Water Supply and Rain-fed Maize Production in a Semi-Arid Zone Alfisol of Nigeria

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1. Abstract

A randomised complete block design (CRBD) with six treatments, replicated four times was established in an Alfisol of the Guinea Savannah around Zaria (11^0 10ˡN and $7^0$35ˡE) for an irrigation field where rain-fed and irrigation maize production were compared in a study of soil water balance and grain yield during the 2003-2005 years. The study revealed that treatment 3 (five daily irrigation) gave optimum grain yields when irrigation is compared with rain-fed, showing that for production of maize (95 TZEE-Y) using between 415 and 540 mm^3 of irrigation water per 4 by 5 m^2 irrigation plot area would ensure sustainable maize grain production. This treatment gave average yield of 2.4-2.8 t/ha compared to 3.5-3.8t/ha for the rain-fed over the period of 2003 to 2005. After a water balance calculations, water use efficiency (WUE) and Nitrogen fertilizer use efficiency (NUE) for sustainable maize production in the Nigerian Guinea Savavnna Kandiustalfs werre determined to range respectively from 4.25-5.81 kg/ha.mm and 60.96 to 69.28 kg/ha indicating optimum values for sustained soil health and soil productivity when compared with other treatments.

2. Introduction

Tropical semi-arid regions usually have large variations in physical conditions over time (weather between years) and location (climate and edaphic). However in Nigeria, the zones are currently witnessing increasing intensification of agricultural production activities. The soils are said to have ustic moisture and isohyperthermic temperature regimes (Odunze *et al* 1993). The soils' ustic moisture regime presupposes that when rainfall during the cropping season is limited, irregular or during the dry seasons, maize production would be strongly affected by soil water availability for crop use. At this instance, supplemental or total water supply by irrigation would be necessary to avert crop failure. Also, land and water degradation decreases crop yields, increases food costs, leading to poverty and can further increase pressure on natural resources. Therefore, intensification of production with a natural resource management focus is likely the only way to reverse degradation, reverse poverty, and improve food and income security, especially for the resource – poor farmer (Peters et al 2001). Such natural resources that would need to be adequately managed in this study are the soil and water.In order to understand effects of increased water availability on the soil and maize grain yield, this study will consider both quantity and timing of water supply from rainfall and irrigation. Maize varies in its susceptibility to moisture stress throughout its growth cycle, and the sub-soils witness impaired drainage conditions with increasing water supply (Odunze, 1998; Odunze et al., 1993). Six irrigation intervals (3, 4, 5, 6, 7 and 8 daily) and rain fed maize production will be compared in this study for their soil water use and maize grain yield. However, over-irrigation can cause nitrate to move below the crop rooting zone and sound nitrogen management cannot be achieved alone with proper nitrogen application (Fares et al. 2000). Consequently, water use efficiency and Nitrogen use efficiency would be calculated in this study to ensure that sound irrigation water and nitrogen use for maize production in the Savanna Alfisol is suggested. Objective of the study therefore are: i) To determine optimal water supply for sustainable maize production in the Zone.(ii) To compare maize grain yield under both rain fed and irrigated conditions and (iii) To suggest appropriate water and nitrogen use efficiencies for sustainable soil productivity focus in the Nigeria Savanna Zone Alfisols.

3. Materials and Methods

Experimental layout is the randomised complete block design (Table 1) with six treatments, replicated four times. The treatments are: T_1, 3-days after irrigation; T_2, 4-days after irrigation; T_3, 5-days after irrigation; T_4, 6-days after irrigation; T_5, 7-days after irrigation; and T_6, 8-days after irrigation. Net plot size measures 5m by 4m /replicate/block. The total net block size therefore is $480m^2$. Each subplot had 6 ridges with four middle ridges as net plot. In each replicate, the six treatments (T_1, T_2, T_3, T_4, T_5 and T_6) were represented. One variety of maize (95TZEE-Y) was planted at 25 cm between stands and 75 cm between row in each plot. Irrigation water was supplied to the plots using the gravity method, and between furrows. Climatological data of the area was obtained from the Institute for Agricultural Research (IAR) Ahmadu Bello University (ABU), Zaria (11^0 10ˡN and $7^0$35ˡE). However, data on Rainfall amount, mean air temperature, and relative humidity was monitored at Centre for Energy Research and Training (CERT) ABU Zaria. Detailed characterization of the soils was also

