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EFFECT OF IRRIGATION AND PLANT DENSITY ON THE GROWTH, YIELD AND WATER USE EFFICIENCY OF EARLY MAIZE IN THE NIGERIAN SAVANNA

B. M. Sani[1], K. O. Oluwasemire[2] and H. I. Mohammed[3]
[1]Agricultural Engineering & Irrigation Programme, NAERLS, Ahmadu Bello University, Zaria, Nigeria
[2]Department of Soil Science, Faculty of Agriculture, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria
[3]Department of Agronomy, Faculty of Agriculture, Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria
E-mail: bashirsani@gmail.com

ABSTRACT

A field experiment was conducted during the dry season of 2002/2003 at the Irrigation Research Farm, Institute for Agricultural Research, Samaru, Nigeria to evaluate the effect of irrigation and plant density on the growth, yield and water use of an extra early maturing maize variety. The trial involved three population densities (38,000, 53,000 and 66,000 plants ha^{-1}) and three irrigation regimes (full, three quarter and half application of the consumptive use at each stage of growth). The nine treatments were laid out in a split plot design with randomized blocks in three replications with irrigation regimes as main plots and population densities as sub plots.

Water use and water use efficiency were highest with application of full consumptive use requirement at each stage of growth. The highest plant population density used water more efficiently (25% less than other populations). Therefore, the water use efficiency of maize was changed through the manipulation of plant population density.

Keywords: Irrigation, maize, water use efficiency, grain yield.

INTRODUCTION

Maize is one of the most important cereal crops grown in Nigeria. The production of the crop has been transformed from that of a minor crop by being grown around the homestead to a major commercial grain crop competing with sorghum and millet as a strategic grain crop in the grain economy of the nation (Elemo, 1993). Until recently, most of the production of the crop has been restricted to the rainy season. However, the introduction of irrigation facilities through the provision of dams and reservoirs and the development of fadamas has necessitated the need for increased maize production in the dry season. The potential of the crop has not been fully exploited due very low yields obtained on most farmers' fields. Maize production in Nigeria is characterized by low productivity mainly due to supra optimal plant density. Irrigation is one of the major means that can be manipulated to increase food crop production in Nigeria. This can be achieved by increasing the cropping intensity and also by increasing the yield per crop per unit area. The cultivation of the crop during the dry season affords the farmers a means of earning extra income at the peak of the dry season when they would, otherwise, have relied on the sale of stored produce. It also guarantees them fodder for the feeding of livestock at a very critical period when most of the previous season's fodder has almost run out or got depleted. Satisfactory production of crops may therefore be obtained when the pattern of crop water requirement matches the pattern of crop growth. In addition, crop type, time of growth and climate must be closely matched for optimum performance in irrigated agriculture. Soil water management is an important and integral part of the overall cropping system. Detailed information is therefore needed in order to develop efficient methods of soil water management that reduce the wastage of water in some of these irrigation schemes, which tend to accelerate their deterioration and reduce output. Such losses can be as a result of under or over irrigation, which leads to retardation of crop growth and development and consequently, yield reduction. This results in rapid deterioration of such schemes as a result of deleterious irrigation practices. One of the important ways of avoiding this is to apply only the necessary quantity of water at each irrigation. It is often assumed that water supply constitutes the primary limiting constraint to production (Payne *et al.,* 1991). However, in a majority of irrigation schemes in Nigeria, it is the abundance of water that is a problem and farmers tend to over apply (Pages, 1995). Plant density is invariably linked with yield, the more plant stands there are up to a certain limit, the higher the expected yield (Bertoia *et al.,* 1998). The dominant production practice is for farmers to plant crops (cereals) at spacings in the range of 30-35cm, which on average gives about 44,000 to 38,000 plants per hectare (Balcet and Candlar, 1981). In addition, in most irrigation schemes in Nigeria, water is not a limiting factor, what tends to happen is rather over-irrigation because of the abundance of water (Pages, 1995). Research has also shown that farmers apply on average twice the moisture consumptive use requirements of crops on each irrigation (Abdulmumin and Maurya, 1987). This is deleterious to crops and retards proper growth and subsequent yield. Farmers thus face the problem of knowing the correct plant density to sow and also the exact amount (or optimum amount) of water to apply, which amount to apply in areas of abundance and areas of scarcity.

