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RESEARCH ARTICLE :

Bio-physical characters of maize (*Zea mays* L.) genotypes to elevated carbon dioxide and temperature regimes

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SUMMARY : Higher atmospheric CO_2 concentration may influence positively plant production.Carbon dioxide was substrate for photosynthesis and gradient increase between the ambient air and mesophyll cells. Plants respond not only to change in surrounding CO_2 concentration, but to modifications of their microenvironment. Plants with C_4 photosynthetic pathway showed negligible photosynthetic response to elevated CO_2 because the C_4 cycle increased the CO_2 concentration in bundle sheath cells to the point where very little photorespiration occurs and calvin cycle is nearly saturated with CO_2 However, there is no consensus on the quantitave effects of increased CO_2 on plant processes and growth because of differences in response at different stages of growth, species of crops and growth limiting environmental factors. The purpose of this paper was to study the biophysical response of maize genotypes to elevated carbon dioxide and temperature regimes. The exposure of the crop elevated CO_2 and temperature regime resulted in the significant decrease in the photosynthetic rates. The minimum reduction was observed in HTMR-1, HTMR-2 and NK 6240 and the maximum in ARJUN and 900M-GOLD. Among the genotypes NK 6240, HTMR-1 and 900 M-GOLD genotype recorded maximum transpiration rate and stomatal conductance whereas, the genotypes HTMR-2 and ARJUN had the least transpiration rate and stomatal conductance. More detailed investigations are needed to complete our imagination about future consequences of possible climate variations, mainly in local level.

KEY WORDS :
Physiology of maize, Elevated CO_2, Temperature, Biophysical parameter

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BACKGROUND AND OBJECTIVES

Global atmospheric CO_2 concentration has been increasing since the beginning of the industrial revolution in the mid-18^{th} century and is predicted to double at some time in the mid- or late 21^{st} century. Humans emitted 6 gigatons of carbon per year into the atmosphere from fossil fuel burning and cement production during the 1990's, yet only about half of this carbon accumulated in the atmosphere. Of the remainder, about half was absorbed by the oceans and half by terrestrial ecosystems. Ecological responses to CO_2 enrichment and climate change are expressed at several interacting levels: photosynthesis and stomata movement at leaf level, energy and gas exchanges at the canopy level, photosynthates allocation at the plant level, and water budget and carbon cycling at the ecosystem level. Increasing level of CO_2 concentration has effect through modification of stomata behaviour on photosynthesis, water use efficiency and crop yield, etc. Stomata movements may change in response to elevated CO_2. A doubling CO_2 concentration reduces the conductance at the leaf level by 30-40 per cent, although large differences among species exist and values as high as 50-70 per cent decrease can be found in the literature with similar response between C_3 and C_4 species. Two responses of crops to elevated CO_2 are an increase e in the rate of photosynthesis and a decrease in stomatal conductance. The increase in net photosynthesis in C_3 species has been reported as high as 50-100 per cent when CO_2 concentration doubles compared to 10 per cent in C_4 species. The partitioning of net radiation on the leaves under elevated CO_2 concentration is modified due to decrease in stomatal conductance, which causes a decrease in transpiration leading to an increase in leaf temperature. The temperature of the leaf surface may rise 0.5 - 1.7°C only due to doubling CO_2 concentration or even upto 3°C, depending on the specie and the weather. Higher leaf temperatures may have important consequences on the longevity an photosynthetic capacity of the individual leaves and at the canopy level, as ageing maybe accelerated and shortening the growing season and estimated that a doubling CO_2 concentration, holding other factors constant, could lead to a 34±6 per cent increase in agricultural yields of C_3 plants and a14±11 per cent in C4 plats with a 95 per cent confidence interval.

RESOURCES AND METHODS

An investigation was carried out to study the response of maize genotypes to elevated carbon dioxide and temperature regimes under Open Top Chamber (OTC's) at Main Agricultural Research Station (MARS), University of Agricultural Sciences, Raichur, Karnataka during Summer and *Kharif* season 2014-15. Five maize genotypes (HTMR-1, HTMR-2, ARJUN, 900M Gold, NK 6240) were sown in each OTC and in reference plot with controlled conditions with a spacing of 60 cm x 20 cm. Five plants were raised for each genotypes, therefore total 25 plants were raised in each open top chambers. For each genotype all the agronomic practices for raising the crop were practiced as per the package of practices of the University of Agricultural Sciences, Raichur. The following traits were recorded under elevated CO_2 and temperature regimes. Normalized difference vegetation index (NDVI), leaf temperature, photosynthetic rate, stomatal conductance, transpiration rate, cob length, and number of rows per cob,number of seeds per cob and grain yield per plant. The temperature and CO_2 treatments were randomly allocated in each of the five growth chambers as follows:

T_1 : Reference open top chamber (390 ppm CO_2)

