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Deficit Irrigation and Nitrogen Effects on Maize Growth in Semi Arid Environment

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Abstract: Growth and yield of maize crop is often limited by variation in the quantity and frequency of irrigation or rainfall in arid and semiarid regions. Besides water, the supply of nitrogen (N) also affects the growth and development of the crop. Therefore, optimization of these two inputs provides a favorable condition for crop growth and productivity. Keeping this in view, an experiment to study the impact of variable water and nitrogen supply on growth and yield of maize hybrid BIO9681 was conducted in the research farm of the Water Technology center (WTC), Indian Agricultural Research Institute (IARI), New Delhi, India. The experiment was carried out during the *kharif* season of 2009 and 2010 with four irrigation levels (*i.e.* rainfed: W_1; 50% FC: W_2; 75% FC: W_3 and full irrigation: W_4) and three nitrogen fertilization levels (*i.e.* not fertilized: N_1; 75 kg N ha^{-1}: N_2; and 150 kg N ha^{-1}:N_3). Generated data of two years experiment were analysed to estimate the grain yield and above ground biomass under varying irrigation and nitrogen supply situations for maize. It was observed that varying levels of irrigation and nitrogen resulted in significant difference in yield of maize. Maximum grain yield and biomass during 2009 were observed for full irrigation (W_4) and N_3 treatment amounting 5930 kg $ha^{-1}$and 18150 kg ha^{-1}respectively. Moreover, the grain yield and biomass during 2010 was maximum for W_4N_3 treatment amounting to 5775 kg ha^{-1}, 17900 kg ha^{-1}. These findings obtained from the experiment will assist in deciding the water and nutrient management strategies of maize crop for enhancing crop productivity under deficit irrigation in the semiarid environment.

Key words: Deficit irrigation · Nitrogen · Maize · Grain yield · Biomass

INTRODUCTION

Water is becoming an increasingly scarce resource worldwide. Therefore, shortage of water coupled with increasing population growth necessitates protocols to enhance water productivity in agriculture [1]. Estimating attainable yield under water-limiting conditions will remain the focal point of investigation in arid and semi-arid regions. Irrigation water management for growing cereal crops assumes importance as majority of cultivated area in the world is under rice, wheat and maize crops [2]. Moreover, maize crop covers about 150 m ha in the world and in India it is about 8.7 m ha [3]. Average yield of maize per hectare is the highest and the area under maize is the third highest after wheat and rice in the world [4]. Maize is a nutrient-rich food grain, which is consumed in different forms in many parts of world including in India. Therefore, research on water and nutrient management for enhancing maize productivity and use of appropriate crop model to simulate maize growth and yield for future years under changing climate scenarios assumes importance. Researchers have revealed that maize is relativity insensitive to water deficits during early vegetative growth because of minimal crop water requirement [5]. However, maize is more sensitive to water stress from flowering through grain filling stage [6]. Payero etal, [7] reported that deficit irrigation of maize distributed over the entire crop growing season might not always result in increasing crop water productivity. This is attributed to variation in the sensitivity of maize crop during different growth stages to water stress. In India, about 80 per cent of maize is grown during the *kharif* or monsoon season (June to September) and the rest is grown during *rabi* season (October to April). In India, there was an increase of about 2.6% of land area under maize coupled with increase in production and productivity by 6.4% and 3.6%, respectively during the period from 2004 to 2008 [3]. Many studies showed that maize grain yields are sensitive

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to moisture stress during the period beginning approximately at tasseling stage and continuing through grain filling stage [8]. Norwood [9] observed that a single irrigation at tassel initiation stage increased the maize yield by 29% over no irrigation and an additional irrigation during the vegetative and grain-filling stages increased maize yield an additional 11 and 13%, respectively. It is also reported that there is a linear relationship between the maize yield and crop water use during the growing season [7]. However, yield difference pertaining to irrigation at different crop growth stages and scheduling irrigation using soil moisture deficit (SMD) approach on regional basis have not been reported to corroborate either the linearity or the non-linearity of the crop water use and maize yield relationship. Maize yield due to deficit irrigation at 50% and 75% levels as compared to the full irrigation would highlight the issues of irrigation water management in the regions with limiting water supply and under climate change scenarios.

