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Effect of Spatial Arrangements of Row Spacing and Plant Density on Water Use and Water Use Efficiency of Maize Under Irrigation

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Abstract
To optimize crop water use and water use efficiency, more of the initial water resource should be routed into transpiration by reducing unproductive water losses such evaporation, drainage and runoff. In this context, a field experiment was conducted for two successive cropping seasons 2008/2009 to 2009/2010 at Kenilworth experimental station to evaluate the effect spatial arrangement of row spacings and plant density on yield and water use efficiency of maize. Three row spacing (0.225, 0.45 and 0.90 m) and five plant densities (50 000, 75 000, 100 000, 125 000 and 150 000 plants ha^{-1}) were used. Treatments were combined in a factorial combination and laid out in a completely randomized design with replications. Spatial arrangement of row spacing and plant density had a profound impact on biomass, grain yield, water use and WUE of maize. The current investigation revealed that highest water use and mean daily ET occurred at the plant density of 125 000 plants ha^{-1}. The interaction effect of row spacing by plant density was significant. The significantly highest biomass WUE was gained by the row spacing of 0.45 m with the plant density of 125 000 plants ha^{-1}. Correspondingly the highest grain yield WUE was obtained from a row spacing of 0.45 m and a plant density of 100 000 plants ha^{-1}. This was followed by a row spacing of 0.90 m at the same plant density and did not differ significantly from aforementioned. Based on this finding it could be concluded that a row spacing of 0.45 or 0.90 m with a plant density of 100 000 plants ha^{-1} is the optimum to be adopted for the ultra-fast maize hybrid under consideration.
Keywords: Spatial arrangement, maize, water use, water use efficiency

1. Introduction

Successful maize production requires an understanding of various management practices as well as environmental conditions that affect crop performance (Eckert, 1995). Thus, crop management practices such as tillage, crop rotation, row spacing and plant density can affect water use efficiency (WUE) of crops (Angus & Van Herwarden, 2001). Selection of appropriate cultivars, planting dates, water supply and cultural practices have shown to affect maize yield potential and stability (Norwood, 2001). Any cropping system that improves WUE is a means of increasing crop production in the face of finite water supplies (Richards *et al*., 2002). Development of agronomic systems that are based on efficiency rather than production will increase the sustainability of production systems (Hatfield *et al*., 2001). Angus & Van Herwarden (2001) and Passioura (2006) also indicated that efficient crop water use can be used to assess whether yield was limited by water supply or some other factors. To increase WUE, more of the initial water resource should be routed into transpiration by reducing unproductive water losses (evaporation of soil water, drainage and runoff). Therefore, WUE by higher plants is of vital importance in agricultural ecosystems (dry land and irrigation) in terms of the development of water conserving agriculture (Udayakumar *et al*., 1998).

Water use efficiency describes a plant's photosynthetic production rate relative to the rate at which it transpires water to the atmosphere and thus measures the performance of a plant (Bacon, 2004). In simple terms, increasing WUE means lowering the water needs to achieve a higher unit of production. Therefore, in agricultural systems, optimum water management should be established to maximize the WUE, which is associated with economic yield produced with corresponding total amount of water consumed (Kafkafi, 1997). This led to the concept of WUE which was defined as crop total biomass or grain yield per unit of water used, which is also a useful factor to determine the seasonal water requirement of a crop (Brown, 1999). High plant densities may deplete most of the available water before the crop reaches maturity, while low densities may leave water unutilized in the soil (Bayu *et al*., 2004). However, optimum plant density varies considerably worldwide, depending on the environment, production system, water supply and cultivar selected (Ozer, 2003). Crop water sensitivity is invariably linked with plant density indicating that the more plants per unit area, the higher the expected yield to a certain limit (Bertoria *et al.,* 1998). Thus, for each production system, there is a plant density that can maximize the utilization of available resources, such as water, allowing the expression of maximum potential attainable yield. In line with this, maize is known to be more sensitive to variations in plant

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density as compared to other members of the grass family where its growth and development is influenced by these variations (Casal, 1985; Almeida & Sangoi, 1996). On the other hand, limited research studies in water use of modern high yielding and ultra-fast maize hybrids at variable plant densities have been reported on. One of the strategies of producing an acceptable yield is manipulation of crop management practices targeted with an efficient utilization of a limited resource like water (Zwart & Bastiaanssen, 2004). Hence, this study was conducted to evaluate the effect of spatial arrangement of row spacing and plant density on water use and water efficiency maize under irrigation.

