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Full Length Research Paper

Impact of different moisture regimes and nitrogen rates on yield and yield attributes of maize (*Zea mays* L.)

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Nitrogen and irrigation, both are essential to determine the yield and quality of maize (*Zea mays* L.). A field study was accomplished to determine the upshots of different levels of irrigation and varying nitrogen rates on yield, yield contributing attributes and radiation use efficiency (RUE) of maize hybrid on sandy clay loam soil. Different nitrogen rates and moisture regime treatments comprised of $N_0 = 0$, $N_1 = 100$ and $N_2 = 200$kg N ha^{-1}, I_1 (25 mm water deficit), I_2 (50 mm water deficit), I_3 (three irrigations during vegetative development + one irrigation at tasseling stage) and I_4 (three irrigations during vegetative development + one irrigation at tasseling stage + one irrigation at silking stage + one irrigation at grain filling stage), respectively. Results showed that maximum grain yield (7.04 t ha^{-1}) was recorded when six irrigations were applied (three irrigations during vegetative development + one irrigation at tasseling stage + one irrigation at silking stage + one irrigation at grain filling stage) coupled with 200 kg N ha^{-1} ($N_2 \times I_4$). The lowest grain yield (2.08 t ha^{-1}) was obtained in response to 25 mm water deficits. Overall, $N_2 \times I_2$ also gave a positive response in terms of yield attributes but highest plant height (160.80 cm), cob length (29.00 cm), number of grains per cob (308.33), 1000-grain weight (294.33 g) and biological yield (25.67 t ha^{-1}) with maximum coefficient of correlation (R^2) values (0.9399; 0.8851; 0.9161; 0.8743 and 0.9126), respectively, was attained with $N_2 \times I_4$ treatment combinations. The superior (RUE) radiation use efficiency (5.33 g MJ^{-1}) with higher R^2 value (0.8821) was significantly affected by nitrogen rates and irrigation levels as obtained from $N_2 \times I_4$ treatment. However, in all treatment combinations, $N_2 \times I_4$ was superior by producing the highest maize grain yield.

Key words: Moisture regimes, nitrogen rates, deficit irrigation, *Zea mays* L., radiation use efficiency, maize yield.

INTRODUCTION

Maize (*Zea mays* L.), an important cereal crop belonging to family poaceae thrives best in tropical regions with mild summers. Its importance arises both because of its higher biological efficiency and because it can be grown over an extremely wide environmental range. It is very important as food for human beings, animals and also provides raw material for many agro-based industries (Ahmad et al., 2007). In Pakistan, maize was grown on an area of 939 thousands hectares with annual production of 3341 thousands tones of grain and average yield about 3264 kg ha^{-1} (Govt. of Pakistan, 2011). Yield per unit area in Pakistan is alarmingly low when compared to the biological potential of the existing maize varieties. The yield potential of Pakistani varieties is fairly high but it is not being completely exploited from farmers due to some management constraints as well as many agronomic, edaphic and environmental factors. The climatic condi-tions and existing varieties in Pakistan are highly favorable for increasing maize production, but poor nutrient management and water scarcity are fundamentals to reach the highest potential (Mohamed, 2010).

Water being a scarce commodity in Pakistan is to be used efficiently for maximum potential yield (Li-Ping et al.,

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Table 1. Soil physico-chemical properties.

Characteristic	Value
Sand (%)	27
Silt (%)	38
Clay(%)	43
Saturation percentage (%)	31.6
Electrical conductivity (dS m^{-1})	1.79
pH	8.5
Organic matter (%)	0.95
CEC ($cmol_c$ kg^{-1})	8.9
Total nitrogen (%)	0.23
Available phosphorus (ppm)	1.00
Extractable potassium (mg kg^{-1})	186

*CEC, Cation exchange capacity.

