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Impact of moisture deficit stress at critical growth stages on growth and yield of hybrid maize

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Abstract

A field experiment was conducted in field no. 37F of Eastern Block Farm at Tamil Nadu Agricultural University, Coimbatore, India, during the *summer* season (January-May) of 2024 to assess the impact of moisture deficit stress at critical growth stages (knee high stage, tasselling and grain filling stages) on growth and yield of hybrid maize. The growth parameters like plant height and dry matter production were significantly affected by moisture deficit stress. Significant decrease in the yield attributes such as cob length (cm), cob weight (g), number of grains per cob, 100-grain weight, shelling percentage (%), grain yield (kg/ha) and stover yield (kg/ha) was observed. Moisture deficit stress at the vegetative stage significantly reduced plant height and leaf area index. Studies revealed that grain yield and dry matter are significantly reduced in the reproductive stage (T_4) and grain filling stage (T_6) compared to control plants provided with irrigation at all critical growth stages (T_7). The yield reduction was found to be higher at moisture stress for 20 days from tassel initiation (41%) and grain filling stage (34%) when compared with the irrigation without moisture stress (T_7-control). The study concluded that moisture stress for 20 days from the tassel initiation stage caused more yield reduction (T_4) followed by the grain-filling stage (T_6). Moisture stress is more detrimental at the reproductive stage compared to the vegetative stage on maize yield.

Keywords

critical growth stages; grain yield; harvest index; maize; moisture stress; stover yield

Introduction

Maize is a major cereal crop worldwide, ranking third in demand next to wheat and rice (1). It is grown on an estimated 150-180 million ha in around 160-165 countries, with global production ranging from 7.1 to 10.14 million metric tonnes (Mt) and an average yield of 4.92 to 5.63 t/ha (1,2). In India, it is cultivated on an area of 10.8 million hectares, with an average production of 38 million tonnes and productivity of 3.5 t/ha (3).

Maize is a water-sensitive crop that requires significant water for optimal growth. However, nearly one-third of the world's cultivated land faces inadequate water supply, posing challenges for maize cultivation and food security. The water requirement of maize varies significantly depending on geographical location, growing season and irrigation method (4). Globally, maize water requirements range from 425-789 mm for furrow irrigation and 351- 685 mm for drip irrigation (5). Moisture stress is a significant abiotic factor limiting crop productivity, affecting plant growth and development across various stages. Maize, in particular, is susceptible to moisture stress throughout its life cycle, with the reproductive stage being especially critical (6,7). Drought or moisture deficit stress is a significant environmental challenge that can result from various factors such as low rainfall, salinity, extreme temperatures and intense light.

To overcome moisture stress plants developed morpho-physiological and biochemical mechanisms (8). C4 plants, such as maize, need adequate water to finish their growth cycle, there are certain stages at which the plants are more susceptible to water scarcity and any stress caused by a water deficit during this period would result in a significant decrease in yield. Understanding how maize plants react to water scarcity at various growth stages of development is important. The present study aims to evaluate the impact of moisture deficit stress at critical growth stages on the growth and productivity of maize.

Materials and Methods

Experimental location

A field experiment was conducted at Agricultural College and Research Institute, Tamil Nadu Agricultural University ($11^0 48'$ N latitude and $76^0 45'$ E longitude with an altitude of 426.9 m above the mean sea level), Coimbatore during the *summer* season (29 January - 8 May) 2024. The soil of the experimental site was clay loam texture with available soil moisture at field capacity and the permanent wilting point was 28.4 percent and 11.4 percent respectively and normal in pH (7.6), non-saline in EC (0.34 dS/m), low in available N (169.0 kg ha^{-1}), medium in available P (19.0 kg ha^{-1}), high in available K (745.0 kg ha^{-1}). The organic carbon status in the experimental soil was 0.84%. The minimum and maximum mean monthly temperatures were 32.9^0C and 23.8^0C, respectively. Relative humidity for forenoon and afternoon ranged from 72 to 84 percent and 28 to 47 percent respectively during the cropping period. Weather data was collected from the Agro Meteorological Observatory at Tamil Nadu Agricultural University in Coimbatore.