2. Materials and methods

2.1 Experimental site

Field experiments were conducted for two consecutive cropping seasons from 2008/09 to 2009/10 at Kenilworth experimental station of the Department of Soil, Crop and Climate Sciences, University of the Free State (UFS), South Africa. The soil type is sandy loam with pH = 5.6, Cation Exchange Capacity = 2.86 me 100 g^{-1}, available P = 29.1 mg kg^{-1}. The weather data of the experimental station is summarized in Table 1

Table 1 Climate data for Kenilworth Experimental Station

	Rainfall (mm)												
Duration	J	F	M	A	M	J	J	A	S	O	N	D	Total
2003-2007	55.7	63.1	131.4	6.5	16.2	0.1	3.3	3.4	18	6.8	49.7	52.4	407
2008	63.2	56.7	45.3	38.9	37.4	23.6	6.9	4.4	6.9	4.4	2.4	11.1	301
2009	67.1	67.9	20.2	21.3	29.2	19.6	10.0	8.7	0.0	97.4	8.5	57.6	408
2010	133.3	34.9	32.0	30.1	39.2	7.6	0.0	0.0	0.1	27.9	52.9	55.3	413
2008-2010	87.9	53.2	32.5	30.1	35.3	16.9	5.6	4.4	2.3	43.2	21.3	41.3	374
	Temperature (°C) from 2008-2010												Mean
Minimum	14.7	12.3	7.7	3.9	0.4	0.8	0.0	0.2	2.1	4.8	9.4	10.3	6
Maximum	34.6	34.6	34.6	31.3	29.6	23.0	20.6	20.1	28.8	31.3	32.3	33.5	30
Mean	24.7	23.5	21.2	17.6	14.9	11.9	10.3	10.2	15.4	18.0	20.9	21.9	18

2.2. Treatments and experimental design

Treatments used in this study were three row spacing (0.225, 0.45 and 0.90 m) and five plant densities (50 000, 75 000, 100 000, 125 000 and 150 000 plants ha^{-1}). The treatments were arranged in factorial combinations and laid out in a randomized complete block design (RCBD) with three replications. Each plot was 3.6 m wide and 8 m long. An ultra fast commercial hybrid, PAN 6236B was planted. The experimental field inverted with a moldboard plough. This was followed by a deep disk action and then a field span tiller to prepare the seedbed. Maize was hand planted on the 10th and 11th of December 2008 and 2009, respectively. Seeds were hand planted by placing two seeds per hill and rows were oriented in a north-south direction. After emergence seedlings were thinned to maintain the desired plant density per plot. After emergence seedlings were thinned to maintain the desired plant density. Weed control was carried out by hand or hand hoeing, while insect damage was visually monitored during crop growing season. A compound fertilizer (2:3:2 (35)) was broadcasted before planting at a rate of 450 kg ha^{-1} (45 kg ha^{-1} N, 67 kg ha^{-1} P and 45 kg ha^{-1} K). Thirty days after planting 200 kg ha^{-1} urea (46% N) was top dressed followed by another top dressing with the same amount of urea at fifty days after planting. The trial was irrigated with a one tower center pivot irrigation system. All emitters were equipped with pressure regulators, which were checked before the onset of the experiment. The coefficient of uniformity was 90%. The application rate measured as 12 mm day^{-1}, which was sufficient for the peak water use of maize for a target mean yield of 10 t ha^{-1}.

2.3. Data collection and analysis

Twenty neutron soil water access tubes were installed prior to planting in the center of each plot to a depth of 1.8 m. Soil water content was measured at 0.3 m intervals to a depth of 1.8 m using a calibrated neutron probe. Irrigation was conducted at weekly intervals from planting to crop physiological maturity based on a predetermined refill point (PRP) from previous studies of the site (Van Rensburg, 1988). The PRP was calculated as the drained upper limit (DUL) of plant available water (PAW) with a value of 421 mm in depth of 1.8 m^{-1}. Thirty mm was subtracted from 421 mm to allow rain storage if rain would occur immediately after irrigation. The profile soil water content was kept at the PRP of 391 mm 1.8 m^{-1} by replenishing it weekly with an amount equal to the deficit i.e. Deficit = PRP – total soil water content. The volumetric water contents were converted into depth of water in mm per 1.8 m soil depth. The change in soil water content (**Δ**W) was calculated as the difference between the total root zone water contents of two consecutive measurements. Precipitation (P) was recorded from rain gauges placed on four corners of the experiment and the recorded values were averaged and taken into account. The water holding capacity of the root zone is expressed by the DUL value of 421 mm. In this study deep percolation (DP) is the internal drainage beyond the root zone and was considered negligible, because the highest measured soil water content was 416 mm, which was below the DUL. Moreover, the rainfall characteristics during the growing seasons were highly influenced by the amount, intensity and duration. Rainfall during the growing season was poorly distributed. The highest rainfall intensity (< 25 mm hr^{-1}) was lower than the infiltration of the soil (33 mm ha^{-1} (Chimungu, 2009) thus it was assumed that runoff was negligible. In field research, water use of a crop has commonly been defined as the evapotranspiration (ET) component of water balance. Therefore, water use of maize is the seasonal ET, which is the quantity of water used in transpiration and that evaporated from the soil from planting to crop physiological maturity and was determined by solving the ET components of the water balance by using equation $ET = P + I \pm R \pm D \pm \Delta W$.

