and biomass yields of the CSC treatment were found to be significantly different ($p < 0.05$) from the other treatments, they were not different from the RWAD treatment which was irrigated at 7 days interval with water application depths of 50 % of WRET ($V7_{100\%}$ $F7_{100\%}$ $G7_{50\%}$) during the grain filling stage in both seasons.

Table 6: Biomass yield, grain yield and harvest index of the maize (SAMAS TZEE) crop in 2009/10 season

		2009/10 season			2010/11 season		
Treatment Class.	Treatment label	GY (t/ha)	BY (t/ha)	HI	GY (t/ha)	BY (t/ha)	HI
CSC	$V7_{100\%}$ $F7_{100\%}$ $G7_{100\%}$	2.91 a	10.00 a	0.29	3.01 a	9.52 a	0.32
SKII	$V14_{100\%}$ $F7_{100\%}$ $G7_{100\%}$	2.35 b	8.44 b	0.28	2.46 c	8.65 a	0.28
	$V7_{100\%}$ $F14_{100\%}$ $G7_{100\%}$	2.27 c	7.56 c	0.30	2.38 c	8.19 b	0.29
	$V7_{100\%}$ $F7_{100\%}$ $G14_{100\%}$	2.12 c	7.70 c	0.28	2.63 b	9.20 a	0.29
RWAD	$V7_{50\%}$ $F7_{100\%}$ $G7_{100\%}$	2.01 d	6.52 d	0.31	2.17 d	7.57 c	0.29
	$V7_{100\%}$ $F7_{50\%}$ $G7_{100\%}$	2.32 b	7.70 c	0.30	2.47 c	7.85 b	0.32
	$V7_{100\%}$ $F7_{100\%}$ $G7_{50\%}$	2.72 a	9.58 a	0.28	2.94 a	9.45 a	0.31

*Treatment means followed by the same letter(s) in any column are not significantly different at 5 % level of significance

A comparison of the means of the grain yields, biomass yields and harvest indices of the SKII and RWAD treatments shows no significant differences, even though the mean grain yields of the RWAD was 5 % and 2 % higher than those of SKII in 2009/10 and 2010/11, respectively. Furthermore, the means of the biomass yield and harvest indices of the two groups were also not significantly different. However, a comparison of grain and biomass yields among the treatments within each group shows highly significant differences ($p<0.01$). Among the treatments in the SKII, the grain yields of the treatment irrigated 14 days interval at vegetative growth stage ($V14_{100\%}$ $F7_{100\%}$ $G7_{100\%}$) was noticed to be 3.0 and 10 % higher than those irrigated at same interval at flowering and grain filling stages in 2009/10 season. The biomass yield of the $V14_{100\%}$ $F7_{100\%}$ $G7_{100\%}$ treatment was also noticed to be higher than the other two treatments in the group by about 10 %. In 2010/11 season however, the grain and biomass yields of the treatment irrigated at 14 days interval at grain filling to maturity stage ($V7_{100\%}$ $F7_{100\%}$ $G14_{100\%}$) was found to be higher than those irrigated at same interval at vegetative and flowering stages by 6.0 and 11 %, respectively. The change in the trend of result between the two seasons may be as a result of the influence of the late rainfall that occurred in 2010/11 season. It may be observed that in the 2009/10 season, the rainfall occurred early in the grain filling stage. Based on the scheduling protocol, irrigation was withdrawn from the $V7_{100\%}$ $F7_{100\%}$ $G14_{100\%}$ treatment earlier than the other treatments since the last irrigation was skipped (see Tables 4 and 5). The withdrawal may have induced moisture stress which affected yields. But in 2010/11 season, there was rainfall after irrigation was withdrawn which may have overturned the impact of the moisture stress withdrawal of irrigation on the yields, hence higher grain and biomass yields in the treatment compared to 2009/10 season. Among the treatments in the RWAD group, the grain and biomass yields of the treatment irrigated with 50% WAD at grain filling stage ($V7_{100\%}$ $F7_{100\%}$ $G7_{50\%}$) was significantly higher than the other treatments in both seasons. This may also not be far from the fact that the rainfalls during that period would have reduced the impact of moisture stress on the yields of the crop that would have occurred due to such irrigation schedule.