2006). Maize cultivation requires large quantities of water seasonally for each developmental stages starting from seed germination to plant maturation (Rashid and Rasul, 2010). The requirements in irrigation water to achieve maximum seed production by a variety of medium maturity oscillate between 500 and 800 m^3. Adequate amount of moisture availability at critical growth stages not only optimizes the metabolic process in plant cell but also increase the absorption of mineral nutrients by the crop. The water deficit at grain filling stage can decrease the maize grain yield about 33% by affecting the 1000-grain weight, grain yield, harvest index and water use efficiency (Sajedi et al., 2009). The components of the photosynthetic apparatus and chlorophyll content could be damaged significantly in drought susceptible genotypes under drought stress conditions (Rong-hual et al., 2006). Corn is relatively insensate to water deficits imposed during early vegetative stages while grain yield is sensitive to water stress from just before silking to grain filling with the greatest degree of sensitivity occurring during period of kernel formation (Andrade et al., 1995). Poor nutrient management is the second main reason of low maize productivity. Increasing nitrogen fertilization rates led to a significant increase in ear length, number of kernel per rows, ear weight and grain yield. Moisture supply is most essential to maximize the nutrient use efficiency about 50% at critical growth stages of maize crop (Patel et al., 2006).This study was therefore planned to assess the optimum level of irrigation regimes and nitrogen rates to enhance the maize grain yield and its components under agro-climatic conditions of Faisalabad.

MATERIALS AND METHODS

Site description

The planned study was performed at the Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan during spring season 2011. The experimental site was bounded by 73° 06′ E, 31° 26′ N and at altitude of 184.4 m above sea level with semi-arid climate. Before sowing the crop, the experimental soil was analyzed for their physic-chemical characteristics (Table 1). Meteorological data (rainfall, relative humidity and air temperatures) were recorded from meteorological observatory in the immediate vicinity of the field during the phase of crop development (Figure 1).

Experimental design and treatments

The experiment was outlined in randomized complete block design (RCBD) with split plot arrangement with three replicates using a net plot size of 3.6 m × 5.0 m for collection of data. Nitrogen and moisture levels were randomized in main and sub-plots respectively. The experiment comprised the following treatment combinations; nitrogen rates: ($N_0 = 0$, $N_1 = 100$, $N_2 = 200$) kg N ha^{-1}; and irrigation levels: (I_1 = 25 mm water deficit, I_2 = 50 mm water deficit, I_3 = three irrigations during vegetative development and one irrigation at tasseling stage, I_4 = three irrigations during vegetative development, one irrigation at each tasseling, silking and grain filling stage).

Crop husbandry

Maize crop (hybrid DK-5219) was sown in February, 2010 with the help of single row hand drill, keeping distances between rows and plants of 75 and 25 cm, respectively, using a seed rate of 25 kg ha^{-1}. Phosphorus and potash were applied at 150 and 100 kg ha^{-1}, respectively to all the plots. Maximum potential soil moisture deficit (D) was used as a criterion for irrigation application at 25 mm and 50 mm moisture deficit (French and Legg, 1979). Daily Penman's potential evapotranspiration (PET) was calculated by using standard software "CROPWAT" (FAO, 1992; FAO, 1993). Daily sum of PET values over time gives a cumulative potential soil moisture deficit (D) as suggested by French and Legg (1979). The amount of water applied was equal to the difference between PET and rainfall + irrigation. Irrigation was applied manually by watering cane. All other agronomic practices were kept normal and uniform for all the treatment combinations. Nitrogen applied in two splits at sowing and 1st irrigation was side dressed at 5 cm depth and 10 cm away from the plant row with the help of single row hand drill. The crop was thinned out at three to four leaf stage in order to maintain the optimum plant population. Crop was harvested on June 15, 2010 and kept in the respective plots for sun drying. The cobs were removed from the dry stalks, unsheathed and threshed mechanically with the help of corn sheller.

Data collection and analysis

Observations regarding plant height (cm), cob length (cm), number of grains per cob, 1000-grain weight (g), biological yield (t ha^{-1}), grain yield (t ha^{-1}) and radiation use efficiency (g MJ^{-1}) were recorded during the course of study. Methods for measuring RUE of maize in the field, usually over periods of several weeks, are well established and involve destructive measurements of above ground crop dry matter combined with continuous (Tollenaar, 1992) or periodic (Westgate et al., 1997) measurements of canopy absorption of incident photosynthetic active radiation (PAR). It is sometimes of interest to evaluate changes in RUE over short periods of time (hours or days), which precludes the direct measurement of changes in whole crop dry matter.

The data collected were analyzed statistically using Fisher's analysis of variance technique and least significant difference (LSD) test at 5% probability level was employed to compare the differences among the treatments' means (Steel et al., 1997).