Where

P = Precipitation during growing season (mm)

I = Applied irrigation (mm)

R = Runoff (-) from, or run-on (+) onto, the soil surface during growing season (mm)

D = Deep water drainage below the rooting zone (-) or upward flux into the root zone (+) (mm),

ΔW = Change in soil water content of the root zone (mm)

Leaf area index was measured using a LI 3000 portable leaf area meter (Lambda Inst.Corp) on randomly selected five plants where three leaves per plant from the bottom, middle and top with the main ear as a reference at silking (63 DAE). Grain was manually harvested from a plot area of 1.8 m x 7 m = 12.6 m^2 and converted to kg ha^{-1} after adjusting the moisture content to 12.5%. Biomass yield was estimated as the sum of stover weighed and the grain yield. Water use efficiency (WUE) was calculated as the ratio of total biomass and grain yield (kg ha^{-1}) to seasonal ET estimated by using equations

$$WUE = \frac{\text{Biomass/Grain yield (kg/ha)}}{\text{ET (mm)}}$$

2.4 Statistical analysis

Data were combined over seasons after carrying out the homogeneity test of variances as suggested by Gomez & Gomez (1984) and subjected to analysis of variance using the general linear model SAS version 9.1 (SAS Inst., 2003). Treatment means were compared using the least significant difference (LSD) at the 5% level of significance.

3. Results and discussion

3.1Results

Summary on the combined analysis of variance over seasons showing the effect of row spacing, plant density and their interactions on seasonal ET and mean daily ET were not significant. In contrast, plant density resulted in significant differences in seasonal and mean daily ET. The greatest amount of water use (428 mm) was recorded at a plant density of 125 000 plants ha^{-1} followed by 100 000 plants ha^{-1} (427 mm). The lowest amount of water (393 mm) was consumed at a plant density of 50 000 plants ha^{-1}. Similarly, the highest mean daily ET of 5.6 mm day^{-1} was recorded at a plant density of 125 000 plants ha-^{1} followed by 100 000 plants ha^{-1} with a mean daily ET of 5.4 mm day^{-1}. The lowest mean daily ET of 5.0 mm day^{-1} was measured at a plant density of 50 000 plants ha^{-1}.

Significant differences were detected due to effect of row spacing by plant density interaction on biomass, grain yield and WUE (biomass and grain yield) of maize. The greatest biomass (22659 kg ha^{-1}) was recorded at a row spacing of 0.225 m with a plant density of 100 000 plants ha^{-1} followed by the same row spacing and a plant density of 125 000 plants ha^{-1} (22473 kg ha^{-1}). The lowest biomass (16884 kg ha^{-1}) was recorded at a row spacing of 0.90 m with a plant density of 50 000 plants ha^{-1}. The highest grain yield (12429 kg ha^{-1}) was obtained from a row spacing of 0.45 m with a plant density of 100 000 plants ha^{-1} followed by a row spacing of 0.90 m at the same plant density (11948 kg ha^{-1}). The lowest grain yield (7774 kg ha^{-1}) was recorded at a row spacing of 0.225 m and a plant density of 50 000 plants ha^{-1}. Regarding WUE, the highest biomass WUE (52.7 kg ha^{-1} mm^{-1}) was recorded at a row spacing of 0.45 m with a plant density of 125 000 plants ha^{-1} followed by a 0.90 m row spacing with a plant density of 100 000 plants ha^{-1} (52.6 kg ha^{-1} mm^{-1}). The lowest biomass WUE (42.4 kg ha^{-1} mm^{-1}) was recorded at a row spacing of 0.225 m with a plant density of 150 000 plants ha^{-1}. The highest grain yield WUE (28.7 kg ha^{-1} mm^{-1}) was recorded at a row spacing of 0.45 m and a plant density of 100 000 plants ha^{-1} followed by row spacing of 0.90 m and a plant density of 100 000 plants ha^{-1} (26.3 kg^{-1} ha^{-1} mm^{-1}). The lowest grain yield WUE (18.6 kg ha^{-1} mm^{-1}) was obtained from a row spacing of 0.225 m with plant density of 150 000 plants ha^{-1}.

Table 2. Effect of row spacing and plant density on water components, crop yield and WUE