done to classify the soils as Kandiustalfs (Survey Soil Staff, 1999). Fertilizer was applied in two splits; with half dose at the first application using NPK (15: 15: 15). The second application (top dressing) of 60 kg N was made at four weeks after planting using Urea (46%); thus attaining the recommended rate of 120kg N, 60 kg P_2O_5 and 60 kg K_2O fertilizer for maize (*Zea Mayas)* in the ecological zone. Water use efficiency (WUE) was calculated using the approach WUE= Yield (Y)/Water consumption (U), WUE therefore = Y/U. But U = I+ (E+R+D)/T where E= evaporation from soil; T = Transpiration; R = Runoff; and D = Drainage; I = Irrigation
Total water applied was calculated by using the formula : Total Water applied= water applied to a plot X 7/treatment days X Length of growing period (11 weeks). Fertilizer use efficiency (NUE) was calculated by use of the formula: NUE =Yield (Y)/ N Fertilizer applied (N). Y in this study was taken as grain yield.

4. Result

Maize Crop-Water Demand:

Table 1 shows volumetric soil moisture stored at 30 cm depth before re-irrigating each treatment, available soil moisture following two days after irrigation, and soil water required to bring the treatment soil to field capacity at each irrigation date. The data shows that at developmental stage, treatment 1 required least moisture (0.11 %) each 3 days while treatme nt 6 required highest volume of water (28 %) to attain field capacity. Also at establishment phase, treatments1 to 4 used up about 39 % of soil water while treatment 6 required 41 % more water to meet available soil water conditions.

Table 1 Maize Water Demand at Development and Establishment Phases at 30 cm depth (cm/30cm)

Treatments	SWS	Wp	FC -SWS
T1 Dev	7.12	4.12	0.11 (1.0 %)
T1 Est	4.36	1.36	2.84 (39 %)
T4 Dev	6.11	3.11	1.09 (15 %)
T4 Est	4.33	1.33	2.87 (39 %)
T6 Dev	5.16	2.16	2.84 (28 %)
T6 Est	4.18	1.18	3.02 (41 %)

NB: SWS= Soil Water Storage before irrigation; Wp = Available soil water at Wilting point; Dev = Development Phase; Est = Establishment phase

In the sixth week of life of the plants, treatment 6 (8 days after irrigation) was severely stressed by the end of 6-7 days (Table 1), leaving only 1.18 $cm^3\ cm^{-3}$ of water at wilting point during the crop establishment phase. This may suggest that for the maize variety 95 TZEE-Y, at six weeks of growth the plant would witness optimum soil moisture demand. The plants had used up ~ 41% of moisture available to it in the depth levels 0-30 cm. This would suggest that the effective rooting depth of maize in the Nigerian Guinea Savanna zone Kandiustalf is about 30 cm. The amount of moisture available at the depth levels 40-60 for instance, did not seem to be available to plant to survive well to the wetting day (Table 1). Upper limit of soil moisture at Field capacity (FC) was determined as 24 $cm^3\ cm^{-3}$ while the lower limit at wilting point (WP) was determined as 8.0 $cm^3\ cm^{-3}$, suggesting that soil moisture at FC at depth 30 cm in the soil would be (0.24 x 30) i.e., 7.2 $cm^3\ cm^{-3}$. Minimum soil moisture storage at WP therefore would be (0.08 x 30) i.e., 2.4 $cm^3\ cm^{-3}$. Plant heights at 2 weeks after germination did not show any significant ($P \leq 0.05$) difference between treatments. However at 4 weeks after germination, treatment 3 (T3) showed significant height difference between treatments to be better than even treatments 1 and 2 (Table 2). Treatment 3 height at 4 weeks after germination (28.10 cm) was significantly high but was followed by treatment 1 (25.98 cm). Treatment 5 (7 daily irrigation) gave the least plant height at 4 weeks after germination. For treatment 1 (two days after irrigation) during the sixth week, plots were wet, simulating a situation of soon-after-rainfall (zero suction) and perhaps suggesting impeded subsurface drainage and temporary stagnation of water resulting from luxury supply of irrigation water (Odunze et al., 1998). This situation may have adversely affected plant growth perhaps resulting from effect of excess water supply to cause leaching loss of nitrates and other soil nutrients. Better plant height under treatment 3 would imply that 5 daily irrigation enhanced maize plant growth. Plant gaits at 2 weeks after germination also showed treatment 1 gaits (0.75 Cm) as significantly bigger than the other treatments. At 4 weeks after germination however, treatments 1 and 2 (2.30 and 2.33 Cm respectively) were not statistically different though they were both significantly bigger than the other treatments (Table 2).

