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Water Productivity of a Maize Crop under Deficit Irrigation Scheduling Using Gravity Drip System

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Abstract

This study was carried out to determine the impact of deficit irrigation scheduling strategies on water productivity of a maize crop using gravity drip system of irrigation. The experimental treatments were based on water application regulated at selected crop growth stages. The treatments comprising a control treatment which was given full irrigation (irrigated at 100 % water requirement) and a full deficit treatment which was irrigated at 50 % water requirement. The other treatments were irrigated at 50 and 75 % of water requirement at different growth stages of the maize crop. The irrigation interval was alternated between three and four days. The overall average dripper discharge was found to be 0.56 l/hr. The depths of water were applied ranged from 432 to 699 mm for both seasons. Grain yields, biomass yields, seasonal evapotranspiration and crop water productivity were determined. The grain and biomass yields for the two seasons ranged from 1.56 to 3.52 and 5.63 to 11.53 t/ha, respectively, while the seasonal evapotranspiration varied from 289 to 483 mm. The irrigation water productivity with respect to grain yield and biomass yield varied from 0.41 to 0.63 and 1.33 to 1.98 kg/m^3 for both seasons. The vegetative stage seems to be very sensitive to yield reduction for both seasons. Therefore, it is more advantageous to apply stress at flowering and grain-filling stage in the study area because of the interception of rain which may overturn the effect of moisture stress during grain-filling stage.The highest crop yield, seasonal water use and water productivity were obtained in the treatment that was fully irrigated, which implies that the deficit irrigation did not improve the crop response or water use efficiency. The results suggest that under high water application efficiency deficit irrigation practice may not lead to higher crop water use efficiency or the maize crop

***Keywords**: Deficit irrigation schedulling; Crop water use; yield reduction; Growth stage; Maize*

Introduction

Maize is one of the third most important cereal in the world after rice and wheat, useful both for human and animal consumption. In 2014, the world production for maize was 823 million tonnes; 53.4 million tonnes for Africa and 7.5 million tonnes for Nigeria (FAO, 2014). Recently, the estimated average annual growth rate in maize production over the last five years in Nigeria was 5.46% about twice the projected 3.2% needed to meet demands; despite the increase in production, the demand for maize is higher even than the target set for self-sufficiency (Ado *et al.*, 2007). No other crop is distributed over so large an area and none occupies a larger hectare in Nigeria like maize.

The Guinea savanna however, is the most important maize growing zone in the country; it is however, characterized drought spells and erratic rain fall which limits production of maize in the region. Maize, besides being a staple food in Nigeria is

used to produce ethanol as biofuel, raw material for industrial products, forage, silage and grains, (Babaji *et al*., 2007, Hussein *et al*; 2001, Mani *et al.*, 1998, 2006a and 2006b; Shaib *et al.*, 1997).
Peasant irrigation farmers in Nigeria irrigate until their fields are inundated, so there is a need for a paradigm shift in the way irrigation is practiced, the call to improve the efficiency and productivity of water use for crop production has never been more urgent than now because of the emerging threat to sustainability of agriculture (Kendall, 2011; Igbadun *et al.,* 2012).One of the ways of effective water management strategies is the use of drip irrigation system and adoption of deficit irrigation scheduling (Segal *et al.*, 2000; Mofoke *et al.*; 2006; Oyebode *et al*., 2011).
Regulated deficit irrigation schedulling practice is the technique of reducing the amount of water applied per irrigation at some stages of the crop growth with the aim of saving water and in some cases energy (Igbadun, 2008; FAO, 2012; Hamid *et al.*,2009; Himanshu *et al.*,2012 Prichad *et al*., 2004; Zhang *et al*., 2004). Research outcome documented on deficit irrigation scheduling with the use of drip irrigation for Samaru-Nigeria in particular is not yet explored, but some researchers in the region reported some findings on deficit irrigation with the use of surface irrigation (Igbadun, 2012; Halilu *et al*., 2014; Ismail et al., 2014; Nega ,2009); in all these results obtained, knowledge gaps remain as to the growth stage deficit irrigation tolerance limit for maize crop under drip irrigation method in the study location and the corresponding impacts on yield, soil water balance and water productivity. The objective of the study is to evaluate the impact of irrigation schedulling strategies on yields, soil water balance and water productivity of a deficit drip irrigated Maize.