RS (m)	PD (ha $^{-1}$)	Seasonal ET (mm)	Mean daily ET (mm)	Biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Biomass WUE (kg ha^{-1} mm^{-1})	Grain yield WUE (kg ha^{-1} mm^{-1})
0.225	50 000	392	5.1	17494de	7774e	44.6de	19.8cde
	75 000	430	5.1	19479de	9695bcd	45.3cde	22.5bcd
	100 000	435	5.4	22759a	9984bcd	52.3ab	22.7bcd
	125 000	458	5.7	22473ab	9381bcde	51.3abc	21.4cde
	150 000	410	4.9	17398ef	7665cde	42.4e	18.6e
0.45	50 000	395	4.9	18079ef	10360bcd	45.7cde	26.2ab
	75 000	417	5.2	21221bc	10722abc	49.1a-d	25.7abc
	100 000	432	5.2	21983ab	12429a	50.8a-d	28.7a
	125 000	419	5.5	22116cde	9738bcd	52.7a	23.2b
	150 000	424	4.8	20348cde	8769de	47.9bc	20.6de
0.90	50 000	393	4.9	16884f	8942bcd	42.9de	25.8abc
	75 000	419	5.0	20036def	10806ab	47.8bc	25.7abc
	100 000	415	5.5	21906def	11948ab	52.6a	26.3ab
	125 000	425	5.1	20749cde	9897bcd	48.8a-d	23.2b
	150 000	406	5.1	20279cde	9167bcd	49.9bc	22.5bcd
	LSD	NS	NS	3777	1917	10.0	4.6
RS mean	0.225	421	5.2	18869b	9139b	44.8b	21.7b
	0.45	418	5.1	22544a	10423a	53.9a	24.9a
	0.90	412	5.1	21329ab	10194a	51.8ab	24.7ab
	LSD	NS	NS	2656	857	4.4	2.0
PD mean	50 000	393c	5.0c	18479b	9462bc	46.9c	24.0b
	75 000	422b	5.1bc	20873ab	10408ab	49.4ab	24.6ab
	100 000	427a	5.4a	21462a	11121a	50.2ab	26.0a
	125 000	428a	5.6a	20988ab	9672bc	50.5a	22.6cd
	150 000	413ab	5.1bc	19735b	8934c	47.7bc	21.6d
	LSD	20	0.2	2057	1107	5.7	2.7
	CV (%)	4.8	4.6	10.5	9.0	10.0	8.7

RS = row spacing, PD = plant density, NS = not significant. Means followed by the same letters are not significantly different

3.2 Discussion

3.2.1Biomass and grain yield

Biomass is a function of numerous interacting environmental and genetic factors and its production is directly related to potential growth and development factors such as solar radiation, water supply, availability of mineral nutrients and crop management practices. Depletion of these sustaining factors will figure forth in low biological yield on an individual plant basis (Donald, 1963; Daughty *et al.*, 1983). Hashemi *et al.* (2005) found similar decreasing trends in biomass with increasing plant densities and reported that the greatest biomass yield was obtained at a plant density of 100 000 plants ha^{-1}. According to Van Averbeke and Marais (1992) the above-ground biomass production of maize did not decrease at plant densities in excess of the critical density but leveled off. Their results also indicated that the above-ground biomass leveled off at plant densities of 80 000 to 100 000 plants ha^{-1} with full irrigation. On the other hand, reduction of biomass for plant densities below 100 000 plants ha^{-1} might be ascribed to a lesser number of plants per unit area and underutilization of available resources. A reduction in row spacing from 0.90 to 0.225 m at an optimum plant density (100 000 plants ha^{-1}) resulted in a gain of 3.9% biomass. This illustrated that subjecting plants to reduced row spacing increased the ability of plants for capturing resources which was reflected as evident in their increased biomass production. Bullock *et al.* (1998) proved that narrow row spacings made more efficient use of available light and shaded the soil surface to a greater degree during the early part of the growing season while the soil is still moist and therefore narrow row spacings are more effective in producing biomass.

Crop yield is a function of a number of factors and processes such as amount of light intercepted by the canopy, metabolic efficiency of plants and the translocation efficiency of photosynthates from leaves to economic parts. These processes are affected by spatial arrangement of row spacing and plant density. Differences in plant densities in this study caused a profound impact on maize grain yield by affecting yield and yield components. Plant density exerts a strong influence on maize growth and yield as a result of the competitive ability of plants at variable densities (Singh & Chaudhary, 2008). Plant density also affects grain yield of maize by influencing the agronomic traits, such as number of seeds per ear, seed weight, number of ears per plant, spikelet differentiation, spikelet fertilization and seed dry weight (Sangoi, 2000). Balanced growth and development of plants need an optimum plant density because optimum density enable plants' efficient utilization of available nutrients, soil water and better light interception coupled with other growth factors. One of the main causes of yield reduction at high plant densities is an increased formation of barren plants. Lemcoff & Loomis (1994) indicated that severe competition among plants in higher density resulted in a limitation of nitrogen and carbon supply with consequent emergence of barren plants and a decrease in the number of seeds per plant and seed size. On the other hand, plant density lower than optimum exhibited lower grain yield per unit area which might attributed to a lower number of plants per unit area. Reduction of plant density below an optimum resulted in a negative impact on grain yield primarily due to underutilization of resources. The same impact was reported by Hashemi- Dezfouli & Herbert (1992) and Echarte *et al*. (2000) that plant density below the optimum led to decreased use efficiency of available resources. Thus, alteration of plant density above or below an optimum plant density results in a negative impact on grain yield presumably due to severe competition or underutilization of resources, respectively.