MATERIALS AND METHODS

The experiment was conducted at the irrigation site of the Institute for Agricultural Research, (IAR) farm at Samaru (11^0 11' N, 7 ^{0}37'E and 675m above sea level), Northern Nigeria. The area lies within the Northern Guinea savannah zone of Nigeria. The length of the dry season is about 180-210 days (October to March) during which no precipitation occurs. Mean daily air temperatures (minimum and maximum) range between 15°C and 38°C. The wind speed ranges from 77.2 km/day in October to 128 km/day in March, with a north easterly to south westerly wind direction dominating from November through April. The soil belongs to the Alfisols group (USDA System, Møberg and Esu, 1991) which has developed on deeply weathered Pre-Cambrian Basement Complex rocks (Ogunwole, 2000) but overlain by aeolian drift of varying thickness. The experiment was designed as a split-plot in randomised complete blocks with three replicates. It comprised six treatments: three maize populations and three irrigation regimes. The main plot was amount of irrigation whereas the subplot was maize population density. There were three levels of the main plot namely full irrigation, three quarters and half respectively (varying the consumptive use requirement of maize). For the subplots, the three levels of maize population were 66,000 plants ha^{-1}, 53,000 plants ha^{-1} and 38,000 plants ha^{-1} respectively (Adhikari, 1990). Water application treatments are application of the calculated potential consumptive use requirements of the crop (ETcrop) as per the requirement for each stage of growth. The values to be applied were calculated based on the method of Doorenbos and Pruitt, 1976 (Table-1). These requirements were varied from 100% to 75% and 50% of ETcrop thus imposing some sort of water stress at each stage of growth. An irrigation frequency of 7-days interval was employed for maize based on the work of Mani *et al.,* (1996) and Michael, (1978). Irrigation treatment was imposed from 3 WAP. The growth stages as defined by FAO (2000), Doorenbos and Pruitt (1976) and Anon. (1989), include the 0-22 days after sowing, DAS (vegetative), 23-45 DAS (anthesis), 46-70 DAS (cob filling) and > 70 DAS (ripening). An application efficiency of 70% was assumed. A cut throat flume calibrated to give the discharge in litres per second (Othman, 2001) against the head was placed appropriately on the farm laterals to measure the amount of water flowing into the plots. A neutron probe, model 503 Hydroprobe (CPN Corp., Martinez, California (USA) which is a nuclear moisture gauge was used to measure soil moisture contents at depths 0-90cm with 15cm increments. Soil moisture content was measured before and after every irrigation. Volumetric water content at each depth was computed using calibration equation for the site by Agber (2002). Water use was calculated by addition of the water content before irrigation and water added during irrigation of the preceding week and subtracting this from the water content of the present week. Water use efficiency was calculated based upon the concept of WUE calculated from any useable product such as grain yield only (Sinclair, 1984)

Compound fertilizer (15:15:15) was used at the rate of 120kgN, 60kgP and 60kgK per ha. Fifty percent of the N and all of the P and K were applied two weeks after sowing. The remaining fifty percent N (60kg/ha) was applied at six weeks after sowing. The plots were hand weeded at two and five weeks after sowing. The soil was ploughed again to earthen up the ridges at six weeks after sowing. Two seeds of the maize seeds were planted and later thinned to one plant per stand. A 100mm cutthroat flume was used to measure the amount of water diverted into each plot.

Total crop evapotranspiration (ET) was estimated using the soil water balance equation.

$$ET = \pm \Delta - I - D - R$$

Where $\pm\ \Delta$ is the change in storage (the difference in volumetric water content of the entire profile between the start and end of the experiment), P is irrigation, D is drainage and R is runoff. Drainage and runoff were assumed to be negligible.