Materials and Methods
The field experiments were carried out at the Institute for Agricultural Research (I.A.R) irrigation farm, Ahmadu Bello University, Zaria, Nigeria during the 2013 and 2014 irrigation cropping season. The study location lies on $11^{o}11'$N and $7^{o}38'$E, and at an altitude of 686m above mean sea level (Odunze, 1998). The weather data during the crop growing seasons are presented in Tables 1, while the soil characteristic of the study location is shown in Table 2.

Experimental Layout and Agronomic Practices
The field experiment in each season consisted of eight (8) treatments (Table 3) replicated three times and laid in a randomized complete block design. The following growth-stages ranges were adopted in this research as reported by Igbadun (2012): Vegetative (15-42DAP); Flowering – tasseling to silking (43-63 DAP) and grain filling to physiological maturity stages (64-95 DAP). The field was divided into plot sizes of 5m by 1.8 m each. Each plot consisted of three drip lines spaced 0.6m apart. SAMMAZ 14 maize variety was planted on the 7th February 2013 in the first season and 6th February 2014 in the second season. In both seasons the planting was done along the drip lines, a plant spacing of 30 cm between plants and 60 cm

between rows(which is a deviation from the conventional spacing which is 25cm by 75cm) was used giving a plant population of 53,333 plants/ha. Agronomic measures as outlined by Igbadun (2012) was adopted.In 2014, however, there was attack of ***aphids*** during the 5th week, which was managed with the application of karate 0.8l/ha using 40ml in 15litres knapsack sprayer as recommended by Avav and Ayuba (2006); the crop attained physiological maturity at 90 days for both seasons.

Table 1: Average weather data for the 2013/2014 crop growing season

Month	Humidity (%)	Max. temp (^oC)	Min. temp (^oC)	Sunshine (Hours)	Wind speed (Km/d)	ETo(mm /d)	Total Rainfall (mm)
January	19.37	32.48	17.74	8.01	142.66	6.82	-
February	13.52	35.50	18.79	7.49	131.44	8.56	-
March	26.37	39.29	22.77	7.63	118.24	9.14	-
April	38.85	37.47	24.77	7.09	143.03	7.89	14.76

Table 2: Physical properties of soils at various depths at the Irrigation Research Farm, IAR, Samaru

Depth(cm)	FC (%Vol)	PWP (% Vol)	Bulk density (g/cm3)	Hydraulic Conductivity (mm/hr)	Clay (%)	Silt (%)	Sand (%)	Texture class[a]
0-15	24.8	13.6	1.58	9.73	22	28	50	Clay Loam
15-30	26.3	15.9	1.58	7.07	26	22	54	Clay Loam
30-45	27.4	17.1	1.57	5.69	28	18	54	Clay Loam
45-60	25.9	15.9	1.58	7.30	26	18	56	Sandy clay loam
60-80	29.5	18.2	1.55	4.23	30	22	48	Sandy clay loam

[a] Based on USDA textural classification

Table 3 Description of Experimental Treatments

Treatment Label.	Treatment Description
$V_{100}\,F_{100}G_{100}$	Water applied was 100% of DRET in all the growth stages.
$V_{75}\,F_{100}\,G_{100}$	Water applied was 75% of DRET at Vegetative (V) Stage and 100% of DRET for Flowering(F) and Grain filling (G) Stages.
$V_{50}\,F_{100}\,G_{100}$	Water applied was 50% of DRET at Vegetative (V) Stage and 100% of DRET for Flowering(F) and Grain filling (G) Stages.
$V_{100}\,F_{75}\,G_{100}$	Water applied was 75% of DRET at Flowering (F) Stage and 100% of DRET at Vegetative (V) and Grain filling (G) Stages
$V_{100}\,F_{50}\,G_{100}$	Water applied was 50% of DRET at Flowering (F) Stage and 100% of DRET at Vegetative (V) and Grain filling (G) Stages
$V_{100}\,F_{100}\,G_{75}$	Water applied was 75% of DRET at Grain filling (G) Stage 100% of DRET at Vegetative (V) and Stages Flowering (F)
$V_{100}\,F_{100}\,G_{50}$	Water applied was 50% of DRET at Grain filling (G) Stage 100% of DRET at Vegetative (V) and Stages Flowering (F
$V_{50}\,F_{50}\,G_{50}$	Water applied was 50% of DRET in all the growth stages

