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Study on the impact of waterlogging stress on growth and yield of hybrid maize (*Zea mays* L.)

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Abstract
A research study was carried out during *summer* season (2023) at the Research farm of Tamil Nadu Agricultural University, Coimbatore to study the impact of waterlogging stress on growth and yield of hybrid maize (*Zea mays* L.). The treatments comprised of two factors *viz.*, waterlogging at three levels, waterlogging for three days (M1), waterlogging for five days (M2) and waterlogging for seven days (M3) and stages of waterlogging, germination stage (S1), third leaf stage (S2), sixth leaf stage (S3) and tasseling stage (S4). Control plot was maintained separately with conventional practices. The growth parameters such as plant height, Dry Matter Production (DMP) and leaf area index (LAI) at all stages of crops were significantly influenced by waterlogging stress. It is also observed that significant decrement in the yield attributes such 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) during waterlogging conditions at third leaf stage (S2) and sixth leaf stage (S3) when compared over the recommended practice. Research study had concluded that TNAU maize hybrid CO 6 was found to be susceptible to physiological stress at earlier stages of waterlogging conditions. The yield reduction was found to be higher at waterlogging for 7 days during germination (42%) and three leaf stage (32%) when compared with the recommended conventional practice.

Keywords: Hybrid maize, waterlogging stress, growth parameters, yield attributes and yield

Introduction
Maize crop is commonly renowned as "Queen of Cereals," because of the ability of the crop with more yields potential amongst all the cereal crops. Maize has mechanism of C4 pathway, having more efficient photosynthetic system with increased yield production and adopted to all agroclimatic zones. Maize being a staple diet for people and also can be used as nutritive supplement feed to livestock. It also plays an significant role in providing raw material for numerous agro-industrial products. In India, production of maize accounts for nearly 9% of all cereal production and regarded as the most significant food grain consumption after wheat (38%) and rice (42%). Currently, India is one of the top five countries in the world for maize exports. It witnessed the greatest growth rate of any food grain. One of the main abiotic stresses in agricultural crop productivity is waterlogging, which affects 10% of the world's land area (Shabala, 2011) [10]. The causes of waterlogging can be due to substantial and frequent rainfall, improper soil drainage, soil texture and high-water table level. Grain yield of maize is significantly reduced by limited crop growth and development during waterlogging conditions (Ren *et al*., 2014) [5]. In India, nearly 2.5 M ha of maize cultivation is being affected by waterlogging, which directly influence in the reduction of annual maize production by 25 to 30 percent on average. Generally, Maize crop largely consumes nutrients and has a good response to frequent irrigation, but susceptible to waterlogging. The susceptibility of Maize plants to waterlogging was due to absence of air holes in their roots, unlike rice plants. Therefore, crops when exposed to prolonged (more than 3 days) excess soil moisture condition, plant roots may undergo hypoxia condition (low oxygen) followed by anoxia (no oxygen). This condition results in the steady drop of oxygen availability to roots (Dennis *et al*., 2000, Zaidi *et al*., 2002) [2, 13]. Certainly, when the soil moisture exceeds 80% of field capacity level, the growth and development of maize crop is greatly diminished (Guoping *et al*., 1988) [3]. The majority of previous research studies mainly focused on how above ground plant parts responded to waterlogging and resulted in significant reduction in the dry matter accumulation, root development, leaf area index and plant height. Additionally, waterlogging increases the susceptibility of lodging and also affect grain filling process and grain quality indices, leading

to a significantly lower grain yield production (Abiko *et al.*, 2012) [1]. It is evident from previous studies that early crop stages of hybrids maize were highly affected by waterlogging stress. Maize plants are extremely vulnerable to waterlogging from sowing of crop till sixth leaf stage. Therefore, present study investigates about effects of maintaining 3days, 5days and 7 days of waterlogging conditions at germination, third leaf stage, sixth leaf stage and tasseling stage of hybrid maize to define the crop responses to waterlogging at different stage affecting plant height, leaf area index (LAI), dry matter accumulation, grain yield and quality.

