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RESEARCH PAPER

Growth and yield attributes of *rabi* maize as influenced by induced moisture stress at critical crop growth stages

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Abstract: A field experiment was conducted during *rabi* 2021-22 at MARS, Dharwad to study the response of *rabi* maize to induced moisture stress at critical crop growth stages and spectral characterization through unmanned aerial vehicle (UAV) and proximal sensing. The experiment was laid out in RCBD with three replications and nine treatments (Irrigations at all stages and skipping at different stages).Results revealed thatirrigations scheduled at all growth stages recorded significantly higher kernel yield (7040 kg ha^{-1}) and number of grains per cob (509.6) over rest of the treatments. Irrigations up to knee high stage recorded significantly lower kernel yield (2628.3 kg ha^{-1}) andnumber of grains per cob (153.5) and these were on par with irrigation skipped at all critical stages (2729.7 kg ha^{-1} and 160.5, respectively).Yield reduction (%) was observed with skipping irrigation only at tasseling (18.4) and only at silking (16.6), at tasseling and silking (47.7), at all critical stages (61.2) and irrigations up to knee high stage (62.7) compared to irrigations at all crop growth stages. At harvest, irrigations at all growth stages recorded significantly higher plant height (176.1 cm), leaf area index (4.06) and total dry matter (214.5 g plant^{-1}). However these parameters were on par with skipping irrigation only at milky stage (173.3 cm, 3.88 and 206.2 g plant^{-1}, respectively).

Key words: Critical stages, Dry matter, Irrigation, Leaf area index, Moisture stress, *Rabi* maize

Introduction

Maize (*Zea mays* L.) is an important annual cereal crop of the world belonging to family poaceae. It is considered as a staple food in many parts of the world. It is a third leading crop of the world after wheat and rice grown primarily for grain and secondly for fodder. Because of highest productivity, maize is referred as “Queen of cereals”. Among different states, Karnataka alone contributes 14 per cent of India’s maize production.

Maize is one of the crop which responds for nutrients and moisture to harness maximum yield potential irrespective of the growing seasons. Yield reduction in maize due to nutrient stress was reported about 30 to 80 per cent (Nziguheba *et al.*, 2008). Several technologies have been developed to manage the nutrients especially nitrogen to increase nutrient use efficiency and yield. Like nutrient, moisture also plays very important role in exploiting full yield potential. Loss of yield in maize due to moisture stress was reported about 30 to 90 per cent depending up on the stage of the crop and the duration of water deficit stress (Mageto *et al.,* 2017). Water requirement of *rabi* maize is around 600 - 900 mm. Critical crop growth stages in maize are seedling stage, knee high stage, flowering (tasseling and silking) and grain filling stage. Moisture deficit at any stage of the crop growth especially at critical crop growth stages leads to drastic reduction in yield. Skipping irrigation at a single critical stage reduced yield by 40 per cent (Cakir, 2004). Moisture stress at different stages will strongly affect vegetative and reproductive growth of maize. Considering above facts, response of growth and yield attributes of *rabi* maize as influenced by moisture stress at critical crop growth stages was studied for irrigation strategies and sustainable agriculture.

Material and methods

The field experiment was conducted during *rabi* season of 2021 at Main Agricultural Research Station, UAS, Dharwad, Karnataka. Maize hybrid NK-6240 with spacing of 60 × 20cm was used for the investigation. During the crop growing period (10th December 2021- 8th April 2022) a total rainfall of 57.2 mm was received in the last two weeks of March (48.8 mm) and first two weeks of April (8.4 mm).There was no influence of rains over skipping of irrigation at critical stages and no deviation in treatment imposition. The soil of the experimental site was medium deep black soil, slightly alkaline (pH 7.8), with normal electrical conductivity (0.32 dS m^{-1}), low in organic carbon content (0.46 %), low in available nitrogen (278.00 kg N ha^{-1}), medium in available phosphorus (35.00 kg P_2O_5 ha^{-1}) and high in potassium (393.00 kg K_2O ha^{-1}).The experiment was laid out in randomized complete block design with nine treatments andthree replications. Treatment comprises irrigations at all growth stages (VE, V4, V8, VT, R1, R3 and R4), skipping irrigation only at tasseling (VT), skipping irrigation only at silking (R1), skipping irrigation only at milky stage (R3), skipping irrigation at tasseling and silking (VT and R1), skipping irrigation at tasseling and milky stage (VT and R3), skipping irrigation at silking and milky stage (R1 and R3), skipping irrigations at all critical stages (tasseling, silking and milky stage) and irrigations upto knee high stage (V8).