DRET= Daily Reference Evapotranspiration

Water applied was based on the daily reference evapotranspiration computed from study area using the Hargreaves equation (Allen *et al.*, 1998) as shown in Table 4 and 5 .Application rate and running time was estimated with the use of Eq.1 and 2.

Application Rate (AR) = $\frac{Qave.LD.Nd}{SB_E}$ (1)

Where: Qave = Average emitter discharge l/hr, $LD =$ Length of lateral lines (m), $Nd =$ Number of drip lines, SB_E = Spacing between emitters (m)

Irrigation Running Time = $\frac{V_{gr}}{AR}$ (2)

In which, V_{gr} = Volume of gross irrigation requirement (l/day), at different deficit irrigation levels and AR = irrigation application rate l/hr

Soil moisture contents of the experimental plots were monitored throughout the crop growing season using calibrated gypsum blocks installed in each experimental plot at 12, 25, 45 and 70cm soil profile depths to monitor soil moisture changes at 0-15,0-30, 30-60, 60-90 cm depths. The calibration curve was expressed as:

GMC = $44.75 * R^{-0.24}$ (3)

where, GMC is the gravimetric moisture content (% dry weight basis) and R is electrical resistance in ohm (Ω).

The actual crop evapotranspiration was estimated as outlined by Michael (1978). Equation 4 was used to estimate the actual crop evapotranspiration (ETa) expressed as:

$$ET_a = \sum_{i=1}^{n} \left[\frac{M1-M2}{100}\right] D_i \times Bd_i$$

(4)

Where: M_1 = gravimetric moisture content (g/g) at first sampling in the ith layer; M_2 = gravimetric moisture content (g/g) at the second sampling in the ith layer; D_i = depth of ith layer (mm) n = number of depth within the soil profile Bd_i = specific gravity of the soil layer

Computation of Crop Water Productivity

The productivity of the seasonal water applied which is defined as the mass of produced (kg) per volume of water applied (m^3) for biomass and grain yield were expressed as:

Water Productivity (Biomass) $= \frac{Biomass yield\ (kg)}{Seasonal water applied\ (m^3)}$ (5)

Water Productivity (Grain yield) $= \frac{Grain yield\ (kg)}{Seasonal water applied\ (m^3)}$ (6)

The grain and biomass yield, seasonal crop water use, biomass and grain yield irrigation water productivity were subjected to statistical analysis of variance and the significance among treatment means was evaluated with Duncan's Multiple Range Test to check significant differences between the treatments (SPSS,2003).

Results and Discussion

Emitter flow rate and soil wetting capacities of drippers

The overall average dripper discharge was found to be 0.557 l/hr while the average maximum and minimum discharge rates were 0.612 and 0.489 l/hr, respectively. The maximum and minimum wetting diameters of the soil obtained after one hour of irrigation were 26.0 and 22.2 cm, respectively, and an average value of 24.3 cm. The field test revealed that on the average with emitter flow rate of 0.557 l/hr, the wetting front on the average can extend to 24.3 cm in the horizontal direction and the results imply that with one inline dripper, 30 cm between two drippers it is possible to irrigate two maize stands if planted 25 cm apart.