WEATHER

The weather situation at the experimental site shown in Table-1 indicates high temperature and evaporation. At seedling stage, the high temperature and evaporation can be overcome by a dense canopy of growing seedlings. The denser treatments may have an advantage over the less dense treatments in terms of canopy spread to act as a barrier to evaporation. Similarly, the denser treatment and full irrigation may impact a cooling effect on the soil. This may be leveraged by the high temperatures prevalent during this period.

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Table-1. Mean of climatic data in Samaru during the dry season of 2002/2003.

Month	**Decade**	**Rainfall** (mm)	**Air Temperature** (^{0}C) **Max**	**Min**	**Evaporation**	**Mean Relative Humidity** (%)
February	1	0.0	35.2	17.8	10.7	70.8
	2	0.0	36.5	19.8	8.9	69.7
	3	0.0	37.5	21.0	10.5	78.3
March	1	0.0	39.4	22.9	12.6	81.5
	2	0.0	36.3	20.5	11.2	73.5
	3	0.0	38.4	25.5	11.6	60.0
April	1	14.5	34.8	21.6	10.2	53.8
	2	16.5	36.0	25.1	7.9	73.8
	3	0.0	38.4	27.3	9.6	81.8
May	1	0.0	38.9	22.0	NA	59.9
	2	12.5	38.2	26.5	NA	66.6
	3	55.8	35.6	23.6	NA	85.5

NA = Data not available

PLANT GROWTH COMPONENTS

Plant height

At 14 days after sowing, DAS, (vegetative stage), Figure-1a, irrigating with Full consumptive use (Full potential ETcrop) irrigation regime resulted in significantly ($P < 0.05$) taller plants (17.31cm) than plants irrigated with 0.75 (15.38cm) CU irrigation regime. There was a significant ($P < 0.05$) difference in height between plants irrigated with 0.75CU regime and those irrigated with 0.50 CU regimes. Plants irrigated with the Full CU regime also had significantly taller plants ($P < 0.01$) than plants irrigated with the 0.5 CU (13.50cm) (S.E = 0.58cm) irrigation regime. At flowering, plants irrigated with the Full CU regime were significantly ($P < 0.05$) taller (131.50 cm) (SE = 4.39cm) than the other treatments. At cob filling, the trend is maintained with plants irrigated with Full CU regime having significantly ($P < 0.05$) taller plants than plants irrigated with 0.75 and 0.50 CU regimes respectively. The tallest plants for all treatments were recorded at 82 DAS (Figure-1a). Both treatments had significantly ($P < 0.05$) (SE = 3.49cm) taller plants than the 0.50 CU regime (208cm). The dominance of taller plants by the Full CU irrigation might be due to the fact that the plants received adequate moisture to satisfy their physiological requirements which translated into more vigorous growth than the other treatments which received less amounts of water under the prevailing environmental conditions.

Plant density effects on plant height at the vegetative stage (Figure-1b) indicate that the trend follows that of irrigation regime with the 38,000 plants ha^{-1} treatment having significantly taller (17.22cm) (SE = 0.18 cm) plants than the 53,000 plants ha^{-1} (16.13 cm) and 66,000 plants ha^{-1} (15.52cm). The tallest plants were recorded at 82 DAS with plant density of 66,000 plants ha^{-1} having a recorded value of 225cm. This was however not significantly different from the 53,000 plants ha^{-1} (222.20cm) and 38,000 plants ha^{-1} (217.0cm). Although there was no significant increase in plant height due to increased plant population, the slight increase at the highest population level was due to greater mutual shading of the plant canopy under high leaf area index. The plants might have used the assimilates in bringing about increase in height in an attempt to reach for more sunlight. Son (1969) observed that intra row spacing did not influence plant height in sorghum. El-Sebaaie (1979) reported from studies on sorghum at Samaru that changing plant distance within the row did not affect plant height except when the inter-row spacing was made narrow (60cm). Similarly, Bertoia *et al.,* (1998) also reported increases in plant height from lower to higher populations.