Table 2 Plant height and Gait (cm) determined, two and four weeks after germination

Treatments	Plant Heights (Cm)		Gaits (Cm)	
	2 WAP	4WAP	2 WAP	4WAP
T1 ; 3 daily	8.21a	25.98ba	0.75a	2.30a
T2; 4 daily	7.85a	23.83ba	0.65ba	2.33a
T3, 5 daily	7.99a	28.10a	0.72ba	2.11ba
T4; 6 daily	7.85a	24.36ba	0.71ba	2.14ba
T5; 7 daily	6.87a	20.04b	0.63b	1.98b
T6; 8 daily	7.43a	22.92ba	0.67ba	2.11ba

Means with the same letters are not significantly different

Water Use Efficiency, Maize Grain Yield and Nitrogen Use Efficiency 3003-2005: Table 3 shows that in 2003 to 2005 treatment one (3 daily irrigation) used significantly ($P \leq 0.05$) more irrigation water, and was followed by treatment 2 (4 daily irrigation) than the other treatments. Treatment 3 (5 daily irrigation) was however moderate in water use (414.56 mm^3 , 482.85 mm^3 and 537.07 mm^3 of irrigation water in respective years). This would suggest that optimal maize production would need between 415 and 540 mm^3 of irrigation water in Kandiustalf of Nigerian Guinea Savanna. Treatments 4 to 6 used significantly ($P \leq 0.05$) lower irrigation water (Table 3). Maize grain yields within the same periods showed consistent significant high yields resulting from treatment 3 (5 daily irrigation), rivalling treatments 1 and 2 in 2005, treatments 4, 5, and 6 in 2003 and 2005 significantly ($P < 0.05$). Perhaps, quantity of water supplied to treatments 1 and 2 amounted to over-irrigation and could have caused nitrate nitrogen to have leached beyond crop root zone (Fares et al. 2000). Treatment 6 also showed least grain yields in each of 2003 and 2005 years (Table 3). However grain yield in 2005 were not statistically different between treatments. It would appear therefore that treatment 3 irrigation water was optimally utilized for maize grain production than the other treatments. Maize grain yield under treatment 3 ranged from 2.23 to 2.5 tha^{-1} over the period 2003 to 2005 and could suggest that optimal grain yield for the maize variety would be over 2.0 tha^{-1} but less than 3.0 tha^{-1} when grown between February and May under irrigation in the Savanna zone Kandiustalfs. Also, Water use efficiency data shows that in 2003, 2004 and 2005 treatment 3 significantly ($P \leq 0.05$) used water more efficiently than treatments 1 and 2 (Table 3). Water use efficiency for treatment 3 range between 4.14 and 5.40 kg/ha-mm, and showed superiority over treatments 1 and 2 in water use for 2003, 2004 and 2005. Treatments 4 to 6 appear to have more efficiently utilized water better than the other treatments (T 1, 2, and 3), but grain yield under treatments 4 to 6 were significantly ($P \leq 0.05$) lower than treatment 3 in 2003 and 2005. Water used under treatments 4 to 6 could have been used largely to overcome moisture stress and less for grain production. Data on Nitrogen Use Efficiency reveal that treatment 3 gave comparable high efficiencies in 2003, 2004, and 2005 with treatments 1 and 2 to be significantly better than treatments 4 to 6 (Table 3). Perhaps, treatments 4 to 6 suffered moisture stress so much to have poorly utilized applied nitrogen for grain production. Treatment 1 appears to have most efficiently utilized applied nitrogen but grain yield under it was not significantly different from treatment 3 especially in 2004 and 2005. Treatment 1 may therefore have used nitrogen more for vegetative production to the disadvantage of grain production when compared with treatment 3. Treatment 3 nitrogen use efficiency range from 60.96 to 69.28 $kgha^{-1}$ and would be inferred optimal for maize production considering that under treatments 1 and 2 nitrogen loss due to leaching may have occurred to discourage better N-use efficiency.

Table 3 Water Use Efficiency, Nitrogen Use Efficiency and Maize Grain Yield 2003-2005.