The Field experiment was laid out in Randomized block design (RBD) with three replications involving 7 treatments which include cessation of irrigation at different plant growth stages, the treatments involve arresting irrigation at different growth stages T_1 (10 Days from the knee-high stage), T_2 (20 Days from knee-high stage), T_3 (10 Days from tassel initiation), T_4 (20 days from tassel initiation), T_5 (10 Days from grain filling stage), T_6 (20 days from grain filling stage), T_7 (control- without moisture stress). For the experimental trial maize hybrid CO H (M) 11 was used and the observations like plant height (cm), leaf area (cm^2), dry matter (kg/ha), grain yield (kg/ha) and 100 seed weight (g) were recorded.

In the field, moisture stress was induced by completely withholding water from the designated treatment plots and discontinuing irrigation for the specified duration according to each treatment. The recommended dose of NPK for maize hybrid, 250:75:75 kg ha^{-1}, as per recommended crop management practices, was followed. Each plot was irrigated at a depth of 50 mm, measured using a Parshall flume, for every irrigation. A buffer channel of 1 m was dug between each treatment plot to prevent water seepage. Irrigation was applied according to the treatments (T_1, T_2, T_3, T_4, T_5 and T_6) and the control (T_7, without moisture stress).

Plant height

Plant height is measured with the help of a scale from the base to the tip of the leaf and is expressed in cm.

Dry matter production

The plant samples are collected from each treatment**.** The samples were air-dried and then oven-dried at 80^0 C till a constant weight was recorded and expressed in kg ha^{-1}.

Yield Parameters

Observations are taken from each treatment. Grain yield and straw yield were accounted for after harvest in the net plots and the harvest index was worked out per standard procedure. The grains from each net plot (after removing the border and sampling rows) were collected.

Harvest index (HI)

Harvest index (HI) was worked out by the formula (9):

$$\text{Harvest Index (\%)} = \frac{\text{Grain yield (kg/ha)}}{\text{Biological yield (kg/ha)}} \times 100$$

Statistical analysis

The data pertaining to the experiment were subjected to statistical analysis by Analysis of variance method as suggested by (10). The data is statistically analysed using R software and AGRES

Results and Discussion

Effect of moisture stress on growth parameters

Effect on Plant Height

The study examined maize plant height under different moisture stress treatments. During Knee-high Stage (25-45 DAS) prolonged moisture stress (T_2) significantly reduced plant height, with T_2 (168.1 cm) being shorter than the control (192.3 cm) at harvest. Treatment T_4(167.3 cm) showed reduced height compared to the control, during moisture stress at the tassel initiation stage highlighting the importance of adequate moisture during this stage. Grain-filling stage (65-85 DAS) moisture stress had a smaller impact on height, with T_5 (187.8 cm) and T6 (183.4 cm) closer to the control (192.3 cm) (Table 1).

Overall, moisture stress during early vegetative and reproductive stages significantly limits plant height, affecting final growth more than stress during grain filling. Maize grown under offseason rainfed conditions, that face frequent spells of drought are subjected to exhibit a lower LAI (due to a decrease in leaf size), crop height and eventually, decreased biomass accumulation (11,12).

Effect on Dry Matter Production

Total dry matter accumulation was significantly affected by moisture deficit stress. Under favorable conditions, maize plants showed slow early growth, which accelerated as more leaves were exposed to sunlight, increasing the rate of dry matter accumulation. In the control treatment without moisture stress (T_7), dry matter accumulation continued steadily until harvest.

Table 1. Effect of moisture stress at critical growth stages of maize on plant height (cm)

Treatments	Plant Height (cm)				
	25 DAS	45 DAS	65 DAS	85 DAS	At Harvest
T1 Moisture stress for 10 days from knee-high stage (25-35 DAS)	42.5	113.3	158.0	168.4	169.2
T2 Moisture stress for 20 days from knee-high stage (25-45 DAS)	43.3	106.3	156.4	166.3	168.1
T3 Moisture stress for 10 days from tassel initiation (45-55 DAS)	44.7	124.7	161.5	189.0	191.4
T4 Moisture stress for 20 days from tassel initiation (45-65DAS)	41.7	118.0	150.7	163.1	167.3
T5 Moisture stress for 10 days from grain-filling stage (65-75 DAS)	44.0	121.9	178.3	185.9	187.8
T6 Moisture stress for 20 days from grain-filling stage (65-85 DAS)	41.0	126.7	177.3	179.1	183.4
T7 Without moisture stress (Control - 11 irrigations)	42.3	126.6	178.2	190.6	192.3
S.Ed	2.0	4.9	7.9	7.1	8.6
C.D (P=0.05)	NS	10.7	17.2	15.4	18.8