3.2.2. Water use

Water use of maize is the seasonal ET, which is the sum of water used for transpiration and that evaporated from the soil from planting to crop physiological maturity. Since seasonal ET and water use are equivalent terms, water use will be used in this discussion. The results indicated that the main effects of row spacing and its interaction with plant density did not have a significant effect on water use. However, plant density affected water use significantly. In general, crop water use exhibited a curvilinear relationship with plant density being the highest at the optimum plant density followed with a subsequent decline as plant density increased beyond this critical level (Figure 1A). Three distinct phases were observed in the relation between water use and plant density. In the first phase, water use rapidly increased from a plant density of 50 000 to 100 000 plants ha^{-1}. It was obvious that both evaporation and transpiration occurred to a large extent due to a lower number of plants per unit area where mutual shading and soil surface coverage were nearly minimum/ negligible. Therefore, increasing the number of plants per unit area was accompanied with a progressive advancement in water use until a maximum of 100 000 to 125 000 plants ha^{-1} was reached. This suggests that plant density levels below 100 000 plants ha^{-1} were below the optimum with a smaller LAI which necessitates the addition of more plants to optimize water use. Otherwise, the available soil water is liable to non-productive losses such as drainage and evaporation. Indeed, the simplest way of increasing LAI is by manipulating plant density, because of their direct relationship. Tetio-Kagho & Gardner (1988) reported that increasing LAI with manipulation of plant density consequently increases water consumption by crops to a certain critical optimum under irrigation and this critical optimum varies with maize cultivar. Amanullah *et al.* (2008) also reported that an increase in plant density is coupled with a corresponding proportional increase in LAI with subsequent maximization of water use.

At the second phase, water use reached the plateau in plant densities between 100 000 to 125 000 plants ha^{-1}. At this plateau increasing plant density from 100 000 to 125 000 plants ha^{-1} (25 000 plants ha^{-1}) surprisingly did not show visible change in water use. The curvilinear correlation between water use and LAI best explains the dependency of water use on LAI indicating that water use is directly related to the number of plants per unit area. According this result the highest water use of 428 mm occurred nearly at a LAI of 6 to 7.5 (Figure 1C). Several researches reported different mean water uses for maize under irrigation like, Morey *et al*. (1980) 375 mm, Hammond (1981) 435 mm and Hook (1985) 430 mm for early maturing maize cultivars whereas Mayaki *et al*. (1976) 625 mm, Retta & Hanks (1980) 550 mm, Mukhala (1998) 718 mm and Ali (2003) 559 mm for late maturing ones. The similarities and differences in water use of these results and the aforementioned could be attributed to maize genotype, length of growing period as well as climatic differences.

Water use increased with an increased LAI up to 7.5 and then declined for LAI values above this. This suggested that the LAI values either below 6 or above 7.5 are negatively associated with water use. This LAI range is a reflection of plant densities between 100 000 and 125 000 plants ha^{-1} where a higher seasonal water use occurred. Adelana & Milbourn (1972) and Duncan (1975) reported mean LAI values of 5 and 5.3 for early maturing maize cultivars under irrigation for a maximum yield with efficient water use. They also indicated a decline in water use when the LAI exceeded 7.5. Barriere & Traineau (1986) reported that the optimum mean LAI was 6 for silage maize, whereas Howell *et al*. (1996) observed a LAI of 5 for a full hybrid maize under irrigation. Van Averbeke & Marais (1992) concluded that plant density and LAI with respect to water use is dependent on the production targeted (biomass or grain yield). For biomass production they recommended a plant density of 110 000 plants ha^{-1} and a LAI of 8 while for grain yield a plant density of 90 000 plants ha^{-1} and a LAI of 7. This indicates that the optimum LAI for optimum water use is in between 6 and 7 which correspond to a plant density of a 100 000 to 125 000 plants ha^{-1}. In this study the optimum grain yield was recorded at the row spacing of 0.45 and 0.90 m and the plant density of 100 000 plants ha^{-1}, which indicates that the optimum LAI was within the limits of 6 to 7 and was achieved at a plant density of 100 000 to 125 000 plants ha^{-1}.

At the third phase, water use declined rapidly with an increase in plant density from 125 000 to 150 000 plants ha^{-1} (Figure 1A). Thus, the addition of more plants per unit area reduced water use. This declining tendency in water use at higher plant densities was likely due to a much greater LAI which resulted in mutual shading of plants with proportional minimization of both transpiration and evaporation. At this declining point the LAI exceeded 7.5. From this it is clear that soil water content was greater than water use indicating that excess water was stored in the soil profile. This probably suggests that an overcrowding plant density impaired transpiration due to a higher LAI which resulted in full coverage of the soil surface and mutual shading of adjoining plants as a result of the close proximity of plants. Hence, the excess water that may have built up in the soil profile is non-productive with respect to crop demand and probably can cause nutrient leaching from root zone. The other negative impact of increasing plant density above the optimum is that the lower leaves becomes unproductive as a result of shading from upper leaves. Hence, optimum plant density should match with the availability of soil water in order to maximize the grain yield. Deviation from the optimum plant density could lead to loss of soil available water (Holt & Timmons, 1968; Karlen & Camp, 1985b; Bayu *et al,* 2004). Therefore, the optimum LAI according to these results was between 100 000 and 125 000 plants ha^{-1}. Mean daily ET in response to plant density followed a similar trend at the mentioned three phases and confirmed the phenomenon (Figure 1B). However, an appropriate recommendation has to be based on the efficiency of water use with respect to the purpose of production either biomass (e.g. silage) or grain yield.