The general trend of the results suggest that skipping regular irrigations as a way of imposing deficit irrigation on the maize crop may be advantageous only if such is done at vegetative growth stage. The impact of such method of imposing deficit irrigation on yield and yield parameters is more when it is done at flowering and grain filling stages. Imposing deficit irrigation by reducing water application depth is of higher advantage during grain filling to maturity stage if the probability of occurrence of rainfall is high during this stage of the maize crop. With 50% water application requirement and effective rainfall twice or more during the grain filling stage, grain and biomass yields could be as high as what is obtainable from the conventional irrigation schedule. The grain and biomass yields ranges obtained in this study were generally lower than what has been reported by researchers around the world who had worked on deficit irrigation on maize crop. Zhang *et al*. (2004) reported grain yield range of 3.53 to 6.17 t/ha and biomass yield range of 7.2 to 12.4 t/ha in China; Mengu and Ozgurel (2008) reported grain yield range of 2.14 to 10.6 t/ha in Turkey, El-Tantawy *et al* (2007) reported grain yield range of 4.68 to 7.83 t/ha in Egypt and Payero *et al*. (2006) reported grain yield range of 2 to 14 t/ha in Nebraska, USA. But it must be noted that crop yield under deficit irrigation is very much depended on crop variety, magnitude of irrigation deficit, irrigation method, climate of study location, and other agronomic practices that influences yield.

Soil Water Balance

Tables 7 and 8 show components of the soil water balance consisting of the seasonal evapotranspiration (SET), seasonal irrigation water applied (SIWA), rainfall depth (RD) and deep percolation (DP). The total seasonal water applied (TSWA) was the sum of the seasonal irrigation water applied (SIWA) and rainfall depth (RD).

Table 7: Seasonal soil water balance of the experimental field in 2009/10 Season

Treatment Class.	Treatment label	SET (mm)	SIWA (mm)	RD (mm)	TSWA (mm)	DP (mm)
CSC	$V7_{100\%}$ $F7_{100\%}$ $G7_{100\%}$	472.8 a*	460.0 a	83.7	543.7	70.9
SKII	$V14_{100\%}$ $F7_{100\%}$ $G7_{100\%}$	412.7 b	380.0 c	83.7	463.7	51.0
	$V7_{100\%}$ $F14_{100\%}$ $G7_{100\%}$	423.2 b	410.0 b	83.7	493.7	70.5
	$V7_{100\%}$ $F7_{100\%}$ $G14_{100\%}$	366.3 d	360.0 d	83.7	443.7	77.4
RWAD	$V7_{50\%}$ $F7_{100\%}$ $G7_{100\%}$	404.1 c	385.0 c	83.7	468.7	64.6
	$V7_{100\%}$ $F7_{50\%}$ $G7_{100\%}$	430.2 b	410.0 b	83.7	493.7	63.5
	$V7_{100\%}$ $F7_{100\%}$ $G7_{50\%}$	453.4 a	410.0 b	83.7	493.7	40.3

*Treatment means followed by the same letter(s) in any column are not significantly different at 5 % level of significance

Table 8: Seasonal soil water balance of the experimental field in 2010/11 Season

Treatment Class.	Treatment label	SET (mm)	SIWA (mm)	RD (mm)	TSWA (mm)	DP (mm)
CSC	$V7_{100\%}$ $F7_{100\%}$ $G7_{100\%}$	486.8 a*	500 a	50	555	68.2
SKII	$V14_{100\%}$ $F7_{100\%}$ $G7_{100\%}$	432.7 c	430 b	50	485	52.3
	$V7_{100\%}$ $F14_{100\%}$ $G7_{100\%}$	431.2 c	410 c	50	465	33.8
	$V7_{100\%}$ $F7_{100\%}$ $G14_{100\%}$	449.3 b	400 c	50	455	5.7
RWAD	$V7_{50\%}$ $F7_{100\%}$ $G7_{100\%}$	424.1 c	430 b	50	485	60.9
	$V7_{100\%}$ $F7_{50\%}$ $G7_{100\%}$	440.2 b	430 b	50	485	44.8
	$V7_{100\%}$ $F7_{100\%}$ $G7_{50\%}$	463.4 a	425 b	50	480	16.6

*Treatment means followed by the same letter(s) in any column are not significantly different at 5 % level of significance

The SET varied from 403.1 to 472.8 mm and 424 to 586.1 mm in 2009/10 and 2010/11 seasons, respectively. There was no significant difference between the SET of both seasons. The least values in the ranges were recorded in the $V7_{50\%}$ $F7_{100\%}$ $G7_{100\%}$ treatments while the highest values were recorded in the CSC treatment in both seasons. The reasons for these may not be farfetched. The CSC treatment was the most irrigated, and also recorded the highest biomass yield (Table 6). These two factors generally lead to higher evaporation and transpiration rates. On the other hand, the $V7_{50\%}$ $F7_{100\%}$ $G7_{100\%}$ treatment recorded the least biomass yield in both seasons, which may be responsible for the low seasonal evapotranspiration rate. Seasonal crop water use of maize crop under deficit irrigation as reported by Kanber *et al*. (1990) was 474.2-605.8 mm in the Cukurova region, while Istanbulluoglu and Kocaman (1996) obtained 353-586 mm in the Thrace region of Turkey. In addition, Tolk *et al*. (1998) obtained 357-587 mm in the USA, and Igbadun *et al*. (2006) reported 385.4-537.1 mm in Tanzania. Also, crop water use for maize without water deficit was reported by Stegman (1986) as 432-514 mm. The range of SET observed in this study is in agreement with the reports given above.