Fertilizers were applied at the rate of 150: 65: 65 N: P_2O_5: K_2O kg ha^{-1} in the form of urea (N), Di-Ammonium phosphate (DAP) and Muriate of potash (K_2O). At the time of sowing, 50 % of N and 100 % of P_2O_5 and K_2O were applied as basal dose followed by 50% of N applied at 35 days after sowing. Irrigation was provided after sowing (VE) to ensure uniform germination and establishment of the crop. Later irrigation was scheduled at four leaf stage (V4) and knee high stage (V8), for all the treatments. Subsequent irrigations were scheduled as per the treatments at tasseling stage (VT), silking stage (R1), milky stage (R3) and dough stage (R4). Irrigation was provided to each plot with 2 inches pipe (siphon) at a discharge rate of 2.5 liters sec^{-1}. Care was taken to minimize horizontal movement of water to other treatments. Growth parameters such as plant height, leaf area and total dry matter production were recorded at VT, R1, R3 and at harvest stage. Yield and yield attributes were recorded at harvest.The data collected from the experiment at different growth stages was subjected to statistical analysis as described by Gomez and Gomez (1984). The level of significance used in 'F' and't' test was P= 0.05. Critical difference (CD) values were calculated wherever the 'F' test was found significant. The mean values were subjected to Duncan's Multiple Range Test (DMRT) using the corresponding error mean sum of squares and degrees of freedom. Karl Pearson correlation studies were worked out to explain the relation among the parameters supporting the objective of investigation.

Results and discussion

At tasseling stage, plant height recorded non-significant among the treatments. At silking stage,significantly higher plant height (170.8 cm) was recorded with irrigations at all crop growth stages compared to other treatments except with the treatments where moisture stressed only at silking and only at milky stage (Table 1). At milky stage, irrigations at all crop stages recorded significantly higher plant height (173.1 cm) over the rest of the treatments. However, it was on par with moisture stress induced only at milky stage (172.0 cm). These results are in conformity with findings of Maqsood *et al.* (2012) who recorded significantly higher plant height with irrigations atvegetative stage (three irrigations) + tasseling + silking + grain filling stages. Significantly lower plant height (151.8 cm) was recorded with irrigations upto knee high stage and it was on par with irrigation skipped at tasseling, silking and milky stage (151.9 cm) and at both tasseling and silking stages (152.8 cm). Similar trend of results was observed at harvest (Table 1). Moisture stress at active growing period (from knee high to tassel initiation) of vegetative stage affect the plant height severely due toreduced cell division, cell elongation and internodal elongation in turn resulted stunted growth of plant. These results are in harmony with the findings of Raibagi (2021) who also recorded significantly lower plant height with irrigations up to twelve leaf stage.

Among the treatments non-significant difference was recorded in leaf area index at tasseling stage (Table 1). Scheduling irrigation at all crop growth stages recorded significantly higher leaf area index (5.72) at silking stage compared to the rest of the treatments and it was on par with irrigation skipped only at silking stage (5.57) and only at milky stage (5.69). At milky stage, irrigations at all growth stages recorded significantly higher leaf area index (5.19) than rest of the treatments except with the treatment where irrigation skipped only at milky stage (4.97). At harvest, significantly higher leaf area index (4.06) was recorded with irrigation at all growth stages compared to other treatments (Table 1). However, it was on par with irrigation skipped only at milky stage (3.88). Irrigating up to knee high stage recorded significantly lowest leaf area index (2.98) and it was on par with moisture stressed at both tasseling and silking stage (3.29) and at all the critical stages (3.02). Moisture stress in the plant affects the rate of cell division and

Table 1. Plant height (cm), Leaf Area index and total dry matter (g $plant^{-1}$) as influenced by moisture stress at critical crop growth stages

