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Response of Maize to Irrigation and Nitrogen Levels

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ABSTRACT

A field experiment was conducted at Experimental Farm, Annamalai University during the summer season of 2011 on sandy loam soil with maize hybrid PEEHM 5 to study the effect of variable irrigation regimes and nitrogen (N) rates on root-shoot characteristics, yield and soil fertility status. The experiment was laid-out in a three-time replicated split-plot design. The treatments consisted of 24 combinations of 3 irrigation regimes: irrigation at 25% depletion of available soil moisture (DASM), irrigation at 75% DASM and no-irrigation (rainfed condition) allotted to main- plots and eight N-rates: control, 40, 80, 120, 160, 200, 240 and 300 kg N ha^{-1} to sub-plots. Irrigation at 25% DASM resulted in significantly higher plant height at tasseling and maturity stages, dry matter accumulation both at knee-high (KH) and tasseling stages, biological yield, harvest index and soil available N compared to water-stressed conditions. However, water-stressed rainfed crop recorded the highest root dry weight. With regard to N-effects, it was found that plant height, dry matter accumulation measured at pre-and post-N top-dressing during KH stage increased upto 160 kg N ha^{-1}, while at tasseling stage increase in these plant parameters was significant only upto 120 kg N ha^{-1}. At KH stage 160 kg N ha^{-1}, whereas at tasseling 120 kg N ha^{-1}, recorded the highest root dry weight. Treatment combination irrigation at 75% DASM and 300 kg N ha^{-1} recorded the highest N-availability in soil.

Key words: *Dry matter, Irrigation, N-rates, Plant height, Root dry weight, Yield.*

INTRODUCTION

Maize (*Zea mays* L.) cultivation holds an immense potential in meeting fast escalating requirements of food-grains, fodder and fuel in many countries of the world including India. Renowned Nobel laureate and the father of the 'Green Revolution', Dr. Norman E. Borlaug, rightly labeled maize as the crop of future. Maize constitute staple food for over 1.2 billion people world-over, particularly in Latin America, Sub- Saharan Africa, and many of the South East Asian countries including India[15]. The crop has adapted to a wide range of environmental and climatic conditions, ranging from 60°N to 40°S latitude, from below sea-level to an altitude of >4,000 m with rainfall varying from < 25 cm to >1,000 cm[16]. Apart from being used as food, maize grainis used for deriving a number of industrial products with diverse utility. Despite its multiple uses, average productivity of maize in India (2.6 t ha^{-1}) is just half of the world average productivity[7,6,9]. The yield potential of maize is greater than any other grain crop, which qualifies it to be regarded as 'miracle crop' and 'Queen of cereals'.

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Water availability and N management are among the most important agronomic practices that determine its yield.

Maize crop is sensitive to both deficit moisture and excess moisture stress; optimum moisture availability during the most critical phase, tasseling and silking is needed to obtain satisfactory yield. Nitrogen changes plant composition much more than any other mineral nutrient as it is an indispensable fundamental constituent of many organic metabolites including amino acids, proteins, nucleic acids, and phytochromes[11,12]. Thus, N is the motor of plant growth and makes upl to 4% of dry matter of the plants[18] and, if applied in sufficient amount, can increase yield by 50% in cereals[3]. Maize requires a heavy amount of N-fertilizers, which is adding to the cost of N-fertilizers, leaching and volatilization losses, groundwater contamination and global warming. There has been a serious concern about environmental implications of N- fertilizers, particularly in green-house gas emission from the agricultural fields[4]. By keeping these facts in view the current study was conducted to examine the effect of different irrigation regimes and N-rates on maize root- shoot characteristics, biological yield, harvest index, and soil fertility status.