MATERIALS AND METHODS

Study Site, Soil and Climate Data: A field experiment was conducted during the year 2009 at Water Technology Center (WTC) research farm of Indian Agricultural research Institute (IARI), New Delhi. The experimental area in IARI farm is enclosed in 28° 39' 25" N latitude and 77° 09' 55" E longitude with an average elevation of 167.5 m above mean sea level. The experiment was undertaken in 1ha block of WTC-01 farm having infrastructure for surface irrigation. The quality of the irrigation water was good and would not to be expected to affect the results of the study. Daily meteorological data, including maximum and minimum temperature and relative humidity, sunshine, wind speed at 2 m above ground and rainfall,were obtained directly from weather station about 150 m from the experimental plots described in (Table 1). The soil physical properties are presented in (Table 2).

Experimental Design: The experiment was planned with randomized complete block design (RCBD) having four irrigation levels *viz.* rainfed and three irrigations at 50, 75, 100 per cent of Field capacity (FC) as main plots and four nitrogen levels (*viz.* not fertilized (poor), 75 (moderate stress) and 150 (non-limited stress) kg N ha^{-1} as sub plots with three replication. There were five furrows in each plot of 3.5 × 3.75 m size and the replications were separated by 2.5 m. The furrows were 75 cm apart with plant spacing of 20 cm in each furrow.

Cultural Practices: The seed bed was prepared by deep plowing, disking and loosening. The field was fertilized at plowing with superphosphate (15.5%) and potassium sulfate (48%) at the equivalent rate of 80 kg P ha^{-1} and 80 kg K ha^{-1}, respectively. The maize hybrid *BIO-9681* was planted manually, two seeds per hole at 0.2 m seed spacing and with 0.75m row spacing at an average in row density of 6.7 seeds m^{-2}. Maize was planted on 22 July and harvested on 27 October 2009 respectively. A furrow method of irrigation, commonly used for row crops in the region, was used. The N fertilizer was applied with three split doses with one-third given as basal, one-third at 21 days after sowing (DAS) and the remaining at 42 DAS of the crop as same rate in 2009. In order to measure yield and yield components, plants of three middle rows of each plot were harvested representing 7.8 m^2 area at the physiological maturity stage of the crop Grain yield was measured as weight of harvested grain in each plot and adjusted to 13% moisture, then converted to ton per hectare for each treatment. Total biomass yield was determined as the total above ground biological yield (grain and all other parts).

Irrigation Scheduling: The quantity of irrigation water for each treatment was calculated based on the soil moisture content before irrigation and root zone depth of the plant using the Eq. 1.

$$SMD= (\theta_{FC}- \theta_i)\times D_{RZ}\times B_d\times f \quad (1)$$

Where

SMD: Soil moisture deficit (mm), θ_{FC}: Soil water content at field capacity, θ_i: Soil water content at before irrigation crops (weight percent), D_{RZ}: Depth of root development (mm), B_d: Bulk density of the particular soil layer (g cm^{-3}) ‘f: Coefficient of each treatment.

Time of irrigations, in this study in full irrigation treatment (i.e.100%) were determined when soil moisture in the root zone approached 50% of total available water(TAW), refilling soil moisture in the root zone to field capacity (FC). In the deficit irrigation treatments (50 and 75%) water was applied on the same day as the fully irrigated plot, but the amount of irrigations depths were reduced to 50 (W_2) and 75% (W_3) for deficit irrigation of the full irrigation (W_4).

RESULTS AND DISCUSSION

Analysis of variance for the design was carried out for the parameters studied following the standard procedures applicable to randomized complete block