Treatments	Total water used (mm^3)			Grain Yield (tha^{-1})			Water use efficiency (kg/ha-mm)			Nitrogen use efficiency (kg/ha)		
	2003	2004	2005	2003	2004	2005	2003	2004	2005	2003	2004	2005
T1: 3days	662.95a	725.93a	782.28a	2.71a	2.35a	2.13ba	4.09b	3.24d	2.72c	74.31a	64.38ba	8.22ba
T2; 4days	505.83b	586.60b	625.64b	1.98cb	2.58a	2.03bac	3.91b	4.39c	3.24bc	54.11cb	70.55a	55.48bac
T3; 5days	414.56c	482.85c	537.07c	2.23b	2.53a	2.23a	5.37a	5.40b	4.14a	60.96b	69.28ba	60.96a
T4; 6days	342.60d	411.43d	485.07d	1.92cb	2.38a	2.05bac	5.46a	5.78ba	4.23a	52.60cb	65.07ba	56.16bac
T5; 7days	310.01d	377.10e	445.32e	1.85c	2.40a	1.58c	5.95a	5.84ba	.54bac	50.55c	58.22b	45.15c
T6; 8days	276.85e	358.25e	412.20f	1.67c	2.28a	1.65bc	6.04a	6.35a	4.00ba	45.76c	62.33ba	45.21bc

Means with the same letters are not significantly different

Maize Grain Yield: Table 4 shows data on both rain-fed and irrigated maize grain yields for 2003 to 2005. In 2003 treatment 1 gave significantly higher grain yield (2.71 tha^{-1}) under irrigation, followed by treatment 3 (2.23 tha^{-1}) to be better than the rest other treatments (T 4, 5, and 6). In 2004 and 2005 treatment 3 showed significantly superior grain yields over treatments 1, 2, 4, 5 and 6 (Table 4) under irrigation. Grain yield under treatment 3 range from 2.23 to 2.75 tha^{-1} that are significantly higher that those under treatments 4 (1.93 to

2.23tha^{-1}), 5 (1.58 to 2.40 tha^{-1}), and 6 (1.65 to 2.2 tha^{-1}). Under rain-fed conditions, there appeared no significant difference between grain yields in treatments, suggesting perhaps that yield potential of the maize variety under rain-fed cultivation would range from 3.50 to about 4.0 tha^{-1} in the Nigerian Guinea Savanna Alfisol. However, both in 2003 and 2004 treatment 3 gave none significantly different but high grain yield as treatments 1 and 2 under rain-fed production. Table 4 therefore show that treatment 3 (5 daily irrigation) would result in sustainable optimal maize grain yield under irrigation in the Nigerian Guinea Savanna zone Alfisol. Also relative decrease in maize grain yield in 2004 and 2005 under T1 compared to T3 would be attributed to effect of impoverished soil conditions following continued supply of excess irrigation water over the three year period.

Table 4 Grain Yields (tha^{-1}) Under Rain-Fed and irrigated Conditions 2003 and 2004:

Treatments	2003 Irrigated	2003 Rain-fed	2004 Irrigated	2004 Rain-fed	2005 Irrigated
T1: 3days	2.71a	3.57a	2.35ba	3.93a	2.13ba
T2; 4days	1.98cb	3.51a	2.58ba	3.80a	2.03bac
T3; 5days	2.23b	3.50a	2.75a	3.83a	2.23a
T4; 6days	1.93cbd	3.47a	2.38ba	3.23a	2.05bac
T5; 7days	1.85cd	3.22a	2.40ba	3.55a	1.58c
T6; 8days	1.66d	3.15a	2.28b	3.70a	1.65bc

Means with the same letters are not significantly different

At developmental stage of maize therefore treatment 1 require least moisture (0.11 %) each 3 days while treatment 6 required highest volume of water (28 %) to attain field capacity. However optimal irrigation water needed to produce over 2.0 tha^{-1} maize grain on a sustainable basis range between 415 and 540 mm^3 supplied on a 5-daily irrigation intervals in a 4 by 5 m^2 irrigation plot. Also optimal water use efficiency for maize crop production under irrigation in the ecological zone range from 4.14 and 5.40 kg/ha-mm. Nitrogen use efficiency for sustainable maize production under irrigation in the zone range from 60.96 to 69.28 kgha^{-1} ,thus ensuring adequate nitrogen fertilizer use by maize crop against possible underground water pollution by nitrogen lost to leaching. Maize grain production under rain-fed conditions appears to yield significantly more grain than under irrigated conditions; averaging between 3.1 and 3.9 tha^{-1}. Average maize grain yield under good irrigation water (T1) and nitrogen fertilizer application range between 2.2 to 2.8 tha$^{-1.}$

5. References

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