MATERIAL AND METHODS

The field experiment was conducted at the Experimental Farm, Annamalai University during Summer 2011. The climate of the area is typical semi-arid and subtropical with hot dry summers and cool winters. During the growing season, the mean weekly maximum, minimum temperature, relative humidity, sunshine hours/day and evaporation were 34.3°C, 23.0°C, 84.6%, 54.4%, 6.3 and 5.1 mm, respectively. The total rainfall (July to October) during crop growth period was 348.9 mm. The experimental field soil was sandy loam in texture having pH 7.6, organic C 0.54%, available N 216 kg ha^{-1}, available P 16.7 kg ha-1 and available K 245 kg ha^{-1}. The experimental maize crop (PEEHM 5) was sown on 22 July 2015 and harvested during the last week of October. The experiment was laid-out in a three-time replicated split-plot design. The treatments consisted of 24-combinations of 3 irrigation regimes: irrigation at 25% depletion of available soil moisture (DASM), irrigation at 75% DASM and no-irrigation (rainfed condition) assigned to main-plots and 8 N-rates: N_0 (control), N_{40} (40 kg N ha^{-1}), N_{80} (80 kg N ha^{-1}), N_{120} (120 kg N ha^{-1}), N_{160} (160 kg N ha^{-1}), N_{200} (200 kg N ha^{-1}), N_{240} (240 kg N ha^{-1}), N_{300} (300 kg N ha^{-1}) assigned to sub-plots. Thus, there were a total of 72 experimental plots of 4.2 m x 3 m each. Six irrigations were given under 25% DASM and 3 under 75% DASM irrigation regime. Maize was planted at a spacing of 60 cm x 20 cm using seed rate of 20 kg ha^{-1}. Nitrogen in form of urea, phosphates (60 kg P_2O_5 ha^{-1}) as single super phosphate, potash (40 kg K_2O ha^{-1}) as potassium chloride were applied; entire dosage of phosphate and potash and one-third dose of N were incorporated into soil basally at the time of final land preparation. The remaining two-thirds quantity of N was band placed in two equal splits, first at knee high (KH) stage and the second just before tasseling. Plant heights were measured at KH, tasseling and maturity stages, for which the height of five tagged plants was measured from base of the stem to the base of last fully opened leaf during pre-tasseling stage and up to the base of the tassels after its emergence. For root dry weight, roots were dug out from a depth of 0-30 cm separately at specified stages, KH and tasseling, thoroughly washed, oven dried at 65°C for 48 hours and dry weights were recorded[5]. Dry matter accumulation was measured by chopping the plant samples into pieces and after sun-drying, oven-dried at 65°C for 48 hours and weights were recorded by using electronic balance. To determine grain yield maize cobs were harvested from net-plot leaving 2-border rows from both sides of the plots and a half meter on opposite directions of the plots. The cobs were dehusked, shelled, cleaned, dried in sun, weighed again and grain yield was adjusted to 14% moisture content. For stover yield, maize stalks were cut at ground level from the net-plot after removal of cobs and weighed after 7-day sun-drying. The biological yield was computed by adding grain and stover yields.

Harvest index was calculated by dividing the grain yield with biological yield. For finding available N in soil, soil samples were collected randomly from the experimental field and were analyzed by alkaline permanganate method. The data were statistically analyzed as per the analysis of variance techniques (ANOVA) for the split-plot design. Wherever the treatment effects were significant, critical differences were computed at 0.05 probability.

RESULTS AND DISCUSSION

Plant height and dry matter accumulation

Plant height was not influenced significantly by irrigation regimes up to KH stage, however at tasseling and maturity stages, the effect of irrigation regimes was significant. At tasseling stage, irrigation at 25 and 75% DASM and at maturity stage 25% DASM resulted in significantly taller plants compared to rainfed crop. Plant height did not differ significantly between two irrigation levels (25 and 75% DASM). Effect of N-rates on plant height was significant at all growth stages. At pre-N top-dressing during KH stage, the plant height increased with increase in N levels up to 300 kg ha but it was at par with plant height recorded in plots treated with 240, 200 and 160 kg N ha^{-1}. A marked variation among graded N-rates was observed up to 160 kg N ha^{-1}, however, it did not differ significantly from immediate lower (120 kg N ha^{-1}) and higher N-rates. Almost a similar trend in plant height was observed at post-N application during KH stage. At tasseling and maturity stages, tallest plants were observed in plots treated with 300 kg N ha^{-1}, however these plants did not differ significantly from the plants receiving 160, 200 and 240 kg N ha^{-1}. This could be due to greater availability and uptake of N during tasseling stage leading to higher plant height. The non-significant effect of irrigation level at the early stage could be due to sufficient rainfall at early stage leading to conducive soil moisture condition in all the treatments, consequently higher growth rate of crop and response to a higher dose of N, while at later growth period, these growth characteristics got affected due to water-stress. Farre and Faci[8] reported that maize is relativity insensitive to water deficits during early vegetative growth because of minimal crop water requirement, but more susceptible during flowering and grainfilling stage.