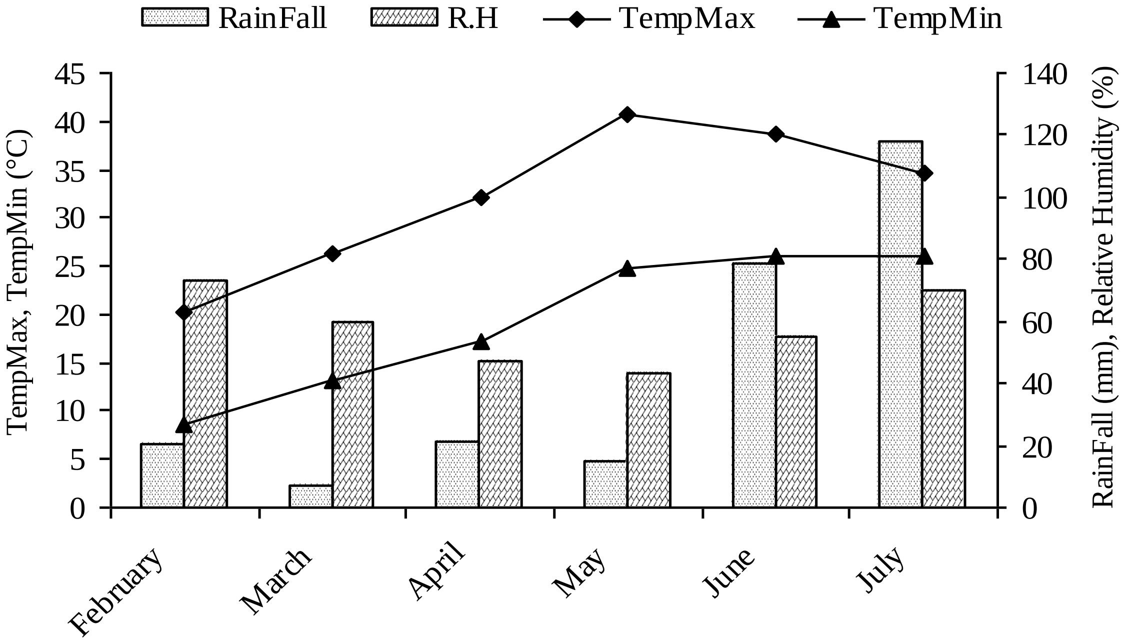

Figure 1. Average minimum and maximum temperatures, relative humidity and monthly rainfall measured at the experimental station during the experiment.

RESULTS AND DISCUSSION

Analysis of variance, means comparison of main effects and their interaction are shown in Tables 2 and 3 respectively. Highest plant height (147.64 cm) was found in treatment N_2 parallel to the control (129.23 cm). These results are in accordance with those of Silva et al. (2000) who reported that plant height increased significantly with the application of different rates of nitrogen. Similarly, when irrigation was studied individually, maximum plant height (151.04 cm) was recorded in the case of I_4 compared to I_1 which showed minimum plant height (119.80 cm) (Table 2). The combined effect of nitrogen and irrigation ($N_2 \times I_4$ and $N_2 \times I_2$) also showed a significant increase in plant height compared to the other treatments (Table 3). These results are in conformity with those of Kassem et al. (1977) and Hussaini et al. (2001) who reported that plant height generally decreased with reduction in irrigation. The coefficient of correlation (R^2) value (0.9399) for plant height and grain yield showed that both were highly correlated (Figure 2).

Effect of different irrigation levels and nitrogen rates as well as their interaction on cob length was found to be significant (Tables 2 and 3). Cob length in I_4 was found to be maximum (23.67 cm) and minimum cob length (11.00 cm) was found in the I_1, and in case of nitrogen levels, N_2 was found best (23.00 cm). Crop plants when irrigated with $N_0 \times I_1$ severely reduced the cob length (6.67 cm) compared to maximum cob length (29.00 cm) which was obtained from $N_2 \times I_4$ treatment. $N_0 \times I_2$; $N_1 \times I_1$ and $N_1 \times I_2$ also reduced the cob length (14.00 cm; 11.00 cm; 14.00 cm), respectively, due to low irrigation levels. The maximum cob length (29.00 cm) was attained with $N_2 \times I_4$ which was statistically at par with $N_2 \times I_2$ with the highest (R^2) value (0.8851) (Figure 2). Similar results were described by Oktem and Oktem (2005) who reported that cob length (20.88 cm) increased by applying nitrogen and irrigation. Number of grains per cob is a major yield contributing to the attribute of maize grain yield. $N_2 \times I_4$ was found to have maximum number of grains per cob (308.33), whereas minimum grains per cob (120.67) were recorded in the treatment $N_0 \times I_1$ in response to interactive effect of nitrogen and irrigation (Table 3). Individually, I_4 showed maximum number of grains per cob (258.22) (Table 2). These results are in accordance with Ali (1991) and Shah (2001) who found that number of grains per cob was significantly affected by high levels of irrigation. The results of this variable were affected similarly by nitrogen that showed maximum values (240.75) in N_2 treatment which are quite in agreement with the work done by Sabir et al. (2000), Mahmood et al. (2001) and Abbas et al. (2005) which observed that number of grains per cob increased significantly with increasing nitrogen rates. Regression line for number of grains per cob with grain yield showed a trend towards greater significance in the relationship with the highest (R^2) value (0.9161) (Figure 2).