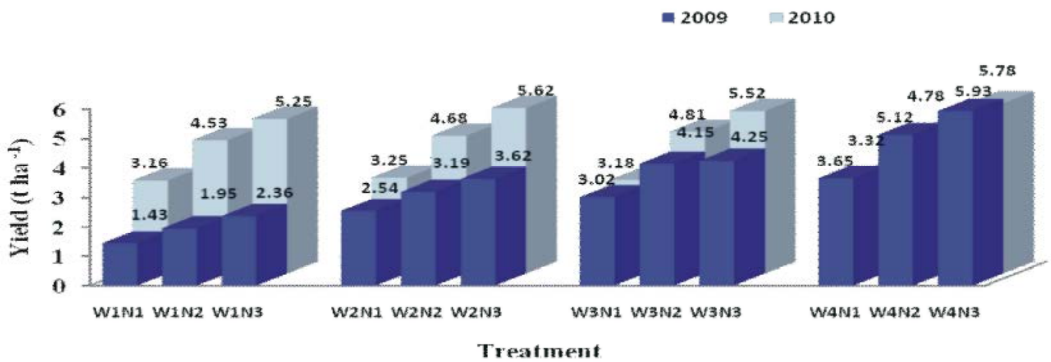

Fig. 1: Amount of grain yield under different treatment during 2009 and 2010

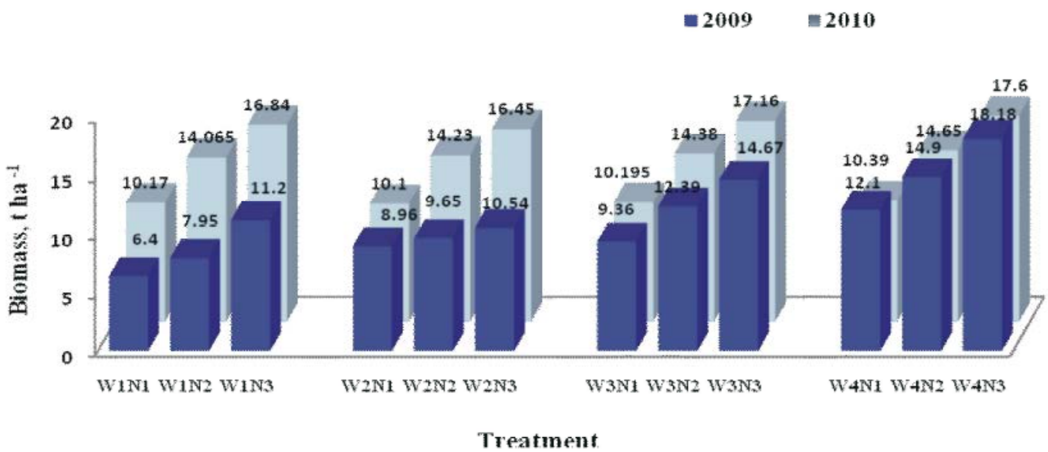

Fig. 2: Amount of above ground biomass under different treatments during 2009 and 2010

Table 1: Weather parameters during entire crop growing season in 2009 and 2010

	Weather Parameters							
	Temperature (max)		Temperature (min)		Rainfall (mm)		Mean RH (%)	
Months	2009	2010	2009	2010	2009	2010	2009	2010
July	35.8	33.7	26.3	26.5	110.5	96.6	55.1	77.8
August	35.1	33.2	26.5	24.7	130.4	333.4	63.4	84.2
September	32.3	31.5	23.5	24.3	260.7	318.1	77.5	81.1
October	34.2	32.5	20.1	19.4	0.3	0	61.9	75.0
Mean	34.3	32.7	24.1	23.7	502	748	64.5	79.5

Table 2: Physical soil properties of experimental field

Soil depth(cm)	Texture	Sand (%)	Silt (%)	Clay (%)	Bd (gm/cc)	Fc (%)	PWP (%)	Ks	θs (cm d^{-1}) (%)
0-15	Loam	48	21	30	1.41	18.3	6.8	380	41
15-30	Sandy-loam	53	19	28	1.43	19.1	6.9	460	40
30-45	Loam	44	23	33	1.39	20.7	8.7	364	44
45-75	Loam	39	25	36	1.37	21.6	9.8	250	47
75-105	Clay. L	38	27	34	1.36	23.0	10.9	180	49

† Bd: Bulk density, Ks: saturated hydraulic conductivity, θs : soil water content at saturation,Fc: field capacity, PWP: permanent wilting point

Table 3: Analysis of variance (ANOVA) for yield, biomass and harvest index (HI) for 2009, 2010