Table 1: Effect of irrigation regimes and N-rates on plant height and dry matter in maize

Treatment	Plant height (cm)				Dry matter accumulation ($g\ plant^{-1}$)		
	Knee high		Tasseling	Maturity	Knee high		Tasseling
	Pre-NTD	Post-NTD			Pre-NTD	Post-NTD	
Irrigation							
Ii	87.3	136.4	196.4	215.4	41.1	92.9	205.3
h	86.7	130.6	194.9	210.1	35.4	77.7	176.0
h	83.9	127.0	174.5	202.5	31.0	69.7	158.3
SEm ±	1.55	4.48	3.25	3.59	0.95	1.34	5.25
CD (P=0.05)	NS	NS	9.29	10.30	2.64	3.72	15.09
N-Rates							
N_0	69.0	115.7	165.7	176.3	21.8	48.2	107.9
N_{40}	76.0	120.9	172.8	189.8	24.3	56.0	128.2
N_{80}	80.9	124.5	182.2	203.1	31.8	73.6	164.3
N_{120}	86.3	129.7	192.5	212.4	38.0	85.4	193.2
N_{160}	91.0	135.9	197.7	219.3	41.9	93.2	210.2
N_{200}	94.3	140.8	200.0	221.4	42.7	95.6	215.4
N_{240}	94.5	141.2	196.7	224.6	43.0	95.1	211.5
N_{300}	95.47	142.07	201.3	227.9	43.2	93.6	208.2
SEm ±	2.38	4.32	3.37	4.52	1.11	48.2	6.68
CD (P=0.05)	6.83	9.33	9.65	12.94	2.24	7.03	13.48

NTD: Nitrogen top-dressing.

Table 2: Effect of irrigation regimes and N-rates on plant height and dry accumulation in maize (g plant^{-1})

Treatment	KH (pre- NTD)			KH (post- NTD)			Tasseling		
	I_1	I_2	I_3	I_1	I_2	I_3	I_1	I_2	I_3
N_0	22.6	22.1	20.6	51.1	48.7	44.8	113.2	110.7	99.6
N_{40}	26.5	24.5	21.8	63.3	55.2	49.7	134.7	129.9	120.0
N_{80}	35.7	31.7	28.2	80.9	76.6	63.5	177.0	166.4	149.4
N_{120}	41.5	38.1	34.4	94.3	85.2	76.7	206.7	194.6	178.2
N_{160}	48.8	40.3	36.5	109.8	89.2	80.6	242.7	201.7	186.2
N_{200}	50.1	41.4	36.5	112.3	90.7	84.0	248.3	204.7	193.2
N_{240}	51.7	41.7	35.5	115.0	88.2	81.9	259.1	201.2	174.1
N_{300}	52.1	43.2	34.3	116.8	87.6	76.3	260.5	198.9	165.2
		SEm±	CD (P=0.05)		SEm ±	CD (P=0.05)		SEm ±	CD (P=0.05)
Two sub-plot means at the same main-plot treatment		1.92	3.88		6.04	12.18		11.57	23.34
Two main plot means at the same or different sub-plot treatments		2.04	4.44		5.80	11.95		11.96	25.79

NTD: Nitrogen top-dressing

Subjecting maize crop to water stress either by giving irrigation at 75% DASM or by not irrigating, led to significant reduction in dry matter accumulation compared to application of irrigations at 25% DASM. Increasing N-rates from 0-160 kg N ha^{-1} at the interval of 40 kg N ha^{-1}, resulted in significant increase in dry matter accumulation at KH (before and after N-top dressing) and tasseling stages. Increasing N-rate beyond 160 kg N ha^{-1} did not bring out significant improvement in dry matter accumulation, rather at tasseling stage there was considerable reduction in dry matter accumulation when N- rates was increased to 240 and 300 kg N ha^{-1} compared to 200 kg N ha^{-1}.