Materials and Methods

An experimental study on the impact of waterlogging stress on growth and yield of hybrid maize (*Zea mays* L.) was evaluated at Research farm of TNAU during *summer* season (2023), lies under Western Agro- Climatic Zone of Tamil Nadu. The study place geographically located with coordinates of 11º N latitude, 77º E longitude and an altitude of 426.7 m above MSL. The soil properties of experimental field was observed to be clay loam texture having moderate value of alkaline pH level (8.11) and normal range of soluble salts with EC value of 0.47 dS m^{-1}. The soil nutrient composition was calculated before sowing and found to be low in available nitrogen (216.3 kg/ha), high in available phosphorus
(42.4 kg/ha) and high in available potassium (370 kg/ha). The seed used for experimental study was TNAU maize hybrid CO 6 with seed rate of 20 kg/ha. The field operation was carried out with recommended cultural practices. The experimental trial was laid out in Strip Plot Design, with the treatment combinations of two factors *viz.*, factor 1.) waterlogging at three levels, waterlogging for three days (M1), waterlogging for five days (M2) and waterlogging for seven days (M3) and factor 2.) stages of waterlogging, germination stage (S1), third leaf stage (S2), sixth leaf stage (S3) and tasseling stage (S4). Control plot was maintained separately with conventional practices for comparison. The biometric observations such as growth parameters (plant height, dry matter production, leaf area index), grain yield and stover yield were recorded at knee high, tasseling, silking and harvest stages as per the standard procedures. N, P and K analysis of post-harvest soil and plant sample at different stages were calculated and nutrient uptake was estimated. The observed data helps to evaluate the effect of the waterlogging conditions over the crop growth rate, nutrient uptake efficiency and soil nutrient status at different stages of growth intervals and its influence over yield production and their attributes.

Results and Discussion

The effect of waterlogging stress for different days and at different growth stages of crop growth had direct significant relationship over the growth parameters of the crop. Plant height provides the physiological indicator of plant's health and growth. In general, maximum plant height was observed in control when compared to the treatments of waterlogging for different days at different growth stages of crop and the minimum reduction was observed in the waterlogging at tasseling stage (S_4) (Table.1 and 2.). When the waterlogging was done from 3 days to 5 days and from germination to tasseling stage, plant height was reduced by 4.5% at harvest stage. The reduction in plant height was due to the direct interaction of with the water and by continuous waterlogging the root system gets destroyed which resulted in the reduction of height of the plant. These data were evident with the results obtained by Rathore *et al*. (1998) [4] and Savita *et al*. (2004) [9].

Table 1: Impact of waterlogging stress at different number of days of waterlogging and different growth stages on plant height (cm) of hybrid maize

Treatments	Knee high stage					Tasseling				
	S_1	S2	S3	S4	Mean	S_1	S2	S3	S4	Mean
M_1	86.13	84.23	88.17	88.42	86.74	246.5	228.8	236.1	243.3	238.7
M_2	86.17	81.03	84.58	89.25	85.26	246.3	223.1	231.9	241.2	235.6
M_3	85.23	78.45	84.17	85.05	83.23	245.1	217.7	230.0	239.9	233.2
Mean	85.84	81.24	85.64	87.57		246	223.2	232.7	241.5	
Control	89					246.87				
	M	S	M X S			M	S	M X S		
S.Ed.	2.4	1.96	4.69			6.12	5.43	12.43		
CD (P=0.05)	5.78	5.54	10.21			14.71	15.35	27.09		

Table 2: Impact of waterlogging stress at different number of days of waterlogging and different growth stages on plant height (cm) of hybrid maize

Treatments	Sulking					Harvest				
	S_1	S2	S3	S4	Mean	S_1	S2	S3	S4	Mean
M_1	251.8	235.9	242.5	250.2	245.1	252.1	235.9	242.8	251.9	245.7
M_2	252.4	229.2	238.0	248.2	242.0	253.4	229.6	238.6	249.5	242.8
M_3	252.2	224.1	236.2	247.8	240.1	252.6	224.6	237.4	248.8	240.8
Mean	252.1	229.8	238.9	248.7		252.7	230.0	239.6	250.1	
Control	255					254.7				
	M	S	M X S			M	S	M X S		
S.Ed.	6.6	5	13.3			6.56	5.1	13.5		
CD (P=0.05)	15.87	14.15	29.06			15.77	14.42	29.42		

After waterlogging, the leaf area index drastically changed. LAI was found to be lower than in the control treatment at all the growth stages for all waterlogging treatments. The leaf area index was reduced by 21.2, 9.6 and 7.7% at three leaf stage, six leaf stage and Tasseling stage respectively. The results are in conformity with the results obtained by Ren *et al*. (2020) [7] and Ren *et al*. (2016) [6] (Table. 3 and 4.).