Treatments	Plant height (cm)				Leaf area index				Total dry matter (g $plant^{-1}$)			
	VT	R1	R3	At harvest	VT	R1	R3	At harvest	VT	R1	R3	At harvest
T_1: Irrigations at VE, V4, V8, VT, R1, R3 and R4	164.1^a	170.8^a	173.1^a	176.1^a	5.24^a	5.72^a	5.19^a	4.06^a	119.3^a	136.2^a	186.6^a	214.5^a
T_2: Irrigations at VE, V4, V8, R1, R3 and R4 (Skipping VT)	152.5^a	155.1^{bc}	161.8^{bc}	163.5^b	5.10^a	5.23^{bc}	4.65^{bc}	3.58^{bc}	110.8^a	123.3^{bc}	159.4^b	176.3^b
T_3: Irrigations at VE, V4, V8, VT, R3 and R4 (Skipping R1)	160.6^a	162.6^{ab}	163.9^b	164.3^b	5.20^a	5.57^{ab}	4.71^{bc}	3.65^{bc}	117.9^a	126.9^{ab}	161.3^b	179.9^b
T_4: Irrigations at VE, V4, V8, VT, R1 and R4 (Skipping R3)	165.3^a	168.3^a	172.0^a	173.3^a	5.22^a	5.69^a	4.97^{ab}	3.88^{ab}	118.9^a	134.5^a	181.7^a	206.2^a
T_5: Irrigations at VE, V4, V8, R3 and R4 (Skipping VT and R1)	150.1^a	152.0^c	152.8^{cd}	153.1^{cd}	5.08^a	5.14^c	4.17^{de}	3.29^{cde}	109.8^a	114.7^c	143.0^{cd}	159.5^{cd}
T_6: Irrigations at VE, V4, V8, R1 and R4 (Skipping VT and R3)	152.2^a	155.2^{bc}	159.2^{bc}	161.5^{bc}	5.11^a	5.22^{bc}	4.35^{cd}	3.4^{cd}	110.1^a	121.1^{bc}	156.3^{bc}	169.7^{bc}
T_7: Irrigations at VE, V4, V8, VT and R4 (Skipping R1 and R3)	158.1^a	159.7^{bc}	160.4^{bc}	161.4^{bc}	5.21^a	5.24^{bc}	4.33^{cd}	3.39^{cd}	116.2^a	120.9^{bc}	154.7^{bc}	167.9^{bc}
T_8: Irrigations at VE,V4,V8 and R4 (Skipping VT, R1 and R3)	151.1^a	151.6^c	151.9^d	152.3^d	5.09^a	5.13^c	3.73^e	3.02^e	109.6^a	113.8^c	138.9^d	148.9^d
T_9: Irrigations at VE, V4 and V8. (Skipping VT, R1, R3 and R4)	149.4^a	151.3^c	151.8^d	152.1^d	5.10^a	5.12^c	3.68^e	2.98^e	109.2^a	113.2^c	138.3^d	148.3^d
S.Em.±	5.1	2.7	2.3	2.7	0.23	0.12	0.15	0.12	3.5	3.2	4.6	5.6

Means followed by same lower case letter/s in a column do not differ significantly by DMRT (P=0.05)

Note: VE = Emergence stage, V4 = four leaves visible with collar (15-20 DAS), V8 = Knee high stage (30-35 DAS), VT =Tasseling stage (50-55 DAS), R1 = Silking stage (60-65 DAS), R3 = Milky stage (75-80 DAS) and R4 = Dough stage (90-95 DAS).

Table 2. Yield and yield attributes of maize as influenced by moisture stress at critical crop growth stages