Irrigation regime x N-rates interaction effects were significant for dry matter accumulation at all the stages. At KH stage (pre N-top dressing), dry matter accumulation increased significantly with each increment of 40 kg ha^{-1} upto 160 kg ha-1 when irrigation was given at 25% DASM and the further increase in N-doses did not cause significant improvement in dry matter accumulation. However, under rainfed and restricted irrigation conditions, dry matter accumulation increased significantly upto 120 kg ha^{-1} and 40 kg ha^{-1} rate was at par with no-N and 80 kg N ha^{-1} application. By and large, the same trend was observed in KH stage (post-N). While, under irrigation at 75% DASM, N-rates 80 and 120 Kg ha^{-1} did not differ significantly from each other. At tasseling stage, dry matter accumulation increased up to 300 kg ha^{-1} for irrigation at 25% DASM and 200 kg ha^{-1} for irrigation at 75% DASM and rainfed conditions, but this dry matter accumulation was not significantly different from the one recorded with 160 kg ha^{-1} for irrigation at 25% DASM and 120 kg ha^{-1} for other two irrigation regimes.

In general, irrigation regimes did not differ significantly at lower N-rates (up to 120 kg ha^{-1}), but at higher N-rates (160-300 kg ha^{-1}), irrigation at 25 and 75% DASM recorded significantly higher dry matter accumulation and the trend was almost common for all the three stages. Between the former two, 25% DASM was better. Abrecht *et al.*[1] and Singh *et al.*[17] also concluded that water-deficit caused the reduction in plant height and overall vegetative growth of maize. Yadav *et al.*[20] reported considerable enhancement in plant height, LAI and dry matter production by maize with increasing N-rates upto 180 kg ha^{-1}. The lower dry matter accumulation at lower doses could be due to deficiency of N, which is the building block of protein, a constituent of chlorophyll, which is essential for carbohydrate formation that finally led to slower dynamics of dry matter accumulation[2].

Table 3: Effect of irrigation regime and nitrogen rates on dry root weight, biological yield, harvest index of maize, and available soil -N status

Treatment	Root dry weight (g plane^{-1})		Biological yield (t ha^{-1})	Harvest index	Available soil N (kg ha^{-1})	
	Knee high stage	Tasseling stage			Knee high stage	Tasseling stage
Irrigation	I_1	I_2	I_3	I_1	I_2	I_3
I_1	29.2	47.5	13.4	0.34	209	198
I_2	35.8	47.7	11.2	0.32	221	206
I_3	39.4	49.3	8.7	0.29	232	210
SEm ±	0.80	0.89	0.32	0.01	3.9	5.2
CD (P=0.05)	2.23	NS	0.89	0.02	10.7	14.5
N-Rates						
N_0	27.3	36.3	6.2	0.31	173	165
N_{40}	32.9	42.6	8.4	0.31	183	176
N_{80}	33.7	45.2	9.8	0.36	198	196
N_{120}	34.7	51.4	11.7	0.34	217	207
N_{160}	38.7	53.0	13.3	0.33	233	218
N_{200}	39.4	52.9	13.3	0.31	244	219
N_{240}	37.3	52.4	13.2	0.30	251	240
N_{300}	34.3	52.3	12.6	0.29	264	242
SEm ±	1.05	2.52	0.48	0.02	1.7	16.5
CD (P=0.05)	2.13	5.08	0.97	0.04	3.5	33.2

Root dry weight

At KH stage, crop undergoing mild water-stress under rainfed conditions, recorded significantly higher dry root weight than the crop irrigated at 25% DASM and 75% DASM. Between the latter two, irrigation at 75% DASM led to significantly higher dry root weight production. This could be due to diversion of assimilates to the root for its growth for the higher absorbance of water and mineral nutrients. Wang *et al.*[19] also reported that maize plants under alternate partial root-zone deficit irrigation produced 49% more root biomass and increased root: shoot ratio by 54%, compared to the fully irrigated control in a controlled environment study. However at tasseling stage, the irrigation regimes did not differ significantly for root biomass.