Table 3: Impact of waterlogging stress at different number of days of waterlogging and different growth stages on leaf area index (LAI) of hybrid maize

Treatments	Knee high stage					Tasseling				
	S_1	S2	S3	S4	Mean	S_1	S2	S3	S4	Mean
M_1	1.69	1.48	1.61	1.65	1.61	4.32	4.15	4.24	4.29	4.25
M_2	1.62	1.13	1.64	1.65	1.51	4.32	4.02	4.14	4.28	4.19
M_3	1.59	0.85	1.58	1.58	1.40	4.33	3.79	4.02	4.29	4.11
Mean	1.63	1.15	1.61	1.63		4.32	3.99	4.13	4.29	
Control	1.78					4.36				
	M	S	M X S			M	S	M X S		
S.Ed.	0.05	0.02	0.05			0.13	0.05	0.13		
CD (P=0.05)	0.12	0.06	0.11			0.32	0.16	0.28		

Table 4: Impact of waterlogging stress at different number of days of waterlogging and different growth stages on leaf area index (LAI) of hybrid maize

Treatments	Silking					Harvest				
	S_1	S2	S3	S4	Mean	S_1	S2	S3	S4	Mean
M_1	5.47	4.73	5.18	5.26	5.16	5.94	4.81	5.42	5.51	5.42
M_2	5.42	4.65	5.03	5.17	5.07	5.89	4.77	5.36	5.49	5.38
M_3	5.39	4.15	4.81	5.03	4.85	5.81	4.43	5.29	5.41	5.24
Mean	5.43	4.51	5.01	5.15		5.88	4.67	5.36	5.47	
Control	5.63					5.93				
	M	S	M X S			M	S	M X S		
S.Ed.	0.16	0.07	0.16			0.12	0.07	0.16		
CD (P=0.05)	0.39	0.2	0.34			0.3	0.2	0.35		

The Table. 5. revealed that the waterlogging stress for different days and at different stages had significantly influenced the 50% tasseling and silking. Among them, waterlogging at three leaf stage (V3) for 3, 5 and 7 days had taken 63, 64 and 66 days, respectively for 50% tasseling and 67, 70 and 73, days respectively for 50% silking, where 50% tasseling and silking were occurred at 56 and 61 days respectively under normal conditions of crop growth (control).

Table 5: Impact of waterlogging stress on 50% tasseling and silking at different number of days of waterlogging and different growth stages of hybrid maize

Treatments	50% Tasseling					50% Silking				
	S_1	S2	S3	S4	Mean	S_1	S2	S3	S4	Mean
M_1	57	63	59	57	59	61	67	65	61	63
M_2	57	64	61	56	60	61	70	66	62	65
M_3	57	66	65	57	61	61	73	70	66	67
Mean	57	64	62	57		61	70	67	63	
Control	56					62				
	M	S	M X S			M	S	M X S		
S.Ed.	1.31	1.32	3.32			1.74	1.79	3		
CD (P=0.05)	3.16	3.74	7.22			4.19	5.05	6.54		