The results revealed that moisture deficit stress significantly affects dry matter production in maize, with the most notable reductions observed during the tassel initiation and knee-high stages. T_4 (moisture stress for 20 days from tassel initiation) resulted in the lowest dry matter production at harvest (13,370.6 kg/ha), indicating the high sensitivity of this stage. The grain-filling stage exhibited more resilience to short-term moisture stress (T_5), while prolonged stress (T_6) still caused a significant reduction in DMP, though less than during tassel initiation (T_4), with a final dry matter of 13,762.5 kg/ha. The control (T_7) without stress had the highest dry matter production (15,693.7 kg/ha), affirming the importance of continuous irrigation. Statistical analysis (Critical Difference (C.D) at P=0.05) reveals significant differences in dry matter accumulation, especially at 45, 65 and 85 DAS (Table 2). Maize accumulates more dry matter when there is optimum irrigation, as water is a critical input for photosynthesis and overall plant development. Similar findings were reported (13). Studies found that a serious decrease in dry matter weight was recorded for plants exposed to water stress during the tasselling stage and during the ear formation stage. Specifically, it was noted that short-term water stress at the beginning of the intensive vegetative growth stage caused significant losses in final dry matter weight, particularly during the tasselling and ear formation stages (14). Water deficit stress at the vegetative stage leads to a notable decline in plant height and leaf area, which are critical factors for dry matter accumulation (15).

Effect of moisture stress on Crop growth rate (g m^{-2} day^{-1})

The crop growth rate is significantly varied due to moisture stress. The results indicated a decline in CGR at different growth stages under moisture stress compared to the treatment without stress (T_7). Moisture stress for 10 and 20 days after tassel initiation (T_3, T_4) led to the most significant reduction in CGR, with the 20-day stress (T_4) having the greatest impact. In contrast, moisture deficit during the grain-filling stage (T_5, T_6) had a smaller effect, especially with a shorter stress duration of 10 days from grain filling (T_5). Moisture stress at the knee-high stage (T_1, T_2) resulted in a moderate reduction in CGR, with partial recovery in later stages (Table 3). The control treatment (T_7) exhibited stable growth overall. The moisture deficit stress delayed flowering and maturity, which hindered maize growth by keeping the plants in a stressed state longer, reducing biomass accumulation (16) and ultimately lowering CGR (17).

Yield and productivity

Cob length and kernels/cob

The timing of water stress affects source-flow-sink relationships, influencing leaf productivity, assimilate translocation and yield formation. In the present study, under different moisture stress treatments, the results revealed that moisture stress imposed at the reproductive stage(T_4) and grain filling stage(T_6) had more negative impact than moisture stress at the vegetative stage with context to yield attributes as there is a significant reduction in cob length (cm) and no. of kernels/cob. Maximum Cob Length

Table 2. Effect of moisture stress at critical growth stages of maize on dry matter production (kg/ha)

Treatments	Dry matter production (kg/ha)				
	25 DAS	45 DAS	65 DAS	85 DAS	At harvest
T1 Moisture stress for 10 days from knee-high stage (25-35 DAS)	406.3	5178.5	9051.2	13330.3	16124.0
T2 Moisture stress for 20 days from knee-high stage (25-45 DAS)	423.9	4557.5	8371.1	12667.3	15418.7
T3 Moisture stress for 10 days from tassel initiation (45-55 DAS)	404.2	5982.0	8742.9	13040.9	15858.5
T4 Moisture stress for 20 days from tassel initiation (45-65DAS)	403	6004.0	7694.7	11946.0	12172.8
T5 Moisture stress for 10 days from grain-filling stage (65-75 DAS)	415	5902.0	9707.3	12746.4	15871.4
T6 Moisture stress for 20 days from grain-filling stage (65-85 DAS)	432.3	6093.0	9660.3	12041.0	13760.6
T7 Without moisture stress (Control – 11 irrigations)	409.6	5994	9775.9	14381.1	16478.3
S.Ed	14.9	213.2	397.2	496.8	730.0
C.D (P=0.05)	NS	464.7	866.8	1082.4	1591.0