There was no observed significant interaction effect for the treatments.

Leaf area index (LAI)

The trend of irrigation effects on LAI (Figure-2) indicates an increasing pattern up to the cob filling stage from whence the values start decreasing. At the early stage of growth, Figure-2a (0-14 DAS, vegetative stage), plants irrigated with the Full consumptive use (Full potential ETcrop, Full CU) regime had significantly ($P<0.05$) higher LAI value (0.48) (SE = 0.02) than plants irrigated with either 0.75 (0.024) or 0.50 (0.023) irrigation regimes. At flowering, LAI values indicate that the full CU irrigation treatment had a higher LAI value (1.20) than the other treatments. The highest LAI values were obtained at 64 DAS (cob filling stage). This ranged from 2.48 for the Full

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CU regime to 2.21 for the 0.75 CU regime and 2.10 for the 0.50 CU regime. The trend of LAI over the growth period suggested that increasing irrigation amount led to an increase in LAI values. The lowest LAI values were recorded on plots irrigated with the 0.50 regime which is supposed to be a stress treatment. This shows that the amount of water applied to crops at different growth stages must be such as to meet their consumptive use requirements. This result is in tandem with those of Ballatore *et al.,* (1977) Quayyum and Kamal (1986) and Vasic (1988). Plant density effects on leaf area index (Figure-2b) showed an increasing pattern up to 64 DAS before falling. The LAI values did not indicate any significant difference amongst the treatments. However, the 66,000 plants ha^{-1} treatment recorded the highest LAI values (2.45 at 64 DAS); this was followed by the 38,000 plants ha^{-1} treatment (2.30) and lastly the 53,000 plants ha^{-1} treatment (2.23). The LAI values at 82 DAS showed that the 66,000 plants ha^{-1} treatment had significantly ($P < 0.05$) (SE = 0.05) higher LAI than the 38,000 plants ha^{-1} treatment (1.73), there was however no significant difference in LAI between the 53,000 (1.86) and 38,000 plants ha^{-1} treatments. The significantly higher LAI values recorded for the 66,000 plants ha^{-1} treatment over the other treatments was because of the fact that the land area remained constant and only the plant population was increased which led to an increase in stand count hence more plants which translates to more leaves and leaf area index when water does not seem to pose a limitation to growth and development. This is corroborated by the findings of Sulewaska (1990) who reported that at increased plant population, leaf area and leaf area index are increased in maize plants.

Figures 1 and 2: Effect of irrigation and plant density on plant growth components.