T_2 : Ambient CO_2 @390 ± 25ppm with 2^0C rise in temperature

T_3 : Elevated CO_2 @ 550 ± 25ppm with normal temperature

T_4 : Elevated CO_2 @ 550 ± 25ppm with 2^0C rise in temperature

T_5 : Reference plot (Open field)

OBSERVATIONS AND ANALYSIS

Significant difference was observed among the treatments, genotypes and also interaction effect at 30 and 60 DAS but non- significant difference was observed among the genotypes at 90 DAS. In general irrespective of the genotypes, mean of all the genotypes showed that the highest NDVI was observed in e-CO_{2+} e–temp treatment except 90 days, followed by e-CO_2 except 90 days, reference plot except 30 days, and a-CO_2 andleast NDVI was observed in a-CO_{2+} e –temp treatment except 30 and 60 days. Irrespective of the treatments, the genotype HTMR-2 recorded maximum NDVI was noticed except 90 DAS and followed by, HTMR-1 except 90 DAS, 900M-GOLD except 30 and 90 days and NK 6240, and the lowest NDVI was noticed in ARJUN genotype.Among the treatments, e-CO_2 treatment recorded maximum photosynthetic rate followed by,e-CO_{2+} e –temp, a-CO_2 and a-CO_{2+} e –temp and the least photosynthetic rate was observed in reference plot. Among the genotypes HTMR-1, NK 6240 and HTMR-2 genotypes recorded the highest photosynthetic rate, whereas and ARJUN and 900M-GOLD had less photosynthetic rate under altered conditions. This was mainly due to the e-CO_2 increase net photosynthesis in C_3 plants and C_4 plants because higher CO_2 can suppress RuBP oxygenase activity; decrease photorespiration (C_3

Table 1 : Effect of elevated CO_2 and temperature regimes on NDVI

Treatments	NDVI																	
	30 DAS						60 DAS						90 DAS					
	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean
T_1	0.58	0.57	0.51	0.62	0.60	0.57	0.63	0.66	0.60	0.67	0.66	0.64	0.50	0.48	0.47	0.52	0.52	0.50
T_2	0.61	0.67	0.59	0.63	0.58	0.61	0.74	0.74	0.65	0.69	0.70	0.71	0.56	0.38	0.42	0.39	0.43	0.44
T_3	0.70	0.71	0.62	0.65	0.65	0.67	0.73	0.75	0.73	0.69	0.68	0.71	0.61	0.70	0.66	0.68	0.58	0.65
T_4	0.69	0.72	0.72	0.67	0.67	0.69	0.73	0.74	0.75	0.74	0.73	0.74	0.61	0.66	0.57	0.57	0.60	0.60
T_5	0.49	0.67	0.49	0.51	0.50	0.53	0.67	0.74	0.63	0.66	0.62	0.66	0.58	0.52	0.54	0.62	0.58	0.57
Mean	0.61	0.67	0.59	0.61	0.60		0.70	0.73	0.67	0.69	0.68		0.57	0.55	0.53	0.56	0.54	
		S.E±		C.D. (P=0.01)				S.E±		C.D. (P=0.01)				S.E±		C.D. (P=0.01)		
A		0.008		0.031				0.006		0.022				0.008		0.029		
B		0.008		0.031				0.006		0.022				0.008		NS		
A x B		0.019		0.070				0.013		0.049				0.018		0.066		

T_1 = Ambient CO_2 (390 ppm)
T_2 = 390 ppm CO_2+ 2^0 C in temperature
A= Treatments
T_3 = Elevated CO_2 (550 ppm) with normal temperature
T_4 = 550 ppm CO_2+ 2^0 C in temperature
B=Genotypes
T_5 = Reference plot (open field)
NS=Non-significant

plants); and increase carbon assimilates for plant growth and development. Elevated CO_2 accelerates the photosynthetic rate, stimulates plant growth, and increases the carbon: nitrogen ratio of most plant species (Poorter *et al.*, 1997; Curtis and Wang, 1998 and Barbehenn *et al.*, 2004). Likewise, results of the study on spring wheat (*Triticum aestivum* L.) revealed that the host plants grown at e-CO_2 (550 and 700 ppm) generally had greater starch, sucrose, glucose, total non-structural carbohydrates (TNCs), free amino acids, soluble protein and less fructose and nitrogen as reported by Chen *et al*. (2004). Whereas, under elevated temperature conditions photosynthetic rate was low mainly because plant could not maintain appropriate metabolism to keep normal development like photosynthesis, nutrient uptake, photorespiration, cell development, and so on and also higher temperature disrupts the movement of water, ion and organic solute across plant membranes, which interferes with photosynthesis and respiration (Christiansen, 1978). This was supported by number of authors (Berry and Bjorkman, 1980).