Table 3. Effect of moisture stress at critical growth stages of maize on crop growth rate (gm^{-2}day^{-1})

Treatments	CGR (gm^{-2}day^{-1})			
	25-45 DAS	45-65 DAS	65-85 DAS	At Harvest
T_1 Moisture stress for 10 days from knee-high stage (25-35 DAS)	23.9	16.2	24.7	6.1
T_2 Moisture stress for 20 days from knee-high stage (25-45 DAS)	20.7	17.6	21.9	5.7
T_3 Moisture stress for 10 days from tassel initiation (45-55 DAS)	27.9	12.6	22.6	5.5
T_4 Moisture stress for 20 days from tassel initiation (45-65DAS)	28.0	8.1	20.5	6.2
T_5 Moisture stress for 10 days from grain-filling stage (65-75 DAS)	27.5	20.1	18.1	6.2
T_6 Moisture stress for 20 days from grain-filling stage (65-85 DAS)	28.3	17.9	14.3	5.6
T_7 Without moisture stress (Control)	28.0	15.1	25.5	6.3
S.Ed	1.03	1.94	3.01	1.69
C.D (P=0.05)	2.31	4.22	6.58	NS

and kernels/cob were observed under normal irrigation without moisture stress (T_7) whereas lowest Cob Length and kernels/cob 15.8, 283.5 were found in treatments T_6 and T_4, respectively, (moisture stress at grain filling and tasseling stage) (Table 4). Water deficit stress significantly affects cob length, particularly when stress coincides with the development stage (7). The late vegetative and maturation stages are also crucial, with water stress during maturation having a stronger effect on yield than during the late vegetative stages (18).

Water deficit stress significantly impacts maize yield and yield components, with the severity of effects varying based on growth stage and stress intensity. Water deficit stress at the tasselling and grain-filling stages can decrease yield by 66.4% and 44.9%, respectively (19). To maximize maize yield, it is crucial to avoid water stress during critical growth stages, particularly silking and grain-filling and to optimize irrigation and fertilization practices (19,20). The maturation stage is also critical, as water stress during this period directly reduces grain-filling rate and duration, strongly impacting yield (18).

Water deficit stress significantly impacts maize yield and water use efficiency, with the timing and severity of stress playing crucial roles. Stress during the reproductive and maturation stages has a more pronounced effect on yield compared to vegetative stages (18,21). Stress during the vegetative stage reduces leaf area and photosynthetic capacity, while stress during maturation directly impacts grain filling (18).

100 seed weight

The results obtained indicate that moisture stress at critical growth stages had a significant impact on 100 seed weight. The control treatment (T_7- normally recommended irrigation at all growth stages) and moisture stress at the vegetative stage(T_1) resulted highest 100 seed weights of 35.3 g and 34.1 g respectively. Moisture stress at the grain filling stage(T_6) and stress at tasselling stage (T_4) had recorded least 100 seed weights i.e., 22.72g and 26.2 g, respectively (Table 4). Moisture deficit stress progressively impacts kernel setting, with deficits just before and during flowering reducing kernel sink and retarding grain-filling (22).

Grain yield, Stover Yield and Harvest Index

The analysis of variance (ANOVA) revealed a significant difference in grain yield, straw yield and harvest index of maize due to moisture stress during the *summer* season of 2024 (January to April). Irrigation without any moisture stress at critical growth stages(T_7) has recorded the highest grain yield, stover yield and harvest index of maize during summer 2024. Moisture stress for 20 days. Studies have shown that drought stress reduces seed yield, harvest index and 100-seed weight in maize cultivars (23).

Among the treatments, T_7 has the highest grain yield followed by T_1 and T_5which are at par with each other. T_1 and T_5 have less yield reduction 7.9% and 11% respectively. Conversely, treatment T_4 has the lowest grain yield followed by T_6 (moisture stress for 20 DAS during the grain filling stage) suggesting that there is a significant reduction in grain yield of nearly 41% compared to normally recommended irrigation (T_7 - control) (Table 4). Studies have shown moisture deficit stress during silking is detrimental in maize, reducing grain yield by up to 42% (19). Severe drought can reduce maize yield by up to 70% (6).