Grain and Biomass Yield

Table 6 shows the grain yield, biomass yield and harvest index of the maize crop for the two seasons. There was no significant difference between the yields for the two seasons at 95% probability level. When the application depths were varied at the vegetative stage for during 2013 cropping season, 75% (V_{75} $F_{100}G_{100}$) and 50% (V_{100} $F_{50}G_{100}$), the grain and biomass yields were 12.7 %, 30.4 % and 13.7 % and 31.2% less than when 100 % water was applied to all the crop growth stages (V_{100} $F_{100}G_{100}$) accordingly. Also, when the depth of water applied was varied at 75 % (V_{100} F_{75} G_{100}) and 50% (V_{100} F_{50} G_{100}) at the flowering stage, the reduction in grain and biomass yield were 8.8 %, 26.8 % and 9.4 %, 36.7 %, respectively, with respect to the control. When the depth of application was varied at the grain filling stage at 75 % (V_{100} $F_{100}G_{75}$) and 50 % (V_{100} $F_{100}G_{50}$) the corresponding grain and biomass yield reduction were 0.9, 4.7 % and 2, 5.9 %. The highest yield reduction value of 54% and 49.4% for grain and biomass yield was observed when 50% depth of water was applied throughout the crop growth season. The vegetative stage seems to be very sensitive to yield reduction, so it is advantageous to impose deficit irrigation during the grain-filling stage. The highest and lowest grain yield reduction values of 48.4 and 2 % were obtained for treatment $V_{50}F_{50}$ G_{50} and V_{100} F_{75} $G_{100,}$ respectively in 2014 cropping season, while the highest and lowest biomass yield reduction value of 36.6 and 1.5 % were obtained for treatments $V_{50}F_{50}$ $G_{50}$and $V_{100}F_{100}G_{50\,,}$respectively. However, treatments V_{100} F_{100} G_{75},V_{100} F_{75} G_{100}andV_{100} F_{100} G_{75} were statistically not significantly different from the control at 95% probability level, which is indicative of the fact that it will be advantageous when deficit irrigation is imposed on grain-filling stage for the variety used.

Table 4: Irrigation water Applied throughout 2013 cropping season

Treatments	Days applied after Planting																								Total water applied (mm)
	1	4	7	11	14	17	21	24	28	31	35	38	42	45	48	52	55	59	62	66	69*	73	77	80*	
V_{100} F_{100} G_{100}	20	20	20	20	30	20	40	40	40	30	40	20	20	30	50	20	40	30	30	30	26	20	30	33	699
V_{75} F_{100} G_{100}	20	20	20	20	30	15	30	30	30	23	30	15	15	30	50	20	40	30	30	30	26	20	30	33	637
V_{50} F_{100} G_{100}	20	20	20	20	30	10	20	20	20	15	20	10	10	30	50	20	40	30	30	30	26	20	30	33	574
V_{100} F_{75} G_{100}	20	20	20	20	30	20	40	40	40	30	40	20	20	23	38	15	30	23	23	30	26	20	30	33	649
$V_{100}F_{50}$ G_{100}	20	20	20	20	30	20	40	40	40	30	40	20	20	15	25	10	20	15	15	30	26	20	30	33	599
V_{100} F_{100} G_{75}	20	20	20	20	30	20	40	40	40	30	40	20	20	30	50	20	40	30	30	23	26	15	23	33	679
V_{100} F_{100} G_{50}	20	20	20	20	30	20	40	40	40	30	40	20	20	30	50	20	40	30	30	15	26	10	15	33	659
V_{50} F_{50} G_{50}	20	20	20	20	30	10	20	20	20	15	20	10	10	15	25	10	20	15	15	15	26	10	15	33	434

*= rainfall depth

Table 5: Irrigation water Applied throughout 2014 cropping season

Treatments	Days applied after Planting																							Total water applied (mm)
	1	5	8	12	15	19	22	26	29	33	36	40	43	47	50	54	57	61	64	68	71*	75	78	
V_{100} F_{100} G_{100}	40	25	35	25	35	30	30	30	35	30	40	30	40	30	35	20	30	10	30	35	10	20	30	675
V_{75} F_{100} G_{100}	40	25	35	25	26	23	23	23	26	23	30	23	40	30	35	20	30	10	30	26	10	20	30	614
V_{50} F_{100} G_{100}	40	25	35	25	18	15	15	15	18	15	20	15	40	30	35	20	30	10	30	26	10	20	30	549
V_{100} F_{75} G_{100}	40	25	35	25	20	40	40	40	30	40	20	20	30	23	26	15	23	8	30	26	10	20	30	628
$V_{100}F_{50}$ G_{100}	40	25	35	25	35	30	30	30	35	30	40	30	20	15	18	10	15	5	30	26	10	20	30	597
V_{100} F_{100} G_{75}	40	25	35	25	35	30	30	30	35	30	40	30	40	30	35	20	30	10	23	26	10	15	23	646
V_{100} F_{100} G_{50}	40	25	35	25	35	30	30	30	35	30	40	30	40	30	35	20	30	10	15	18	10	10	15	618
V_{50} F_{50} G_{50}	40	25	35	25	18	15	15	15	18	15	20	15	20	15	18	10	15	5	15	18	10	10	15	432