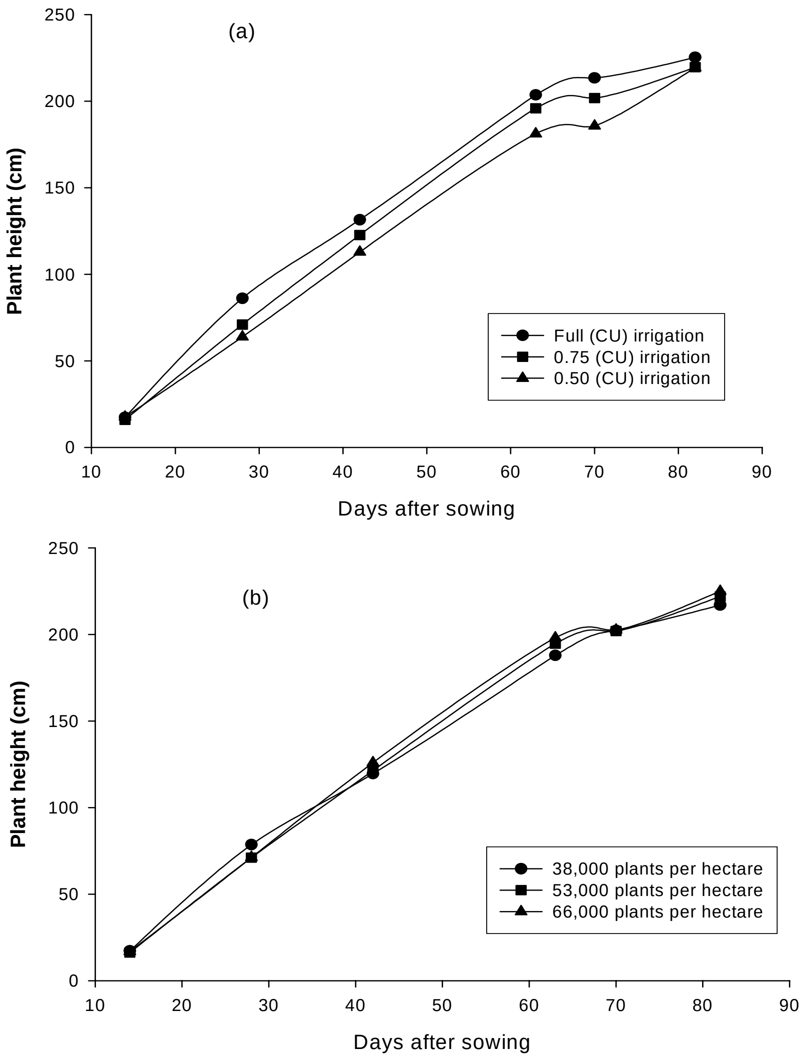

Fig. 1. Trend of maize plant height over time as affected by (a) irrigation (b) plant density at Samaru during 2003 dry season.

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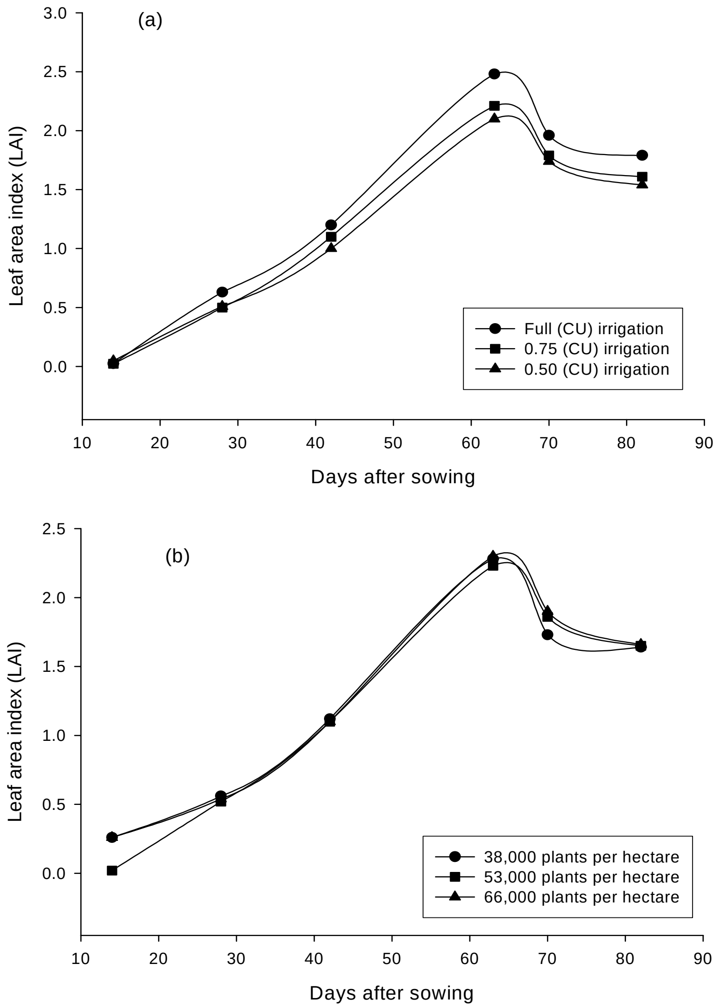

Fig. 2. Trend of maize leaf area index (LAI) over time as affected by (a) irrigation and (b) plant density at Samaru during 2003 dry season.