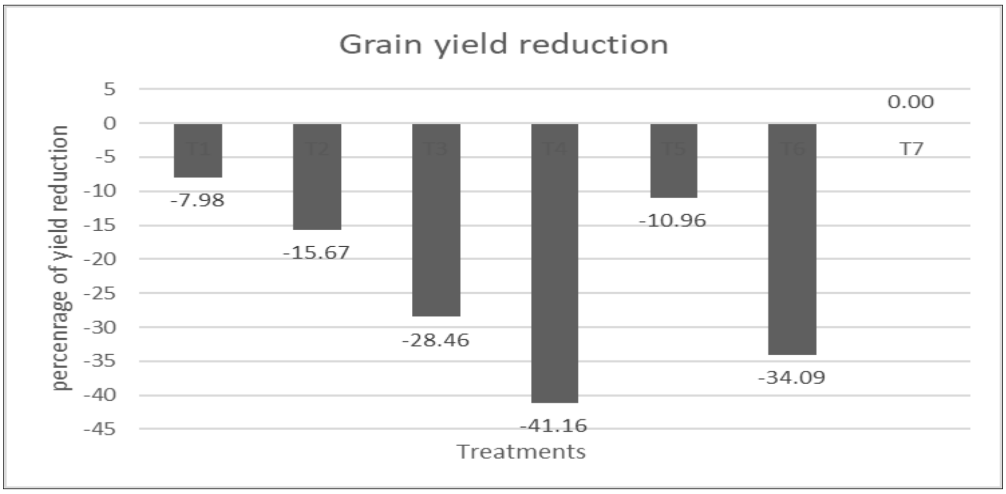

Fig. 1. Percentage grain yield reduction of maize.

Table 4. Effect of moisture stress at critical growth stages on yield attributes

Treatments	Length of the cob (cm)	No. of Kernels/ cob	No. of kernel rows/cob	100 seed weight (g)	Grain yield (Kg/ha)	Stover Yield (Kg/ha)	Harvest index (%)
T1	17.5	362.7	15.3	35.7	6875	10810	39
T2	16.0	326.7	14.7	27.6	6301	9585	38
T3	18.2	317.5	12.7	33.7	5345	10753	36
T4	15.8	283.5	10.2	26.2	4396	8346	35
T5	21.0	351.5	15.3	28.5	6653	10369	38
T6	16.6	291.0	14.3	22.7	4924	9145	35
T7	22.0	385.1	15.7	35	7472	11075	40
S.Ed	0.62	0.86	0.73	2.07	347.4	558.2	-
C.D (P=0.05)	2.33	NS	NS	4.51	757	1216.2	-

T1 Moisture stress for 10 days from knee-high stage (25-35 DAS), T2 Moisture stress for 20 days from knee-high stage (25-45 DAS), T3 Moisture stress for 10 days from tassel initiation (45-55 DAS), T4 Moisture stress for 20 days from tassel initiation (45-65DAS), T5 Moisture stress for 10 days from grain-filling stage (65-75 DAS), T6 Moisture stress for 20 days from grain-filling stage (65-85 DAS), T7 Without moisture stress (Control - 11 irrigations)

Conclusion

The present field study concluded that the moisture stress of 10-days and 20-days duration at vegetative, reproductive and grain-filling stages significantly impacted grain yield, stover yield and harvest index. It is concluded that moisture stress for 20 days during the reproductive stage caused more yield reduction followed by the grain-filling stage. Moisture stress is more detrimental at the reproductive stage compared to the vegetative stage on maize yield. It was found that growth parameters like plant height, Leaf area index and Leaf number were more affected due to moisture stress at the vegetative stage compared to the reproductive stage. Results of the experiment revealed that maize plants responded differently to water cessation treatments. The plants showed variations in the response table when the irrigation ceased at various growth stages, which affected their growth and, eventually, their yields.

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Authors' contributions

Conceptualization and writing carried out by NMR. Review, editing and supervision by SS and SAP. Validation of the article by SAP, VK and KVN. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare

Ethical issues: None

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