Maximum 1000-grain weight (294.33 g) was found in the combination $N_2 \times I_4$ which was followed by $N_1 \times I_4$ having 253.0 g 1000-grain weight, while minimum values were observed in $N_0 \times I_1$ (Tables 2 and 3). These results are in accordance with Hokmalipour et al. (2010) who

Table 2. Yield response of maize (*Zea mays* L.) under different nitrogen and irrigation levels.

Treatments	Plant height (cm)	Cob length (cm)	Number of grains per cob	1000-grain weight (g)	Biological yield (t ha^{-1})	Radiation use efficiency (g MJ^{-1})	Grain yield (t ha^{-1})
Nitrogen rates (N) kg ha^{-1}							
N_0	129.23^{b}	14.16^{c}	182.08^{b}	172.89^{b}	12.50^{b}	2.52^{c}	3.53^{b}
N_1	133.80^{b}	17.08^{b}	195.17^{b}	195.98^{b}	13.92^{b}	3.04^{b}	4.05^{b}
N_2	147.64^{a}	23.00^{a}	240.75^{a}	230.77^{a}	18.83^{a}	3.82^{a}	5.37^{a}
LSD (*P*= 0.05)	10.13	2.58	34.33	26.27	2.61	0.29	0.92
Irrigation levels (I)							
I_1	119.80^{c}	11.00^{c}	142.56^{c}	140.73^{c}	10.11^{c}	1.67^{c}	2.62^{c}
I_2	136.09^{b}	18.33^{b}	201.67^{b}	182.38^{b}	13.89^{b}	2.98^{b}	4.20^{b}
I_3	140.63^{b}	19.33^{b}	221.56^{b}	224.79^{a}	16.11^{b}	3.43^{b}	4.58^{b}
I_4	151.04^{a}	23.67^{a}	258.22^{a}	251.63^{a}	20.22^{a}	4.40^{a}	5.86^{a}
LSD (*P*=0.05)	7.75	3.52	23.02	26.88	2.51	0.47	0.78

Any two means not sharing a letter differ significantly at 5% probability level according to LSD test.

Table 3. Interactive effect of nitrogen and irrigation levels on yield and yield components of maize (*Zea mays* L.).

Treatments	Plant height (cm)	Cob length (cm)	No. of grains per cob	1000-grain weight (g)	Biological yield (t ha^{-1})	Radiation use efficiency (g MJ^{-1})	Grain yield (t ha^{-1})
Interaction (N × I)							
$N_0 \times I_1$	115.03^{e}	6.67^{f}	120.67^{f}	120.00^{d}	9.00^{e}	1.10^{f}	2.08^{f}
$N_0 \times I_2$	118.43^{e}	14.00^{de}	165.00^{e}	151.67^{d}	10.33^{de}	2.23^{e}	3.03^{ef}
$N_0 \times I_3$	139.30^{bcd}	17.67^{cd}	211.00^{cd}	212.33^{bc}	14.33^{cd}	3.26^{d}	4.22^{cde}
$N_0 \times I_4$	144.17^{bc}	18.33^{bcd}	231.67^{bc}	207.57^{bc}	16.33^{bc}	3.46^{d}	4.78^{bc}
$N_1 \times I_1$	118.67^{e}	11.00^{ef}	154.33e^{f}	145.00^{d}	10.00^{de}	1.93^{e}	2.50^{f}
$N_1 \times I_2$	129.66^{cde}	14.00^{de}	173.33^{de}	164.67^{cd}	11.00^{de}	2.36^{e}	3.25^{ef}
$N_1 \times I_3$	138.70^{bcd}	19.67^{bcd}	218.33^{c}	221.27^{b}	16.00^{bc}	3.46^{d}	4.68^{bcd}
$N_1 \times I_4$	148.17^{ab}	23.67^{ab}	234.67^{bc}	253.00^{ab}	18.67^{bc}	4.40^{b}	5.76^{ab}
$N_2 \times I_1$	125.70^{de}	15.33^{cde}	152.67^{ef}	157.20^{d}	11.33^{de}	2.00^{e}	3.28^{def}
$N_2 \times I_2$	160.17^{a}	27.00^{a}	266.67^{b}	230.80^{b}	20.33^{b}	4.36^{bc}	6.33^{a}
$N_2 \times I_3$	143.90^{bc}	20.67^{bc}	235.33^{bc}	240.77^{b}	18.00^{bc}	3.56^{cd}	4.85^{bc}
$N_2 \times I_4$	160.80^{a}	29.00^{a}	308.33^{a}	294.33^{a}	25.67^{a}	5.33^{a}	7.04^{a}
LSD (*P*=0.05)	15.28	5.85	48.23	47.79	4.54	0.77	1.47