GRAIN YIELD

The results for grain yields (Table-2) indicate that irrigation treatments affected grain yield significantly. The highest grain yield (3348 kg ha^{-1}) which was recorded by the Full CU irrigation treatment was significantly ($P < .05$) (SE = 358.4 kg ha^{-1}) greater than that recorded by the 0.50 CU irrigation regime (2372 kg ha^{-1}). The 0.75 CU irrigation treatment yielded about 25% less grain (2724 kg ha^{-1}) than the Full CU irrigation treatment. The difference in grain yield was however not statistically significant between the treatments. The implication of this for soil health is that for this particular condition it is more sustainable to apply 75% water requirement than Full requirement as the yield is similar. The results indicate that plants subjected to water stress tend to yield less than plants supplied with adequate water requirements. The significant difference in yield between the full irrigated plants and those stressed indicate that the imposed water stress caused a reduction in the physiological activities of the plant as such the plant could not achieve full growth potential which was exhibited in the significantly lower yield recorded. This is in tandem with results obtained by Nadanam and Morachan, (1974), Hiraoka *et al.,* (1976), Lazarov *et al.,* (1976),Warrick and Gardner, (1983), Karlen and Camp, (1985) and Averbeke and Marais (1992), who all reported increasing yield with increase in irrigation water supplied.

Plant density effects on yield (Table-2) reveal that plant density of 66,000 plants ha^{-1} produced the highest yield (3598 kg ha^{-1}). This was significantly ($P < 0.05$) (SE = 298.6) different from the other treatments. The results also show that the 53,000 plants ha^{-1} treatment produced the next highest yield (2925 kgha^{-1}) and this is attributable to soil type, fertility level, variety and other environmental conditions and that fertile soils require higher populations than poor soils (Baker, 1975). Reports by Musick (1994), de Almeida *et al.,* (1998), Widdicombe and Thelen, (2002) and Bertoia (2000) also showed increasing yield by increasing the plant population up to a certain limit usually above 70,000 plants ha^{-1}.

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Interaction between plant density and irrigation regime on grain yield was significant (Table-3). The highest plant density produced significantly higher yield at the full irrigation treatment when compared with the 50% irrigation regime. Reducing the irrigation regime by half resulted in significant reduction in yield at the highest population as compared with other plant population levels.

CROP WATER USE

The crop water use trend is shown in Table-4. The values indicate that for the irrigation treatments, full CU irrigation treatment used more water than the other treatments (504.86 mm), this was followed by 0.75 CU treatments (411.87 mm) and the 0.50 CU irrigation treatment used the least water (344.89 mm). For the plant density treatments, the 66,000 plants ha^{-1} treatment used more water (442.37 mm) the 38,000 plants ha^{-1} is next (441.22 mm), while the 53,000 plants ha^{-1} treatment used the least water (426.87 mm). The calculated values for water use (Table-4) indicate that the crops irrigated with full CU irrigation used more water. The high water use for this treatment may be due to the abundance of soil moisture in the soil and the plants tend to grow luxuriantly and hence use more water. Aujla *et al.,* (1984) report that irrigation levels may not have much impact on soil water content beyond the surface soil layers. For Samaru soils, it has been mentioned by Kowal (1970) that in the lower depths of the soils, the amount of available water decreases and the proportion of strongly held water increases so that the extraction of water by plants becomes increasingly difficult with time. This means that varying the amount of water applied does not always translate to higher soil water content. As the soil dries, difficulty in plant's ability to extract water increases. The moderate values recorded for the 0.75 CU irrigation treatment is also related to the explanation above, the more water in the soil the more the uptake by plants which manifests in the water use figures recorded. The same holds for the values recorded for the 0.50 CU treatments. Reducing the amount of water by half resulted in lower water use values recorded.