Further analyses of the SET reveal that the values were significantly different ($p<0.05$) both within and among the scheduling concepts in both seasons. Among the SKII treatments, skipping the regular irrigation at grain filling stage reduced SET by about 12.6 to 15.5 % in 2009/10 season. But in 2010/11 season, the SET of that treatment was about 4 % higher than the others in the group. The change in trend may be as a result of the rainfall which occurred after irrigation was withdrawn from that treatment that season. Among the RWAD treatments, irrigating with 50% of WRET at vegetative growth stage led to SET reduction of about 6.5 to 12.2 %. The average seasonal ET of the RWAD was about 7% higher than the SKII, but about 10 % less than the CSC.

The total irrigation water applied ranged from 360 to 460 mm and 410 to 500 mm in 2009/10 and 2010/11 seasons, respectively. The difference in water application depths between the two seasons was as a result of one regular irrigation that was skipped for all treatments at grain filling stage in 2009/10 season because of the rainfall event which occurred a day before the irrigation was due (see Table 4). The total seasonal water applied to the field (including rainfall) varied from 443.7 to 543.7 mm and 465 to 555 mm for 2009/10 and 2010/11 seasons, respectively. Only the water applied in the CSC treatment was within the range of 500-800 mm given by Doorenbos and Kassam (1979) as water requirement of a maize crop for maximum production. This implies that beside the CSC treatment, others had deficit water supply. This further explains the differences in yield between the CSC and the other treatments.

The deep percolation ranged from 40.3 to 70.9 mm and 5.7 to 68.2 mm in 2009/10 and 2010/11 seasons, respectively. The least deep percolation were recorded from the treatments in which regular irrigation were either skipped or water application depths reduced at grain filling to maturity stages, while the highest values of deep percolation were recorded in the fully irrigated treatment. While it was expected that the fully irrigated treatment will generate higher deep percolation losses, the rainfalls seem to have contributed larger to the deep percolation in both seasons. These results agree with the fact that deficit irrigation is a means of reducing deep percolation losses on the field. More so, it suggest that deep percolation losses may be reduced by either skipping regular irrigation event or reduce water application depth at grain filling to maturity stage of the crop.

Water Productivity

Table 9 shows the productivity of seasonal water applied to the field (PSW) with respect to grain and biomass yield for the two seasons.

Table 9: Irrigation water productivity for grain and biomass yields ((kg/m^3) of maize crop in 2009/10 & 2010/11 seasons

	2009/10 season		2010/11 season	
Treatment	$IWP_{(grain\ yield)}$	$IWP_{(biomass\ yield}$	$IWP_{(grain\ yield)}$	$IWP_{(biomass\ yield)}$
$V7_{100\%}$ $F7_{100\%}$ $G7_{100\%}$	0.54	1.84	0.54	1.72
$V14_{100\%}$ $F7_{100\%}$ $G7_{100\%}$	0.51	1.82	0.51	1.78
$V7_{100\%}$ $F14_{100\%}$ $G7_{100\%}$	0.50	1.67	0.51	1.76
$V7_{100\%}$ $F7_{100\%}$ $G14_{100\%}$	0.48	1.74	0.58	2.02
$V7_{50\%}$ $F7_{100\%}$ $G7_{100\%}$	0.42	1.35	0.45	1.56
$V7_{100\%}$ $F7_{50\%}$ $G7_{100\%}$	0.48	1.61	0.51	1.62
$V7_{100\%}$ $F7_{100\%}$ $G7_{50\%}$	0.55	1.94	0.61	1.97

*Treatment means followed by the same letter(s) in any column are not significantly different at 5 % level of significance