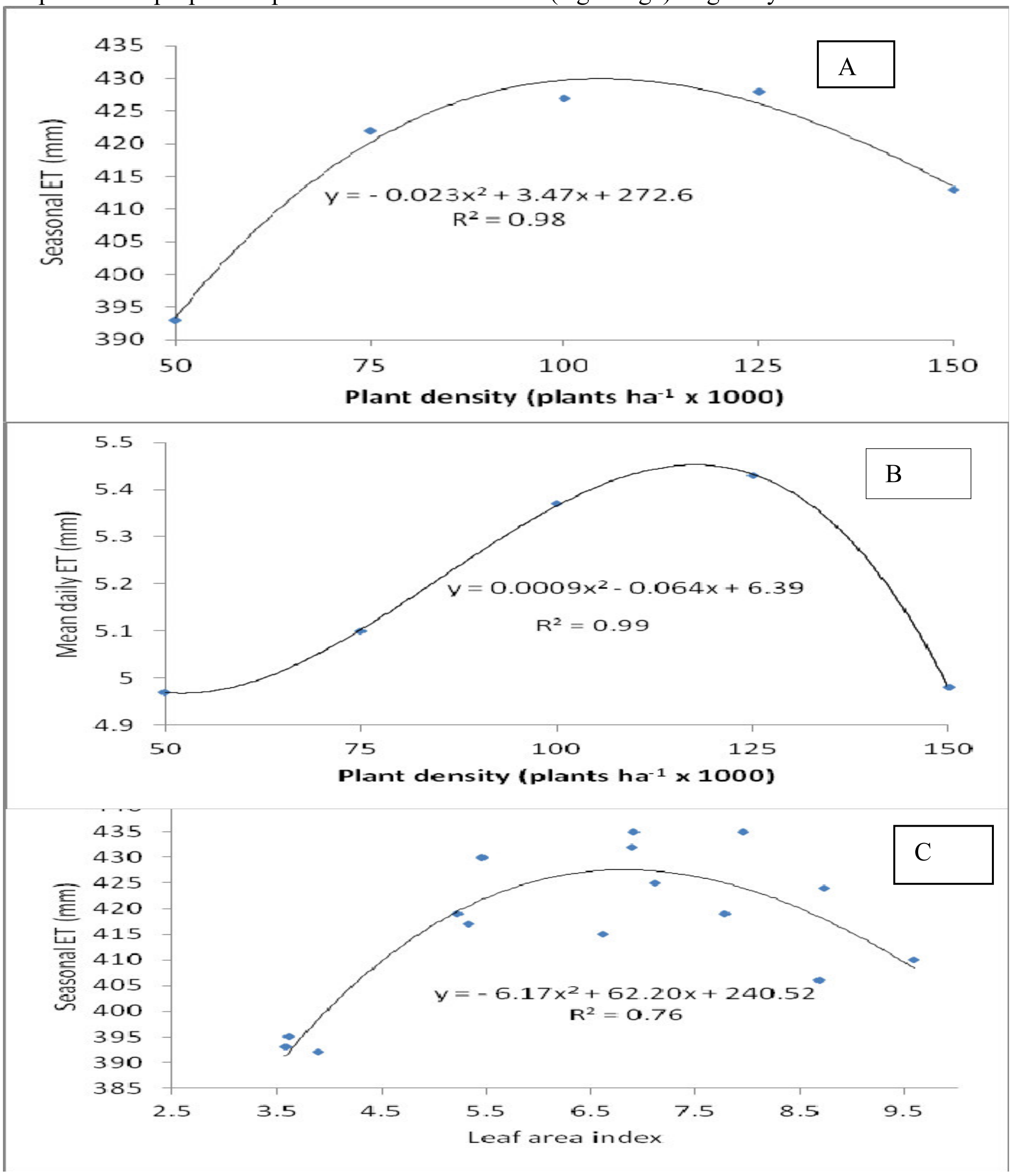

Figure 1. Water use (A) and daily ET (B) as affected plant density and their correlation with LAI (C)