Treatment details	Kernel yield (kg ha^{-1})	Reduction in kernel yield (%)	No. of grains cob^{-1}	Cob weight (g)	Grain weight cob^{-1}(g)
T_1: Irrigations at VE, V4, V8, VT, R1, R3 and R4	7040.7^a	-	509.6^a	174.8^a	130.1a
T_2: Irrigations at VE, V4, V8, R1, R3 and R4 (Skipping VT)	5744.7^c	18.4	386.1^c	164.5^b	118.8^b
T_3: Irrigations at VE, V4, V8, VT, R3 and R4 (Skipping R1)	5874.7^c	16.6	400.9^c	165.2^b	119.3^b
T_4: Irrigations at VE, V4, V8, VT, R1 and R4 (Skipping R3)	6411.0^b	9.0	463.3^b	170.0^{ab}	124.4^{ab}
T_5: Irrigations at VE, V4, V8, R3 and R4 (Skipping VT and R1)	3681.3^e	47.7	297.1^e	142.2^d	98.5^d
T_6: Irrigations at VE, V4, V8, R1 and R4 (Skipping VT and R3)	4271.3^d	39.3	350.3^d	153.4^c	109.2^c
T_7: Irrigations at VE, V4, V8, VT and R4 (Skipping R1 and R3)	4016.0^{de}	43.0	330.8^d	150.7^c	106.9^c
T_8: Irrigations at VE,V4,V8 and R4 (Skipping VT, R1 and R3)	2729.7^f	61.2	160.5^f	123.9^e	84.3^e
T_9: Irrigations at VE, V4 and V8. (Skipping VT, R1, R3 and R4)	2628.3^f	62.7	153.5^f	123.2^e	83.7^e
S.Em.±	171.6	-	10.3	2.7	2.4

Means followed by same lower case letter/s in a column do not differ significantly by DMRT (P=0.05)

Note: VE = Emergence stage, V4 = four leaves visible with collar (15-20 DAS), V8 = Knee high stage (30-35 DAS), VT =Tasseling stage (50-55 DAS), R1 = Silking stage (60-65 DAS), R3 = Milky stage (75-80 DAS) and R4 = Dough stage (90-95 DAS).

cell elongation. Plant adopts leaf rolling to avoid interception of light under limited moisture situation. Further, with the advancement of stress, leaf senescence was recorded all which led to lower LAI. Similar results were reported by Hammad *et al.* (2012) who also recorded significantly higher LAI with eight irrigations and it was on par with seven irrigations by skipping irrigation at grain filling stage

At tasseling stage, there was no significant difference in total dry mater production among the treatments (Table 1). At silking stage, irrigation scheduled at all stages recorded significantly higher total dry matter production (136.2 g plant^{-1}) than the other treatments except skipping of irrigation at silking and at milky stage alone (Table 1). Total dry matter production at milky stage was recorded significantly higher (186.6 g plant^{-1}) with irrigation at all crop growth stagesover rest of the treatments. However it was statistically on par with moisture stressed only at milky stage (181.7 g plant^{-1}). Hammad *et al.* (2012) also reported no significant difference in plant dry matter with skipping of irrigation at grain filling stage compared to irrigations at all stages. Significantly lower total dry matter (138.3 g plant^{-1}) was recorded with irrigation up to knee high stage andit was on par with irrigation skipped at both tasseling and silking stage (143.0 g plant^{-1}) and at all critical stages (138.9 g plant^{-1}). At harvest, similar trend of total dry matter production was recorded. The rate of dry matter accumulation depends on rate of photosynthesis, photosynthetic area to intercept radiation, leaf rolling, leaf senescence, leaf area index and fixation of CO_2 per unit leaf area. This is also due to strong and positive correlation (Fig.1) of total dry matter at harvest with LAI (r=0.93).

Moisture stress induced at critical crop growth stages of maize had a significant influence on its yield. Significantly higher grain yield (7040.7 kg ha^{-1}) was obtained with irrigations at all growth stages (Table 2). Similar results are reported by Suneethadevi and Praveenrao (2001) who recorded significantly higher yield (6.91 t ha^{-1}) by scheduling irrigation at all crop growth stages. In maize crop each growth stage has its own importance in determining the yield but the most influencing stages on grain yield are tasseling, silking followed by milky stage. Similar findings are reported by Gouranga and Verma (2005) who recorded significantly higher yield (5187 kg ha^{-1}) with no moisture deficiency at tasseling, silking and grain filling stage.

When moisture stress induced by skipping irrigation only at tasseling stage caused a yield reduction of 18.4 per cent compared to the yield of fully irrigated treatment (Table 2). Reduction in yield at this stage is due to improper anthesis and reduced pollen viability which in turn due to increased temperature in micro climate of the crop. Reduced pollen viability affects fertilization ultimately results in reduced filled grains per cob. Moisture stressed only at silking stage reduced yield up to 16.6 per cent compared to yield of fully irrigated treatment (Table 2). Stress at this stage affects the silk length and its receptivity of pollen thereby fertilization gets affected which in turn causes kernel abortion *i.e.* scattered and improper filling of grains on the cob. Skipping of irrigation only at milky stage reduced yield up to 9.0 per cent compared to fully irrigated treatment.At milky stage moisture stress had impact on kernel size and its consistency which determines the grain quality and weight. Cakir (2004) also reported 40 per cent of yield reduction due to moisture stress at single critical stage.