Assimilation rate significantly increased in all the genotypes when CO_2 was increased such increase in assimilation rates was due to increase in intercellular CO_2 concentration, which clearly suggests that the chloroplast is substrate limited. Considerable amount of information is available to suggest that the assimilation rate increases substantially when the plants were exposed to increasing CO_2 concentration. Among the treatments a-CO_{2+} e – temp treatment had recorded maximum transpiration rate and stomatal conductance followed by e-CO_{2+} e –temp, a- CO_2, reference plot, and least transpiration rate and stomatal conductance was noticed e- CO_2 treatment. Among the genotypes NK 6240, HTMR-1 and 900M-GOLD genotype recorded maximum transpiration rate and stomatal conductance whereas the genotypes HTMR-2 and ARJUN had the least transpiration rate and stomatal conductance. Under elevated CO_2 condition transpiration rate and stomatal conductance was lowered mainly due to decrease in the water vapour pressure of the air inside the plant stand (Kocsis, 2007) and due to stomatal closure, and abundant carbon-dioxide concentration raised the intensity of photosynthesis. Elevated CO_2 reduce transpiration by partially closing the stomata and decreasing stomatal conductance. Similar results were obtained by Leakey *et al.* (2004) and found

Table 2 : Effect of elevated CO_2 and temperature regimes on transpiration rate (m mol of $H_2Om^{-2}s^{-1}$)

Treatments	Transpiration rate(m mol of $H_2Om^{-2}s^{-1}$)																	
	30 DAS						60 DAS						90 DAS					
	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean
T_1	1.48	1.28	0.98	1.52	1.63	1.38	2.06	1.99	1.95	2.43	1.99	2.08	2.88	2.57	2.52	2.94	3.02	2.79
T_2	2.13	1.92	2.15	1.65	2.55	2.08	2.54	2.59	2.31	2.40	3.11	2.59	3.12	3.23	2.82	3.02	3.67	3.17
T_3	1.27	1.00	0.57	1.03	1.25	1.02	2.04	1.74	1.48	1.78	2.00	1.81	2.60	2.28	2.10	2.31	2.69	2.40
T_4	1.71	0.96	1.02	1.91	1.99	1.52	2.16	1.88	1.85	2.53	2.52	2.19	2.72	2.66	2.32	2.71	2.65	2.61
T_5	1.33	1.04	0.64	1.49	1.60	1.22	2.28	1.90	1.43	2.11	2.60	2.06	2.63	2.51	2.10	2.70	2.70	2.53
Mean	1.58	1.24	1.07	1.52	1.81		2.22	2.02	1.80	2.25	2.44		2.79	2.65	2.37	2.74	2.95	
		S.E.±		C.D. (P=0.01)				S.E.±		C.D. (P=0.01)				S.E.±		C.D. (P=0.01)		
A		0.059		0.222				0.023		0.085				0.012		0.046		
B		0.059		0.222				0.023		0.085				0.012		0.046		
A x B		0.133		0.496				0.051		0.190				0.028		0.103		

T_1 = Ambient CO_2 (390 ppm)
T_2 = 390 ppm CO_2+ 2^0 C in temperature
A= Treatments
T_3 = Elevated CO_2 (550 ppm) with normal temperature
T_4 = 550 ppm CO_2+ 2^0 C in temperature
B=Genotypes
T_5 = Reference plot (open field)

Table 3 : Effect of elevated CO_2 and temperature regimes on stomatal conductance (mmol $CO_2m^{-2}s^{-1}$)

Treatments	Stomatal conductance (µmol $CO_2m^{-2}s^{-1}$)																	
	30 DAS						60 DAS						90 DAS					
	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean
T_1	0.299	0.276	0.287	0.279	0.295	0.287	0.393	0.364	0.383	0.368	0.387	0.379	0.195	0.186	0.186	0.194	0.190	0.190
T_2	0.253	0.251	0.240	0.247	0.254	0.249	0.338	0.348	0.335	0.325	0.346	0.338	0.142	0.148	0.137	0.155	0.158	0.148
T_3	0.251	0.242	0.231	0.242	0.248	0.243	0.347	0.342	0.329	0.335	0.372	0.345	0.140	0.131	0.129	0.148	0.166	0.143
T_4	0.263	0.251	0.250	0.249	0.270	0.257	0.344	0.334	0.341	0.333	0.344	0.339	0.142	0.137	0.144	0.137	0.156	0.143
T_5	0.420	0.360	0.384	0.354	0.342	0.372	0.439	0.435	0.438	0.435	0.405	0.430	0.239	0.213	0.206	0.205	0.206	0.214
Mean	0.297	0.276	0.278	0.274	0.286		0.372	0.364	0.365	0.359	0.370		0.171	0.163	0.160	0.167	0.175	
		S.E.±		C.D. (P=0.01)				S.E.±		C.D. (P=0.01)				S.E.±		C.D. (P=0.01)		
A		0.003		0.011				0.004		0.016				0.004		0.013		
B		0.003		0.011				0.004		NS				0.004		NS		
A x B		0.007		0.026				0.010		NS				0.008		NS		

