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Research Paper

Effect of Deficit Irrigation on Growth and Yield of Sugarcane

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Field trials were conducted at the sugarcane experimental field in National Cereals Research Institute Badeggi during the growing seasons of 2011 and 2012.The sugarcane crop was exposed to certain levels of water stress at the initial, mid-season stage and the late season. The results showed that cane and sugar yield produced when water stress was imposed at the late season stage was not significantly ($P \leq 0.05$) from yields obtained at full irrigation. The late season stage was the least sensitive to water stress. However, water deficit during the mid-season stage significantly ($P \leq 0.05$) decreased cane and sugar yield when compared with other treatments.

Key words: Deficit irrigation, Growth stages, Sugarcane.

INTRODUCTION

Farming is a victim of climate change, which is leading to unpredictable pattern of rainfall. Due to the greater competition between agricultural water supply, domestic and industrial supply, it is crucial to manage agricultural water efficiently in order to ensure its cost-effectiveness and sustainability.

Researches have been conducted on how to manage irrigation water efficiently in sugarcane growing areas of the world especially in Australia and South Africa (Robertson et al., 1997) and Brazil (Chaudhry and Leme, 1996) and to develop strategies that would optimize the use of limited water by the crop. 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 which involves applying water less than the 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 scheduling where water is applied short of the crop water requirement throughout the crop growing season.

Deficit irrigation or regulated deficit irrigation is one way of maximizing irrigation production efficiency for higher yields per unit of irrigation water applied. The crop is exposed to certain levels of water stress either during a particular period or throughout the whole growing season. The expectation is that any yield reduction will not be significant when compared with the benefits gained through diverting the saved water to irrigate other crops.

Research findings reported that deficit irrigation saved significant irrigation water without significant yield losses (Stegman et al., 1990; Igbadun et al., 2006; Pandey et al., 2000; Ayana, 2011). The total growing season of sugarcane plant can be divided into 4 growth stages; initial stage from sowing to 10 % ground cover, development stage from 10 % to 70 % ground cover, mid-season stage including flowering and yield formation and late season stage (Ellis and Lankford, 1990).

The main objective of deficit irrigation is to increase the water production efficiency of a crop by eliminating irrigation that has little impact on yield. The resulting yield reduction may be small compared with the benefits gained through diverting the saved water to irrigate other crops for which water would normally be insufficient under traditional irrigation practices.

MATERIALS AND METHODS

Field trials were conducted at the sugarcane experimental field in National Cereals Research Institute Badeggi during the 2011 and 2012 irrigation season. Badeggi lies on latitude 9° 05.527'N longitude 5° 50.900' E Altitude 246 m in the Southern Guinea Savanna of Nigeria.The soils of the area have been described as Nupe sand stone. The climate has distinct dry and wet season with maximum temperature of 35°C. The experiment was planted in the month of November during the dry season.

Furrow irrigation was used for the experiment and a Parshal flume installed to measure the quantity of water entering the field plots. Four irrigation treatments were applied in this study: (a) optimal irrigation with full irrigation and no stress condition. Irrigation water was applied when the available soil moisture in the root zone was 60 % of the total available soil moisture (40 % depletion) with soil moisture tension of-33 kPa (b) Stress applied at initial stage of growth. (c) Stress applied at mid-season stage and (d) Stress applied at the late season stage. Generally, in treatments with stress conditions, irrigation water was applied when the soil moisture content was 20-25 % of the total available soil moisture in the root zone (75-80 % depletion) at respective growth stages with soil moisture tension of – 75 kPa. To ensure successful deficit irrigation the water retention capacity of the soil was determined using a tensiometer. Field capacity of the soil measured 2 days after irrigation was -33kPa. Sampling with the tensiometer was done before irrigation throughout the growing season.The sugarcane variety used for the experiment was an industrial cane NCS 008 and the plot size was 5 x 4 m.

The reference evapotranspiration (ETo) for the area was calculated using FAO-Penman-Monteith approach (Smith, 1991) and the cropwat software. The computation of the evapotranspiration in mm/day for each month of the growing season was done upon entry of the following meteorological data: monthly mean maximum and minimum temperatures, relative humidity, wind speed, sunshine hours and solar radiation. Rainfall was measured during the rainy season using a rain gauge. Rainfall was converted to effective rainfall (Re) according to the following formula:

$$Re = 0.9 \times (R-2) \leq SMD$$

Where R = rainfall, SMD = soil moisture deficit.