			Mean Square		
2009	Source	df	Yield	Biomass	HI
	Reps.	2	13552	27221.33	0.5253
	Irrigation (I)	3	12127220**	58615870**	0.1357**
	Error (I)	6	24567.33	160339.50	0.2695
	CV (%)		4.65	3.50	1.80
	Nitrogen (N)	2	6909488**	92892930 **	0.2388**
	I×N	6	450672 **	3257768**	0.1510*
	Error (N)	16	20531.25	99276	0.504
	CV (%)		4.25	2.75	2.46
	Reps.	2	6784	100778.7	0.2499
	Irrigation (I)	3	169026.4*	933186.3*	0.3669*
	Error (I)	6	14445.03	147465.5	0.1383
	CV (%)		2.67	2.78 1.14	
2010	Nitrogen (N)	2	16728360**	0.138228**	0.5088**
	I×N	6	26192.33^{NS}	245429.3^{NS}	0.7481^{NS}
	Error (N)	16	12795.11	140935.1	0.5008
	CV (%)		2.51	2.71	2.18

*, ** are Significant in 0.05 and 0.01 probability levels and NS, not significant, respectively.

†, I×N: Interaction effect of water and nitrogen.

Table 4: Comparison of yield and biomass of two years 2009 and 2010

Year	Treatment	level	Yield (Kg ha $^{-1}$)	Biomass (Kg ha^{-1})	HI (%)
2009		W_1	2004.1	8195.1	24.2
	Irrigation	W_2	3116.2	11168.9	28.1
		W_3	3535.9	12105.9	29.6
		W_3	4813.9	14354.3	33.6
		CD(p=0.05)	180.8	461.9	0.6
	Nitrogen	N_1	2592.2	8682.2	29.2
		N_2	3401.7	11439.3	29.06
		N_3	4108.7	14246.6	28.36
		CD (p=0.05)	123.9	336.5	0.61
2010		W_1	4312.9	13557.9	31.7
	Irrigation	W_2	4515.7	13570.1	33.2
		W_3	4575.1	13981.2	32.7
		W_4	4625.1	14212.9	0.43
		CD (p=0.05)	138.6	443	
	Nitrogen	N_1	3240	10213.3	31.8
		N_2	4704.6	14333	32.8
		N_3	5576.75	16945.3	32.9
		CD (p=0.05)	97.85	324.7	0.6

Table 5: Crop water use, irrigation water depth, grain yield, above ground biomass and harvest index (HI) under non-limiting N fertilized (N_3) during 2009 and 2010

Year	Treatment	Irrigation water applied (mm)	Crop water use (mm)	Grain yield (kg ha^{-1})	Relative Yield (%)	Biomass (Kg ha^{-1})	HI (%)
2009	W_1	0	250	2630	44.3	10240	25.7
	W_2	105	355	3625	61.1	14010	25.9
	W_3	158	408	4250	71.6	14670	29.0
	W_4	210	460	5930	100	18140	32.7
2010	W_1	0	423.4	5250	91	16430	31.9
	W_2	24	447.4	5422	97	16370	34.3
	W_3	39	462.1	5525	96	17370	31.8
	W_4	58	481.4	5775	100	17600	32.8

Table 6: Crop water use, irrigation water depth, grain yield, above ground biomass and harvest index (HI) under moderate-limiting N fertilized (N_2) in 2009 and 2010

Year	Treatment	Irrigation water applied (mm)	Crop water use (mm)	Grain yield (kg ha^{-1})	Relative yield (%)	Biomass (Kg ha^{-1})	HI (%)
2009	W_1	0	250	1950	38.1	7950	24.5
	W_2	105	355	3190	62.3	10540	30.3
	W_3	158	408	4450	65.3	12390	33.5
	W_4	210	460	5120	100	14900	34.4
2010	W_1	0	423.4	4535	94.2	14100	32..2
	W_2	24	447.4	4685	97.3	14230	32.9
	W_3	39	462.1	4815	100	14620	32.9
	W_4	58	481.4	4785	99.3	14650	32.7

Table 7: Crop water use, irrigation water depth, grain yield, above ground biomass and harvest index (HI) under poor-limiting N fertilized (N_1) in 2009 and 2010