Effect of N-rates on dry root weight was significant at both growth stages. Application of N at any rate enhanced dry root weight significantly over no-N application. At KH stage, application of 200 kg ha^{-1} produced the highest dry root weight that was similar to dry root weight resulted from the application of 120, 160, and 240 kg ha^{-1} but significantly higher than the ones recorded from 300 kg ha^{-1} and lower N- rates. At tasseling stage, also the highest dry root weight was recorded with the application of 160 kg ha^{-1} that was very close to the dry root weight found with the application of 120, 200, 240 and 300 kg ha^{-1}, and significantly higher than lower N-rates. The increment of root biomass could likely be due to increased photosynthesis leading to higher biomass accumulation. However at excess N-dose, non-significant effect could be possibly due to trade-off of photo-assimilate between root and shoot that led to higher shoot growth.

Table 4: Interaction effect of irrigation regimes and nitrogen rates on available soil-N (kg ha^{-1}) in maize

Treatments	Knee high stage			Tasseling stage		
	I_1	I_2	I_3	I_1	I_2	I_3
N_0	180	172	163	204	196	186
N_{40}	173	179	181	198	205	207
N_{80}	182	194	189	208	222	217
N_{120}	207	208	203	236	238	233
N_{160}	221	221	214	254	254	246
N_{200}	237	243	232	273	279	267
N_{240}	232	257	256	268	295	293
N_{300}	245	269	255	281	309	292
	SEm±	CD (P=0.05)		SEm±		CD (P=0.05)
Two sub-plot means at the same main-plot treatment	5.3		15.3	18.7		53.6
Two main-plot means at the same or different sub-plot treatments	7.7		22.2	19.8		56.8

Biological yield, harvest index

Biological yield was significantly affected by irrigation regimes, N-rates and their interaction. Irrigation at 25% DASM (13.38 t ha^{-1}) produced higher biological yield by 19.9 and 54.7%, than irrigation at 75% DASM and rainfed, respectively. Kresovic *et al.*[10] reported that non-limited irrigation (100% irrigation), 75% of unlimited irrigation, and 50% of unlimited irrigation increased maize yield by 47.8, 32.8, and 22.9% compared to rainfed crop, respectively. The N- treatment of 160 kg ha^{-1} gave the highest biological yield (13.3 t ha^{-1}) which was 115.9% higher than control and 5.4 % higher than 300 kg N ha^{-1}. The yield was found to be increasing significantly up to 160 kg ha^{-1}, whereas, 200 kg N ha^{-1} exhibited significantly higher yield than control, 40, 80 and 120 kg N ha^{-1}. The interaction of irrigation and N treatment revealed that irrigating crop at 25% DASM and 240 kg N ha^{-1} provided the highest biological yield (16.65 t ha^{-1}). Higher biological yield due to frequent watering might be due to higher nutrient uptake and proper physiological function that improved crop growth and biological yield. Nandal and Aggarwal[13] observed a linear response of maize to N-fertilization up to 200 kg N $ha^{'1}$. Irrigating crop at 25% DASM (0.34) and 75% DASM (0.32) produced significantly higher harvest index than rainfed (0.29). Low harvest index under rainfed treatment could be due to water-stress leading to lower grain yield. In support of this, Farre and Faci[8] observed a significant influence of water-deficit on harvest index. Nitrogen rate of 80 kg ha^{-1} gave the highest harvest index (0.36). The reason behind this result could be that at this treatment, there was lesser vegetative growth compared to other N treatments.

Available N in soil

Available N-content in soil under maize crop was significantly influenced by irrigation, N and their interaction at KH stage. However at tasseling stage, their interaction was non-significant. At KH stage, rainfed plots had the maximum available N content followed by irrigation at 75% DASM and rrigation at 25% DASM. Similar kind of response was found at tasseling stage too. A higher value of N in soil in rainfed condition might be due to lower uptake and lower leaching loss comparing other treatments. However, available N in soil increased with increase in N-application rate with maximum value being at 300 kg N $ha^{'1}$. The interaction effect of the combination, irrigating crop at 75% DASM and 300 kg N ha^{-1} registered the maximum available soil N content. At tasseling stage, with the increase in N levels soil available N-content increased significantly upto 160 kg N $ha^{'1}$ with the maximum value being again at 300 kg $ha^{'1}$. Parmar *et al.*[14] also reported similar findings.

CONCLUSION

From the given experiment, it could be finally concluded that irrigating crop at 25% DASM and 160 kg N $ha^{''1}$ resulted to better shoot growth and biological yield, while root biomass and soil available N were higher under water-deficit condition. However, soil available N increased with increase in N-rates.

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