Soil moisture content was determined using gravimetric method. Samples were taken at 20 cm increment to a depth of 1 m using a soil auger. Sampling was done 1 day before irrigation and 3 days after irrigation throughout the season. Soil samples were oven dried at 105 °C for 24 h. The dry weight (Dw) and the Wet weight (Ww) were determined and the soil moisture content was then calculated following the procedure as described by Farbrother (1973). The % of moisture content on dry weight basis was calculated as:

$$\% Mc = [(Ww - Dw) / Dw] \times 100.$$

Then the gravimetric moisture content was converted to volumetric values (v/v) through multiplication by the dry bulk density (Farbrother, 1973) the seasonal amount of water requirement (CWR) for sugarcane crop was determined as a function of the local climate, crop data and soil data according to the equation given by Doorenbos and Kassam (1979) as :

$$CWR = ETo \times Kc$$

Where ETo is reference crop evapotranspiration and Kc crop factor.

RESULTS AND DISCUSSION

Table 1 shows the physical properties of the soil at the experimental site. Soil samples were taken at 10 cm incremental to a depth of 1 m. The soil texture is sandy loam with bulk density of 1.4-1.5 g/cm^3 and a well-drained soil.

Crop water requirements (CWR)

Table 2 shows the water requirements of the 4 growth stages of sugarcane during the irrigation seasons. Results indicated that the highest period of sugarcane water needs was the mid-season stage with water requirements that ranged from 4.5 to 7.5 mm/day. This is followed by the development stage with 3.06 to 6.30 mm/day, initial stage with 2.50 mm/day and late season stage with a value of 2.70 to 5.20 mm/day water requirements, respectively.

The effective rainfall (Re) was recorded in the months of May to November, the values ranged from 6 to 95 mm. The results also indicated that the reference evapotranspiration (ETo) reached its maximum value of 6.4 mm/day in the month of Apr. then declined reaching its minimum value of 4.4 mm/day during October. Data on irrigation water saved when water stress was imposed at various stages is shown in (Table 3). The analysis indicated that the mid-season stage saved 36% when compared with full irrigation.

Table 1. Physical properties of the soil at the experimental site.

Soil depth (cm)	Sand Depth % Soil	Silt %	Clay %	Bulk density g/cm^3
0-10	79.2	14.3	6.5	1.5
10-20	76.2	14.3	6.5	1.5
20-30	75.1	14.3	6.5	1.5
30-40	73.2	16.3	7.4	1.5
40-50	73.2	16.3	7.5	1.5
50-60	72.2	18.2	8.5	1.5
60-70	72.2	18.2	9.4	1.5
70-80	72’1	18.2	9.4	1.4
80-90	71.2	20.3	11.5	1.4
90-100	70.1	20.3	11.5	1.4

Table 2. Mean monthly sugarcane water requirements.

Growth Stage	Month	Temp°C	ETo Mm/day	Kc	Eta Mm/day	CWR Mm/month	Re mm	CWR-Re Mm/month
Initial stage	Nov	35	5	0.5	2.50	75	0	75
	Dec	32	5	0.5	2.50	75	0	75
Development Stage	Jan	30	5.1	0.6	3.06	91.8	0	91.8
	Feb	30	6.0	0.6	3.60	108	0	108
	Mar	38	6.3	1.0	6.30	189	0	189
Mid-season Stage	Apr	37	6.4	1.1	7.04	211.2	0	211,2
	May	37	6.3	1.2	7.56	226.8	15	211.8
	June	35	6.0	1.2	7.20	216.0	60	156.0
	July	35	5.0	1.0	5.00	150.0	60	90.0
	Aug	34	4.5	1.0	4.50	135.0	95	40.0
	Sep	36	4.5	1.0	4.50	135.0	14	105.0
Late season	Oct	37	4.4	0.8	4.50	105.6	14	91.6
	N0v	37	4.5	0.6	2.70	81.0	6	75.0
Mean		34.8	4.9	0.85	4.61	138.41	21.54	116.87
SE±		1.25	1.48	0.80	1.34	3.52	1.45	

ETa- actual evaporation

Table 3. Effect of deficit irrigation on number of irrigations applied and water saved

Activity	No of irrigations applied	No of irrigations Saved	CWR M^3/ha/season	Water saved M^3/ha/season
Full irrigation	31	0	17518	0
Initial stage	28	3	15670	1350
Development stage	24	7	14633	5646
Mid-season stage	23	8	13002	6329
Late season	28	3	16670	1356

CWR- crop water requirement.