The primary economic output of a crop is its grain yield. It is the behaviour of all yield qualities taken together. The grain yield obtained in the final stage determines the impact of waterlogging stress on different days and crop stages. Grain yield significantly decreased with increased waterlogging duration at different growth periods. Waterlogging during three leaf stage (V3) for seven days has produced the lowest grain yield (3573 kg/ha) which is 32% yield reduction compared to the control (5273 kg/ha) (Table. 6.). Grain yield in treatments of waterlogging for 3 and 5 days during three leaf stage were 4893 kg/ha (7.2%) and 4341 kg/ha (17.6%), respectively. It was followed by grain yield in waterlogging for 3, 5 and 7 days during six leaf stage which were 4924 kg/ha (6.6%), 4388 kg/ha (16.7%) and 3669 kg/ha (30.4%), respectively. Grain yield in waterlogging for 3, 5 and 7 days during tasseling stage were 5057 kg/ha (4%), 4691 kg/ha (11%) and 4052 kg/ha (23.1%), respectively. Grain yield in waterlogging for 3, 5 and 7 days during germination stage were 4857 kg/ha (7.9%), 4573 kg/ha (14.4%) and 3056 kg/ha (42%), respectively. Yield reduction in germination stage was due to the reduction in germination percentage, the percentage were 94%, 78% and 39% for 3, 5 and 7 days. However, waterlogging at three leaf stage (V3) and six leaf stage (V6) significantly decreased the no. of grains per cob, and the effect of waterlogging at three leaf stage (V3) was greater than that at six leaf stage (V6). Waterlogging during germination stage for seven days and waterlogging for 7days at three leaf stage has produced the lowest stover yield 10063

kg/ha (26.9%) and 10773 kg/ha (21.8%), respectively (Table. 6.). The 100-grain weight also decreased with after waterlogging at different growth stages. The lowest 100-grain weight was recorded in waterlogging for seven days at three leaf stage (21.6g) which is 34.5% and followed by waterlogging for five days at three leaf stage (23.3g) which is 29.3% reduction. The results are in concordance with the findings of Tian *et al.* (2019) [11], Youn *et al.* (2008) [12] and Robertson *et al.* (2009) [8].

Table 6: Effect of waterlogging stress at different number of days of waterlogging and different growth stages on grain yield (kg/ha) and stover yield (kg/ha) of hybrid maize

Treatments	Grain yield (kg/ha)					Stover yield (kg/ha)				
	S_1	S2	S3	S4	Mean	S_1	S2	S3	S4	Mean
M_1	4857	4893	4924	5057	4933	12437	11943	12274	13597	12563
M_2	4513	4341	4388	4691	4483	12033	11641	12088	12711	12118
M_3	3056	3573	3669	4052	3588	10063	10773	11069	11852	10939
Mean	4142	4269	4327	4600		11511	11452	11810	12720	
Control	5273					13773				
	M	S	M X S			M	S	M X S		
S.Ed.	115	68	261			367	169	1211		
CD (P=0.05)	277	192	568			882	477	835		

The data on dry matter production (kg/ha) of crop is furnished in Table 7. It showed significant variation due to waterlogging at different stages at harvest. Waterlogging for seven days during germination stage recorded the lowest dry matter production (11804 kg/ha) over other treatments. It was followed by waterlogging for seven days during three leaf stage (12018 kg/ha) and waterlogging for seven days during six leaf stage (12601 kg/ha). The highest dry matter production was recorded in waterlogging for three days during tasseling stage (14619 kg/ha) over other treatments.

Table 7: Effect of waterlogging stress at different number of days of waterlogging and different growth stages on dry matter production (kg/ha) of hybrid maize

Treatments	S_1	S2	S3	S4	Mean	ANOVA	S.Ed.	CD (P=0.05)
M_1	13871	12782	13767	14619	13760	Waterlogging	407	977
M_2	13612	13345	13389	13879	13556	Growth stage	375	1060
M_3	11804	12018	12601	12975	12350	M X S	606	1320
Mean	13096	12715	13252	13824				
Control	14938							

Conclusion

It could be concluded from the study that waterlogging stress caused a decrease in plant height, leaf area index and grain yield and increase in days for 50% tasseling and silking. TNAU maize hybrid Co 6 was most sensitive to waterlogging stress at three leaf stage (V3), followed by six leaf stage (V6) and tasseling stage. The yield reduction in waterlogging during germination stage is due to the lack of germination of seed, the reduction in yield was increased with continuous flooding for 3days, 5days and 7days were 4857 kg/ha (7.9%), 4573 kg/ha (14.4%) and 3056 kg/ha (42%), respectively, despite that, the germinated crop has no significant difference with the control.

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