Any two means not sharing a letter differ significantly at 5% probability level according to (LSD) test.

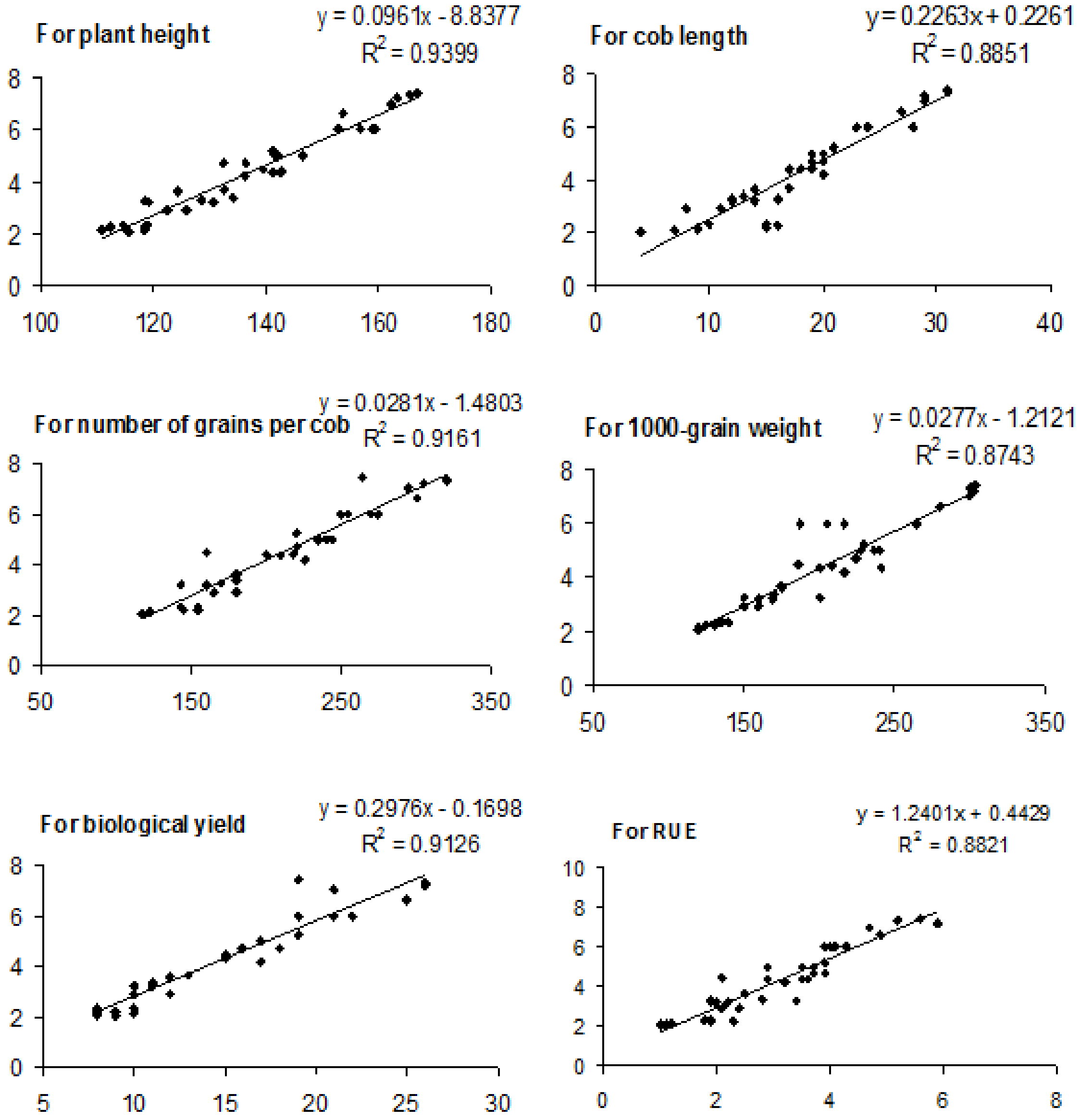

Figure 2. Relationship between maize (*Zea mays* L.) grain yield and its yield components viz. plant height, cob length, grains per cob, 1000-grain weight, biological yield and RUE; X and Y axis represent the grain yield and yield components, respectively as mentioned above each figure.