The water productivity with respect to grain yield varied from 0.42 to 0.55 kg/m^3 in 2009/10 season and 0.45 to 0.61 kg/m^3 in 2010/11 season, while the water productivity with respect to biomass yield varied from 1.35 to 1.94 kg/m^3 and 1.56 to 2.20 kg/m^3 in 2009/10 and 2010/11 seasons, respectively. These results imply that about 420 to 610 g of maize grain was produced from every cubic metres of water, while 1.35 to 2.20 kg of dry matter was produced from every cubic metres of irrigation water. In both seasons, the treatment in which water application depth was reduced by 50 % at grain filing ($V7_{100\%}$ $F7_{100\%}$ $G7_{50\%}$) recorded the highest values of water productivities while the treatment in which water application depth was reduced by 50 % at vegetative growth stage ($V7_{50\%}$ $F7_{100\%}$ $G7_{100\%}$) recorded the least water productivities. Among the SKII treatments, there was no consistency in the order of treatments that recorded the highest productivity, as the $V14_{100\%}$ $F7_{100\%}$ $G7_{100\%}$ treatment which recorded the highest productivity became the least in 2010/11 season, while the $V7_{100\%}$ $F7_{100\%}$ $G14_{100\%}$ recorded the highest productivity in 2010/11 season. The improvement in grain and biomass yield resulting from rainfall may be responsible for this difference. The range of water productivity with respect to grain yield obtained in this study wasclose to 0.40-0.55 kg/m^3 reported by Igbadun *et al* (2006) for irrigated maize in Tanzania. Farré and Faci (2006) had obtained a range of 0.25 to 1.80 kg/m^3 for irrigated maize in the Mediterranean environment.

Crop Yield –Seasonal ET Relationship

Figure 1 shows the graphical relationship between the maize grain yield and seasonal evapotranspiration and between the biomass yield and seasonal evapotranspiration. The figure was plotted with a pooled data of the two seasons since the plotting of the individual year showed no significant difference in their correlations. The relationship between the yields and seasonal evapotranspiration was linear implying that both the grain and biomass yields were increasing linearly with increase in evapotranspiration within the lower and upper bound of the data.

The linear equation for the grain yield (GY in t/ha) and seasonal evapotranspiration (SET in mm) relationship was obtained as:

$$GY = 0.009 * SET - 1.608 \quad , \quad r^2 = 0.813 \qquad (6),$$

while, the relationship between biomass yield (BY) and SET was obtained as:

$$BY = 0.025 * SET - 2.72 \quad , \quad r^2 = 0.592 \qquad (7).$$

While the coefficient of determination of the grain yield-SET relationship can be said to be very good (> 0.8), that of the relationship between biomass yield and SET was only fair (about 0.6). The implications of the relationships are that grain yield of about 89.4 kg/ha will be obtained for every 10 mm increment of seasonal evapotranspiration after the initial threshold of 178.6 mm depth of water use. Biomass yield of 2.0 kg/ha is also expected from every 10 mm increase in SET after the initial threshold 108 mm depth of water use. This information is useful for planning deficit irrigation schedule.

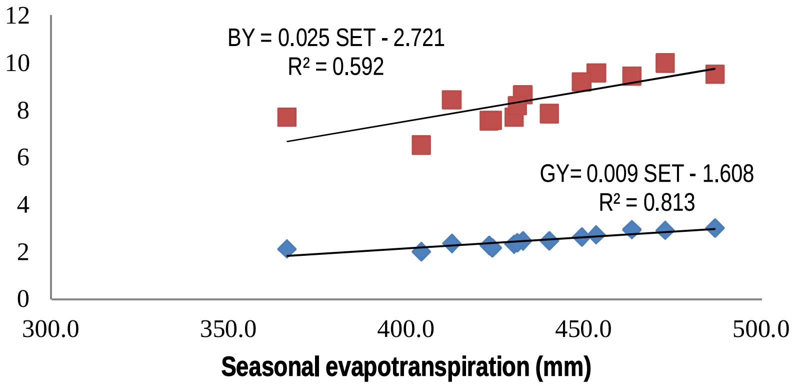

Figure 1: Grain and biomass yields relationships with seasonal evapotranspiration

CONCLUSION

The impact of two methods of administering growth-stage deficit irrigation (GSDISS): reducing water application depth at selected crop growth stages, and skipping regular irrigation interval at selected crop growth stages on yield and soil water balance of a maize crop was studied in Samaru, Zaria. This study reveal that at vegetative growth stage of the maize crop, it is better to skip weekly irrigation (to irrigation every other week) and apply water to meet full water requirement than to maintain regular weekly irrigation but apply water at half water requirement. It is however, more advantageous in terms of grain and biomass yield production to reduce irrigation water application by half water requirement during grain filling to maturity than to skip weekly irrigation. Grain yield, biomass yield and seasonal evapotranspiration from such scheduling was not significantly different from that which received weekly irrigation throughout the crop growing season. Moreover, the productivity of water applied was higher while water loss to deep percolation was drastically reduced.

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