For the plant density treatments, the results indicate that the 66,000 plants ha^{-1} treatment used more water than the other treatments. This may be due to higher density of roots which enabled the plants to extract large amounts of water. The moderate water values recorded for the 38,000 plants ha^{-1} treatment may be due to the more vigorous nature of the growth of the plants, and probably increased evaporation than in the case of the 66,000 plants ha^{-1} treatment. For the 53,000 plants ha^{-1} treatment, the high number of plants competing for soil moisture and a more balanced plant growth pattern may have been the reason for the rather high water use values recorded.

Table-2. Effect of plant density and irrigation on No. of cobs per plant, cob weight, 1000 grain weight, grain weight per cob and grain weight per hectare.

Treatment	**Cob weight** (g)	**1000 grain weight** (g)	**Grain weight per cob** (g)	**Grain weight ha^{-1}** (kg)
Irrigation				
Full	147.1	242.4	111.0	3348.0a
0.75	153.1	249.3	117.9	2724.0ab
0.50	150.5	252.3	116.9	2072.0b
SE ±	5.76	11.67	4.66	358.4
Plant density (plants ha^{-1})				
38,000	154.9a	251.0a	116.6a	2654.0b
53,000	149.5a	247.4a	114.6a	2724.0ab
66,000	146.3a	245.7a	114.7a	3598.0a
SE ±	5.21	10.52	4.44	298.6
Interaction Irrigation x Plant density	NS	NS	NS	**

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Table-3. Interaction between planting density and irrigation regime on maize yield.

Varieties	Irrigation regime		
	Full	**75%**	**50%**
38,000 plants ha^{-1}	2911ab	2289b	2435a
53,000 plants ha^{-1}	2693b	3008a	2210a
66,000 plants ha^{-1}	3735a	2423b	1742b
SE ±	100.3		

Table-4. Water use.

Treatment	Water use (kg/mm)
Irrigation	
Full CU irrigation	504.86
0.75 CU irrigation	411.87
0.50 CU irrigation	344.89
Plant density	
38,000 plants/hectare	441.22
53,000 plants/hectare	426.87
66,000 plants/hectare	442.37

Treatment while the 0.50 CU irrigation treatment was least efficient (6.00 kg grain/mm of water) in using water.

The water use efficiency values obtained reveal that at high moisture content, the moisture was adequate for the plants physiological processes (Table-5). Applying 75% of the moisture requirement at all the growth stages resulted in moderate water use efficiency values. This is in tandem with results by Damdroth and Bramm (1979), Mbagwu and Osuigwe (1985), Morgado and Rao (1985). The plant density treatments reveal that the 66,000 plants ha^{-1} treatment used water more efficiently (8.04 kg grain/mm of water) than the other treatments. The 53,000 plants ha^{-1} treatment was moderate (6.85 kg grain/mm of water) while the least efficient water use (6.0 kg grain/mm of water) was recorded by the 38,000 plants ha^{-1} treatment. The results showed that higher density treatments tend to use more water and produce higher yield. The 66,000 plants ha^{-1} treatment used more water than the other treatments and also had a higher yield than the other treatments.

Table-5. Water use efficiencies.

Treatment	Water use efficiency (kg grain/mm water)
Irrigation	
Full CU irrigation	6.63
0.75 CU irrigation	6.61
0.50 CU irrigation	6.00
Plant density	
38,000 plants/hectare	6.0
53,000 plants/hectare	6.85
66,000 plants/hectare	8.04

CONCLUSIONS

From the results of this study, it can be concluded that for this particular condition, application of full water requirement of plants is not economical. It is advisable to irrigate with 75% water requirement. This gives similar yield while saving a lot on water and labour. However, the 66,000 plants per hectare treatment should be used as it translates to higher yield and more protection for the soil.

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