Soil moisture content

Average values of soil moisture content for depth intervals of 20 cm down to 1 m are shown in (Table 4). Results indicated that the soil water entering the soil profile under stress condition of 75 – 80 % depletion was greater when compared to that under no stress condition that was 40 % depletion. The increase in the soil water under stress condition of 75 – 80 % depletion was mainly due to longer duration of irrigation leading to faster and deeper infiltration rate than expected in those soils (Michael, 1970). The results also showed that there was linear increment of soil moisture from the top soil to the 1 m depth (Table 4).

Table 4. Average values of soil water content for depth intervals from 20 – 100 cm.

Soil depth cm	Soil moisture before irrigation % v/v		Soil moisture 3 days after irrigation % v/v	
	s40 % depletion	75-80% depletion	40 % depletion	75-80 % depletion
0-20	21	16	35	36
20-40	22	17	38	40
40-60	25	20	39	42
60-80	28	22	40	45
80-100	33	28	42	46

Table 5. Effect of deficit irrigation on yield components of sugarcane.

Treatments	Stalk height (cm)	Millable stalks Count (ha)	Cane Yield (t/ha)	Sugar yield (t/ha)
Full irrigation	207.40 a	49125 a	98.20 a	20.00 a
Initial Stage	195.70 b	44875 b	86.60 b	17.00 b
Mid-season stage	189.40 c	40000 c	74.50 c	12.00 c
Late season stage	197.10 b	48625 a	92.40 a	19.00 a
S E ±	0.66	2.06	1.84	0.45

Figures followed by same letter are not significantly different in a column.

Yield and yield components of sugarcane

Results of the stalk height are shown in (Table 5). The tallest plants were produced when full irrigation was applied with a value of 207.40 cm and was significantly different when compared with other treatments. This was followed by the late-season stage, then initial stage and mid-season stage. The significant reduction in stalk height at the mid-season stage was mainly because of the fact that the mid-season stage is the period of the highest crop water needs with a value of 4.5 – 7.56 mm/day. Whereas, the least sensitive stage to water stress was the late-season stage. This is in agreement with the findings of Stegman et al. (1990) who stated that water deficit during the mid-season stage causes a lower rate of stalk elongation and forces the crop to ripen. Also Gorbert and Rhoades (1975), reported that maximum plant height is expected to be obtained if adequate irrigation water is applied throughout the growing season of sugarcane crop.

Millable stalks were also significantly different ($P \leq 0.05$) when compared with the full irrigation treatment. The highest millable stalks were similarly obtained in fully irrigated condition. This was followed by the late season which was not significantly different from the fully irrigated, then initial stage, and development stage, respectively (Table 5).

Table 5 also shows the effect of deficit irrigation on sugarcane and sugar yield in this environment when compared to full irrigation and the stress conditions imposed at the 4 growth stages of the crop. The results showed that the highest cane and sugar yield was obtained in the fully irrigated treatment. This was also followed by late season, initial stage and mid-season stage, respectively. The results also showed that cane and sugar yield produced when water stress was imposed at the late season stage was not significantly different ($P \leq 0.05$) from yields obtained at full irrigation. Indicating that the late season stage was the least sensitive to water stress. However, water deficit during the mid-season stage significantly ($P \leq 0.05$) decreased cane and sugar yield when compared with other treatments. This could mainly be due to the fact that the mid-season stage is most sensitive to water stress. These results are in agreement with those reported by Jones and Ritchie (1990) who also reported that the reduction in yield as a result of deficit irrigation practice at mid-season stage was significantly high. The improvement of sugar yields during the late season stage was as a result of water stress that forced the cane to ripen (Abdel-Wahab, 2005).

Conclusion

The impact of deficit irrigation on the growth stages revealed that the mid-season stage is the most critical of all the growth stages for irrigation of sugarcane crop. This stage should not be skipped as it is going to reduce the cane and sugar yield significantly. However, irrigation at the late-season could be skipped without significant losses in cane and sugar yield and is going to hasten the ripening of the cane. It is recommended that irrigation should be stopped 1 month before harvest to increase sucrose accumulation in the sugarcane crop.

AUTHORS` DECLARATION

We declare that this study is an original research by our research team and we agree to publish it in the journal.

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