*= rainfall depth

Table 6 Grain yield, biomass yield and harvest index of the maize crop for 2013/2014

Treatments	2013 cropping season			2014 cropping season		
	GY (t/ha)	BY (t/ha)	HI (%)	GY (t/ha)	BY (t/ha)	HI (%)
V_{100} $F_{100}G_{100A}$	3.39a	11.12a	31	3.43a	11.38a	31
V_{75} F_{100} G_{100A}	2.96bc	9.6bc	30	3.12bc	10.74bc	32
V_{50} F_{100} G_{100A}	2.36de	7.65de	30	2.80bc	10.00bc	32
V_{100} F_{75} G_{100A}	3.09bc	10.07bc	31	3.50bc	11.17ab	31
$V_{100}F_{50}$ G_{100A}	2.48dc	7.04dc	27	2.96bc	10.37bc	32
V_{100} F_{100} G_{75A}	3.36ab	10.9ab	29	3.35ab	10.17ab	32
V_{100} F_{100} G_{50A}	3.23bc	10.46bc	31	3.22bc	11.21ab	31
V_{50} F_{50} G_{50A}	1.56e	5.63e	31	1.77c	7.21c	31

Treatment means followed by the same letter(s) in any column are not significantly different at 5% level of significance. GY = Grain yield; BY = Biomass Yield; HI = Harvest Index (%)

The grain and biomass yield ranges obtained in this study were in agreement with the report of Sefer *et al*. (2011), who obtained grain yield ranging from 1.93- 10.4 t/ha under clay loam soil with the use of drip irrigation system in the Eastern Mediterranean climatic conditions of Turkey; Sani*et al.*,(2011) in Samaru Nigeria who reported grain yield of 2.7 - 3.8 t/ha in year 2000 and 2.5- 4.0 t/ha in year 2001 and Lyocks *et al.*,(2013) who found that grain yield ranged from 2.05- 3.98 t/ha within Samaru Region. Garba and Namo (2013) reported grain yield of 3.88 and 3.49 t/ha within two savanna agro-ecologies of Saminaka (lowland) and Vom (mountainous) in Nigeria. Differences in grain and biomass yield reported, may be due to the following: crop variety, extent of irrigation deficit, irrigation method, climate and other agronomic practices.

Soil Water Balance

Table 7 shows the soil water balance for 2013 and 2014 season, during the 2013 cropping season. The crop water use for treatments V_{100} $F_{100}G_{100}$ and V_{100} $F_{100}G_{75}$ were not significantly different, though the crop water use reduction when compared to the conventional irrigation schedule was 4%. When 25 and 50% deficit was imposed on the vegetative stage the crop water use reductions were 9 and 19%. Also, when 25 and 50% deficit was imposed on the flowering stage the reduction in crop water use were 7 and 12%. Furthermore, when 50% was imposed on the grain-filling stage and throughout the growth stages, the resultant crop water use reductions were 9 and 36%, when compared to the conventional irrigation schedule for 2013/2014. Crop water use range reported herein, were consistent with the findings of Viswanatha *et al* (2002) and Mahdi *et al* (2011) who also worked on drip irrigated maize. Table 8 show the productivity of seasonal water applied to the field during the two seasons with respect to grain and biomass yields.