Irrigation skipped at tasseling and silking stage, tasseling and milky stage and silking and milky stages recorded yield reduction of 47.7, 39.3 and 43.0 per cent, respectively compared to the irrigation at all critical crop growth stages (Table 2). Similar results were reported by Yildirim *et al.* (1996) who recorded yield reduction of 25.2 per cent by skipping irrigation at both tasseling and silking. Further, moisture stressed at all the critical stages such as tasseling, silking and milky contributed 61.2 per cent of yield reduction. Moisture stress induced in the entire reproductive phase *i.e.* by irrigating only up to knee high stage recorded yield reduction of 62.7 per cent compared to irrigation at all crop growth stages (Table 2). Lack of efficient fertilization as well as translocation of the carbohydrates from source to sink due to inadequate moisture at the root zone resulted in drastic reduction of cob size with few filled grains which in turn contributed for poor yields. This might also be due to strong and positive correlation (Fig.1) of kernel yield

Fig.1 Correlation of kernel yield, no. grains per cob^{-1}, cob weight, grain weight cob^{-1}, LAI at silking stage and total dry matter

	Kernel yield (kg ha^{-1})	No. of grains cob^{-1}	Cob weight (g)	Grain weight cob^{-1} (g)	LAI at silking stage
Kernel yield (kg ha^{-1})					
No. of grains cob^{-1}	0.96*				
Cob weight (g)	0.97*	0.99*			
Grain weight cob^{-1} (g)	0.98*	0.99*	0.99*		
LAI at silking stage	0.89*	0.84*	0.82*	0.84*	
Total dry matter at harvest (g plant $^{-1}$)	0.95*	0.94*	0.91*	0.93*	0.93*

Note: * P = 0.05 level of significance

withno. grains per cob^{-1} (r = 0.96), cob weight (r = 0.97), grain weight cob^{-1} (r = 0.98) and total dry matter (r = 0.95). These results are in conformity with findings of Yildirim *et al.* (1996) who recorded 50.8 per cent yield reduction by skipping irrigation at both flowering and milking stage.

Irrigation scheduled at all crop growth stages recorded significantly higher number of grains per cob (509.6) over rest of the treatments (Table 2). Among various irrigation schedules at critical crop growth stages, irrigation at all the crop growth stages recorded significantly higher cob weight (174.8 g), grain weight per cob (130.1 g) compared to rest of the treatments except with skipping of irrigation only at milky stage (170.0 g and 124.4 g, respectively). Significantly lower cob weight (123.2 g), grain weight per cob (83.7 g) was recorded with irrigations up to knee high stage. However, it was statistically on par with irrigation skipped at all the three critical stages (123.9 g and 84.3 g, respectively). This is due to inadequate moisture at the crop root zone led to poor translocation of energy reserves from source to sink causing reduction in number, size and consistency of grains. This is also due to strong and positive correlation (Fig.1) of no. grains per cob with total dry matter (r = 0.94), cob weight (r = 0.99) and grain weight per cob (r = 0.99). These results are in line with the findings of Suneethadevi and Praveenrao (2001) who recorded significantly higher number of grains cob^{-1} with irrigations at all crop growth stages and significantly lower number of grains cob^{-1} with irrigations up to vegetative period.

Conclusion

Scheduling irrigations at all stages recorded significantly higher kernel yield compared to other treatments. Yield reduction (%) was observed with skipping irrigation at tasseling and silking (47.7), at tasseling and milky stage (43.0), at silking and milky stages (39.3), only at tasseling (18.4), only at silking (16.6) only at milking (9.0), at all critical stages (61.2) and irrigations upto knee high stage (62.7) compared to irrigations at all growth stages. At harvest, significantly lower plant height, leaf area index and total dry matter was recorded with irrigations upto knee high stage. However, these parameters were on par with skipping irrigation at all critical stages and at both tasseling and silking.

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