3.2.3. Water use efficiency

Water use efficiency refers to the ratio of yield either biomass or grain to water use (seasonal ET) during crop growth. Spatial arrangement of row spacing by plant density resulted in an influence on WUE of maize. A basic principle that should be implemented to manage the soil water balance is ensuring minimum unproductive water loss in order to increase the amount of water that can be transpired. Indeed, row variations coupled with varying plant density influences WUE by affecting the magnitude of land surface coverage (LAI), light distribution, relative directional skewness (north-south or east-west) and land surface area occupied by a single plant. In an attempt to explain and understand row spacing by plant density effect on WUE, the biomass WUE is grouped into three *viz.* WUE values above 50 kg ha^{-1} mm^{-1} (*high*), 46 to 50 (*moderate)* and WUE values below 46 kg ha^{-1} mm^{-1} (*low)* (Table 3). A relatively high WUE was recorded for spatial arrangements of 0.45 x 125 000, 0.90 x 100 000, 0.225 x 100 000, 0.225 x 125 000 and 0.45 m x 100 000 plants ha^{-1} with biomass WUE ranging from 50.8 to 52.7 kg ha^{-1} mm^{-1} with the highest at a row spacing of 0.45 m with a plant density of 125 000 plants ha^{-1} (Table 3 & Figure 2). The approximate amount of water used by these spatial arrangements of row spacing and plant density ranged from 415 to 458 mm. In this category the physiological efficiency (HI) of converting DM to economic yield varied from 0.42 to 0.57 at the higher LAI values (> 6) with the exception of 0.225 m x 125 000 plants ha^{-1}. The lower LAI value at this treatment was probably due to overcrowding where plants attained a smaller LAI on an individual basis. Row spacings of 0.225 and 0.45 m at a plant density of 125 000 plants ha^{-1} showed a higher WUE, but were associated with a lower HI. Spatial arrangements with a moderate WUE encompassed 0.90 x 150 000, 0.45 x 75 000, 0.90 x 125 000, 0.45 x 150 000 and 0.90 x 75 000 combinations with HI values ranging between 0.43 and 0.51. The LAI values varied from 5.32 to 8.98 with the lowest at a row spacing of 0.45 m with a plant density of 75 000 plant ha^{-1} and the highest at 0.45 m x 150 000 plants ha^{-1}. In line with this, treatments with low WUE consisted of 0.45 x 50 000, 0.225 x 75 000, 0.225 x 50 000, 0.90 x 50 000 and 0.225 x 150 000 plants ha^{-1} (Table 3 & Figure 2).

Basically efficient water utilization requires that plant density should be matched with the water supply intended to maximization of plant transpiration with a corresponding minimization of soil water evaporation. Hence, deviation of row spacing and plant density from the optimum (0.45 m x 100 000 plants ha^{-1}) resulted in a negative impact on biomass WUE by affecting the DM accumulation during the growing season. In line with this, a row spacing of 0.45 and 0.90 m at a high plant density (PD ≥ 125 000 plants ha^{-1}) was characterized by a higher LAI (≥ 7) and low HI (< 0.50) suggesting that overcrowding impaired translocation of assimilates from source (vegetative part) to sink (the grain). On the other hand, a lower plant density (PD ≤ 75 000 plants ha^{-1}) with a row spacing of 0.45 and 0.90 m resulted in a lower LAI and relatively greater HI, which suggests lack of competition among plants. However, from an economic point of view one needs to take into account grain yield maximization with adjustment of optimum plant density. Mohamed *et al.* (1986) reported that in a too dense stand, the photosynthetic efficiency of leaves were affected due to more competition for available soil water which adversely affected plant growth and development resulting in a low DM accumulation with corresponding decline in WUE. Moreover, Momoh & Zhou (2001) indicated that a high plant density caused water stress resulting in a reduction in growth, development and grain yield with a consequent decline in WUE. On the other hand, at low plant densities a lower LAI and less coverage of the soil surface where soil water was subjected to evaporation resulted in low productivity in terms of per unit of water consumed. Stanhill (1986), Tuong & Bhuiyan (1999) and Bayu *et al.* (2004) indicated that the soil available water at low plant densities was subjected to non-photosynthetic losses such as evaporation, seepage and runoff that results in a reduction of the total productive water use by crop plants.

Table 3. Biomass WUE ranked from high to low with respective of water use, HI and LAI

Category of WUE	RS (m)	PD (X 1000)	Biomass WUE (kg^{-1} mm^{-1})	Water use (mm)	HI	LAI
	0.45	125	52.7	419	0.44	7.78
High	0.90	100	52.6	415	0.56	6.62
	0.225	100	52.3	435	0.42	7.96
	0.225	125	51.3	458	0.41	5.22
	0.45	100	50.8	432	0.57	6.89
	0.90	125	49.9	406	0.45	8.98
Moderate	0.45	75	49.4	435	0.44	6.91
	0.90	125	49.1	417	0.51	5.32
	0.45	150	48.8	425	0.48	8.12
	0.90	75	47.9	424	0.43	8.72
	0.45	50	45.7	395	0.54	3.60
Low	0.225	75	45.3	430	0.49	5.46
	0.225	50	44.6	392	0.44	3.89
	0.90	50	42.9	393	0.53	3.58
	0.225	150	42.4	410	0.44	9.59