found that increasing irrigation frequency significantly increased 1000-grain weight. The results related to nitrogen rates are also in accordance with Khaliq et al. (2008) who found that 1000-grain weight increased significantly by the application of different rates of nitrogen. Linear correlation with the highest (R^2 = 0.8743) value between1000-grain weight and grain yield was also found to be significant (Figure 2). There was a significant progressive increase in biological yield (grain plus straw yield) with each increase in irrigation level and nitrogen rates. In response to interaction effect, maximum biological yield (25.67 t ha^{-1}) was achieved in the case of $N_2 \times I_4$ interaction study which also showed a high correlation between grain and biological yield with R^2= 0.9126 (Figure 2), followed by the $N_2 \times I_2$. Minimum value (9.00 t ha^{-1}) was observed in the case of $N_0 \times I_1$. When considering only the main effects, N_2 and I_4 were responsible for maximum biological yield (18.83 and 20.22 t ha^{-1}), respectively (Tables 2 and 3). These findings are in conformity with those of Sabir et al. (2000) who reported that biological yield increased with increase in nitrogen rates while irrigation level are confirmed by the work of Khaliq et al. (2009) who reported that grain yield and dry matter yield (17.61 t ha^{-1}) increased with increasing irrigation frequencies.

Effect of different irrigation levels and nitrogen rates as well as their interactive effects on radiation use efficiency was found to be significant (Table 2 and 3). Maximum RUE value (5.33 g MJ^{-1}) was obtained under N_2 × I_4 treatment with greater R^2= 0.9126 which showed a strong correlation between RUE and grain yield (Figure 2). Minimum RUE (1.10 g MJ^{-1}) was recorded in N_0 × I_1 treatment. This shows that nitrogen and irrigation both increased radiation use efficiency of maize plants (Table 3). Individually, N_2 and I_4 treatments reported the maximum (3.82 g and 4.40 g MJ^{-1}) while N_0 and I_1 accounted for the minimum (2.52 g and 1.67 g MJ^{-1}) RUE respectively (Table 2). The increase in RUE may be ascribed to a greater assimilate production or a decreased partitioning of current assimilates to the root system (Whitfied,et al., 1989; Ahmad et al., 2008). These results are in accordance with the work by Ullah (2002) who reported that increase in irrigation level has a significant effect on radiation use efficiency of maize.

Treatments N_2 × I_4 showed the highest grain yield values (7.04 t ha^{-1}) which was statistically at par with the grain yield observed in N_2 × I_2 and N_1 × I_4 (6.33 and 5.76 t ha^{-1}, respectively), while minimum value (2.08 t ha^{-1}) was recorded in N_0 × I_1. Treatments N_0 × I_2 and N_1 × I_2 behaved statistically similar and did not respond well in terms of maize grain yield (Table 2). Water stress is actually the main cause of reduced grain yield of maize crop. Individual effects of nitrogen and irrigation are statistically significant for the variable grain yield (Table 3). Nitrogen application had much greater effect on maize grain yield and this could be due to the fact that application of nitrogen fertilizer in plants increases uptake of other nutrients. Actually, the supply of nitrogen enhanced the development of small roots and root hairs which, in turn facilitated the absorbing ability per unit of dry weight (Hammad et al., 2011). Satchithanantham and Bandara (2001) and Gheysari et al. (2009) also found that increasing irrigation frequency and nitrogen application significantly increased maize grain yield.

Conclusions

Adequate nutrition and proper soil moisture are important constraints in producing a good crop stand. Nitrogen is needed at high concentrations in the plants at critical growth stages to obtain maximum yield and quality in maize and its response to higher irrigation level is positive. It is recommended that we must utilize 200 kg nitrogen with three irrigations during vegetative development, irrigation at each tasseling, silking and grain filling stage to achieve higher grain yield.

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