The water productivity with respect to grain and biomass yield varied from 0.47 to 0.53kg/m^3 and 1.53 to 1.73 kg/m^3, respectively during 2013 cropping season, for 2014 cropping season, the water productivity with respect to grain yield and biomass yield varied from 0.41 to 0.63kg/m^3 and 1.76 to 1.98 kg/m^3, respectively.

Crop yield – Seasonal ET Relationship

The linear equations for the biomass (BY), grain yield (GY in t/ha) and seasonal evapotranspiration (SET in mm) for field were obtained as:

$$BY= 0.025*SET - 0.83; \quad R^2 = 0.60 \qquad (7)$$

$$GY = 0.009*SET - 0.80; \quad R^2 = 0.74 \qquad (8)$$

The implication of these expressions are that about 2.5 t/ha of biomass will be obtained from every 10 mm increment of seasonal evapotranspiration after the initial threshold of 332 mm depth of water use ; while 0.9t/ha grain yield will be obtained from every 10mm increment of seasonal evapotranspiration after the threshold of 89mm depth of water used.

Table 7: Seasonal soil water balance of the field in 2013 and 2014 season

	2012/2013 cropping season				**2013/2014 cropping season**			
Treatments	RD (mm)	SIWA (mm)	TSWA (mm)	SET (mm)	RD (mm)	SIWA (mm)	TSWA (mm)	SET (mm)
$V_{100} F_{100} G_{100A}$	59	640	699	483a	39	636	675	453a
$V_{75} F_{100} G_{100A}$	59	578	637	441d	39	575	614	412bc
$V_{100} F_{75} G_{100A}$	59	592	651	453c	39	589	628	421bc
$V_{100} F_{50} G_{100A}$	59	540	599	428e	39	558	597	399c
$V_{100} F_{100} G_{75A}$	59	621	680	470b	39	607	646	433ab
$V_{100} F_{100} G_{50A}$	59	600	659	464bc	39	579	618	414bc
$V_{50} F_{50} G_{50A}$	59	375	434	320f	39	393	432	289e

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

Table 8: Irrigation water productivity for grain and biomass yields (kg/m^3)

	2014 cropping season		2013 cropping season	
Treatments	IWP (biomass yield)	IWP (grain yield)	IWP (biomass yield)	IWP (grain yield)
$\mathbf{V_{100} F_{100} G_{100A}}$	1.98a	0.63a	1.73a	0.53a
$\mathbf{V_{75} F_{100} G_{100A}}$	1.75c	0.51b	1.51b	0.46ab
$\mathbf{V_{50} F_{100} G_{100A}}$	1.82ab	0.51b	1.33c	0.41c
$\mathbf{V_{100} F_{75} G_{100A}}$	1.86ab	0.56ab	1.55b	0.47ab
$\mathbf{V_{100} F_{50} G_{100A}}$	1.74c	0.50c	1.51b	0.46b
$\mathbf{V_{100} F_{100} G_{75A}}$	1.88ab	0.58ab	1.60ab	0.49ab
$\mathbf{V_{100} F_{100} G_{50A}}$	1.81b	0.54b	1.59ab	0.49ab
$\mathbf{V_{50} F_{50} G_{50A}}$	1.76c	0.41c	1.53b	0.47b

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

Equation 8 and 9 indicates that if the seasonal evapotranspiration was 10 % less than the total ET required for maximum yield with deficit regulated along crop growth stages, then the actual grain yield will be 12.3 % less than the maximum yield, while the actual biomass yield will be 10.9 % less than the maximum yield. The yield response factor (Ky) obtained in this study were 1.23 and 1.09, Doorenbos and Kassam (1979) also reported a Ky value of 1.25 which was higher than what was obtained in the study herein.

$$1- GYa/GYm = 1.23\,(1-ETa/ETm) + 0.066 \qquad (8)$$

$$1- BYa/BYm = 1.09\,(1-ETa/ETm) + 0.063 \qquad (9)$$

Conclusion

This study reveals that vegetative stage of the maize crop is more sensitive compared to flowering and grain-filling growth stage. It is more advantageous in terms of grain and biomass yield production to impose stress during the flowering and grain-filling stage, which is usually intercepted by the onset of rains, which may result in an economic yield for farmers in the study area.

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