Year	Treatment	Irrigation water applied (mm)	Crop water use (mm)	Grain yield (kg ha^{-1})	Relative yield (%)	Biomass (Kg ha^{-1})	HI (%)
2009	W_1	0	250	1430	42.1	6400	22.3
	W_2	105	355	2535	74.7	8950	28.3
	W_3	158	408	3015	89	9360	32.2
	W_4	210	460	3395	100	10420	32.6
2010	W_1	0	423.4	3160	95.3	10170	31.1
	W_2	24	447.4	3245	97.8	10100	32.1
	W_3	39	462.1	3180	96	10200	31.2
	W_4	58	481.4	3315	100	10390	31.9

design (RCBD). When the treatment effects were found significant, mean differences were tested using Duncan's Multiple Range Test (DMRT) at 5% or 1% level of probability. Analysis of variance was computed using the MSTATC software. Measurements included: grain yield, biomass and harvest index. A linear relationship between crop water use and yield and biomass for maize has been reported by other researchers [7]. The ANOVA presented in Table 3, shows that during two years of the study, there were significant effects due to primary factors and their interactions.

Grain Yield: The results showed that maize grain yield was significantly affected at ($P\leq 0.01$) and ($P \leq 0.05$) level by irrigation and nitrogen treatments in 2009 and 2010. Irrigation treatments resulted in differences in grain yield under different fertilizer levels as shown in Table 3 and 4. Increased water amounts resulted in a relatively higher yield, since water deficit was main yield-limiting factor in 2009. The maximum and minimum yield was obtained at full irrigation (W_4) in interaction with non limited fertilized (N_3) and rainfed conditions in interaction with poor fertilized (N_1) at the rate of 5930 and 1430 kg ha^{-1} in 2009 respectively (Fig.1). Also, the maximum and minimum grain yield was obtained in full irrigation treatment (W_4) in interaction with non-limited fertilized (N_3) and rainfed treatment (W_1) in interaction with poor fertilized (N_1) at the rate of 5775and 3160 kg ha $^{-1}$ in 2010 respectively (Fig.2). The rainfall ceased before flowering stage 52 (DAS) and three irrigations was applied during flowering and grain formation in 2009, but in 2010 rainfall continued and made up for the soil moisture deficit considerably and only one irrigation was applied during flowering 46 (DAS).

Above-ground Biomass: Above ground biomass was significantly affected ($P \leq 0.01$) and ($P \leq 0.05$) by different water and nitrogen fertilizer level in both 2009 and 2010, respectively (Table 3). The highest level of biomass of maize, obtained from full irrigation treatment (W_4) under non-limited fertilized (N_3) was 18.15 and 17430 kg ha $^{-1}$ and the lowest, obtained from rainfed (W_1) treatment in interaction with poorly fertilized (N_1), 6450 and 10200 kg ha $^{-1}$ in 2009 and 2010 respectively (Figs.1 and 2). Duo to increase the amount of rainfall in 2010, difference of biomass between irrigation treatments was less than of 2009. Increasing the amount of irrigation or rainfall appeared to increase biomass.

CONCLUSION

It was concluded from two years study that the maize grain yield and above ground biomass were significantly affected by irrigation and nitrogen applied during the course of the growing season in 2009 and 2010. Also irrigation water levels were significantly affected at ($P \leq 0.01$) and ($P \leq 0.05$) on grain yield and biomass in 2009 and 2010 respectively, but nitrogen levels were significantly affected at ($P \leq 0.01$) in both experimental years. In both experimental years, grain yield and biomass ranged from 1430 and 6430 kg ha^{-1} in rainfed treatment (W_1) in interaction of non-fertilized (N_1) to 5930 and 18150 kg ha^{-1} in full irrigation (W_4) in interaction with recommended dose of nitrogen (N_3). Duo to increase the amount of rainfall in 2010, difference of yield between irrigation treatments (as compared to control (W_1)) was less than that of 2009. It ranged from a minimum of 13.9 kg grain kgN^{-1} to a maximum of 21.73 kg grain kg^{-1} N under W_1N_3 and W3 (i.e. 75% deficit irrigation level) N_2 treatments, respectively during 2010. A positive linear relationship between crop water use and yield exists during the experimental years; however this slop was slight in 2010.

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