RS = row spacing, PD = plant density

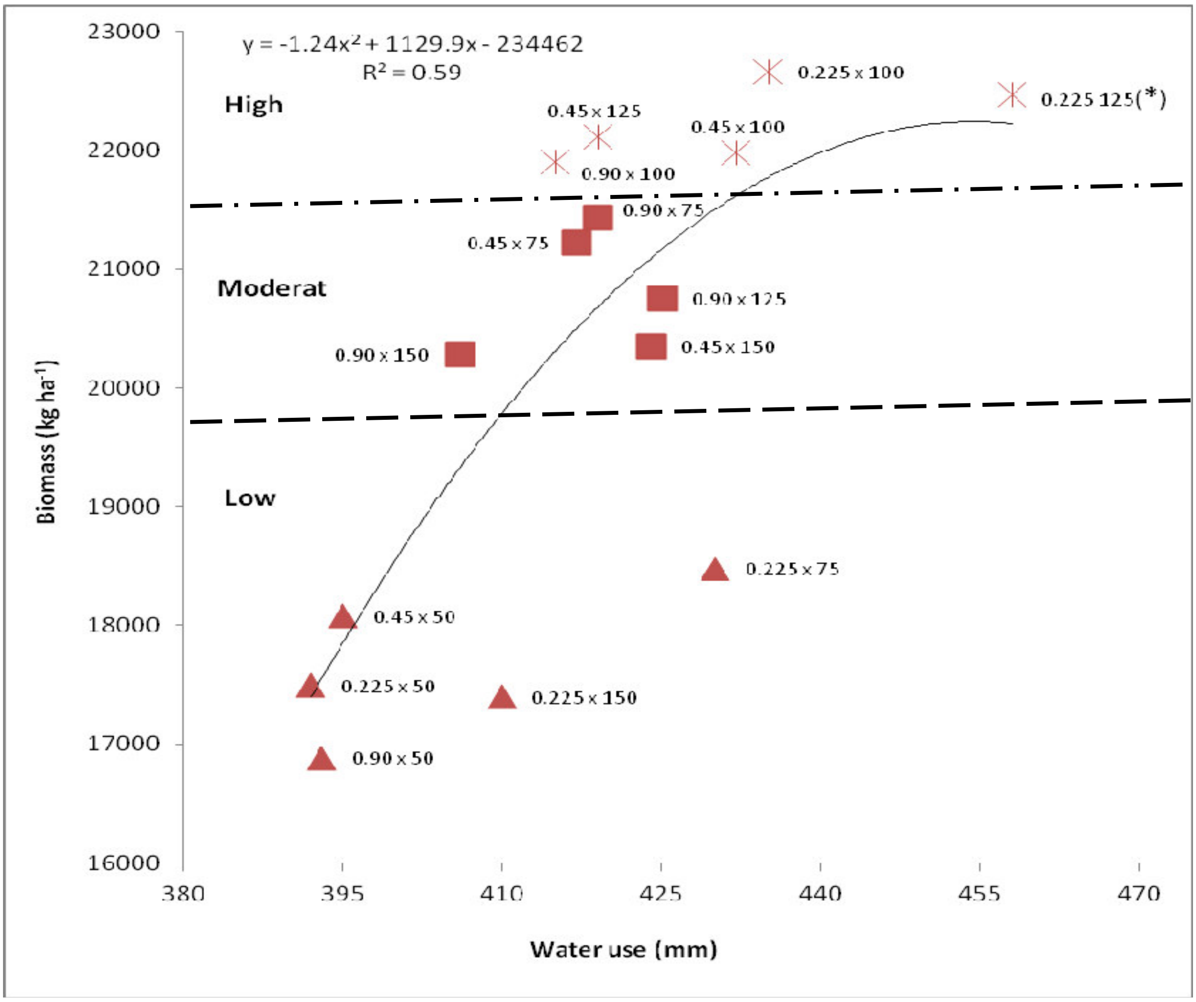

Figure 2. Effect of row spacing and plant density on WUE of maize (*) x 1000,

4. Conclusion

Spatial arrangement of row spacing and plant density had a profound impact on biomass, grain yield, water use and WUE of maize. The current investigation revealed that highest water use and mean daily ET occurred at the plant density of 125 000 plants ha^{-1}. The interaction effect of row spacing by plant density was significant. The significantly highest biomass WUE was gained by the row spacing of 0.45 m with the plant density of 125 000 plants ha^{-1}. Correspondingly the highest grain yield WUE was obtained from a row spacing of 0.45 m and a plant density of 100 000 plants ha^{-1}. This was followed by a row spacing of 0.90 m at the same plant density and did not differ significantly from aforementioned. Based on this finding it could be concluded that a row spacing of 0.45 or 0.90 m with a plant density of 100 000 plants ha^{-1} is the optimum to be adopted for the ultra-fast maize hybrid under consideration.

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