T_1 = Ambient CO_2 (390 ppm)
T_2 = 390 ppm CO_2+ 2^0 C in temperature
A= Treatments
T_3 = Elevated CO_2 (550 ppm) with normal temperature
T_4 = 550 ppm CO_2+ 2^0 C in temperature
B=Genotypes
T_5 = Reference plot (open field)
NS=Non-significant

Table 4 : Effect of elevated CO_2 and temperature regimes on photosynthetic rate ($\mu molCO_2 m^{-2} s^{-1}$)

Treatments	Photosynthetic rate ($\mu molCO_2 m^{-2} s^{-1}$)																	
	30 DAS						60 DAS						90 DAS					
	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean
T_1	29.79	29.25	28.38	28.25	29.90	29.11	43.39	41.93	38.44	39.79	41.64	41.04	22.21	23.10	21.46	23.44	23.39	22.72
T_2	30.13	29.30	24.41	23.60	27.93	27.07	41.08	40.61	39.14	38.15	41.34	40.06	20.38	20.21	18.10	19.35	21.14	19.83
T_3	35.13	34.06	33.54	31.91	33.73	33.67	50.78	52.36	48.88	47.95	50.51	50.10	27.70	27.23	25.23	24.33	26.50	26.20
T_4	33.66	33.81	32.43	32.69	34.71	33.46	49.15	47.00	46.08	46.03	50.46	47.74	25.96	25.31	24.48	24.18	24.88	24.96
T_5	30.06	29.04	25.98	26.38	28.33	27.96	42.43	41.26	39.64	42.86	42.93	41.82	22.89	22.55	21.01	20.13	22.49	21.81
Mean	31.75	31.09	29.75	29.57	31.32		45.36	44.83	42.83	43.34	45.38		23.83	23.68	22.66	22.28	23.68	
		S.E.±		C.D. (P=0.01)				S.E.±		C.D. (P=0.01)				S.E.±		C.D. (P=0.01)		
A		0.234		0.875				0.370		1.382				0.203		0.759		
B		0.234		0.875				0.370		1.382				0.203		0.759		
A x B		0.523		NS				0.827		NS				0.454		1.698		

T_1 = Ambient CO_2 (390 ppm); T_2 = 390 ppm CO_2+ 2^0 C in temperature; A= Treatments
T_3 = Elevated CO_2 (550 ppm) with normal temperature; T_4 = 550 ppm CO_2+ 2^0 C in temperature; B=Genotypes
T_5 = Reference plot (open field); NS=Non-significant

that growth at elevated CO_2 significantly increased leaf photosynthetic rate by upto 41 per cent and also stomatal conductance is lowered by 23 per cent under elevated CO_2 compared to ambient condition in maize. This was supported by no of authors (Stancial *et al*., 2000; Vu 2005 and Rogers *et al*., 2004).

There was significant differences were observed among the treatments, and genotypes but non-significant difference was observed in interaction effect with respect to cob length. The highest cob length was observed in HTMR-1 (16.00 cm) in e-CO_2 treatment, which was followed by HTMR-1 (15.63 cm) in e-CO_{2+} e –temp treatment, and HTMR-1(15.38cm). Among treatments, the lowest cob length was observed in 900M-GOLD and ARJUN (9.69 cm) genotype a-CO_{2+} e –temp treatment. Significant difference was observed among the treatments. But non-significant difference was observed among genotypes and interaction effect. The highest number of rows per cob was observed in HTMR-2 (15.13) in e-CO_2 treatment, which was followed by HTMR-1 (14.88) in e-CO_2 treatment, and NK 6240 (14.00) in a-CO_{2+} e –temp treatment. Among treatments, the lowestnumber of rows per cob were observed in NK 6240 (10.25) genotype in reference plot.Significant difference was observed among the treatments. But non-significant difference was observed among genotypes and interaction effect. The number of grains per cob was highest in HTMR-1 (484) genotype in e-CO_2 treatment, followed by HTMR-2 (463), 900M-GOLD (297) in same treatment. The least number of grains per cob was noticed in 900M-GOLD (147) genotype a-CO_{2+} e –temp treatment.

Significant difference was observed among the treatments. But non-significant difference was observed among genotypes and interaction effect. The lowest grain yield per plant was observed in 900M-GOLD (56.40 g) in a-CO_{2+} e –temp treatment. The highest grain yield per plant was observed in HTMR-1(163.00 g) in e-CO_2 treatment. Elevated CO_2 treatment alone recorded maximum grain yield per plant in all genotypes, followed by interaction effect e-CO_{2+} e –temp treatment in all genotypes. The increase in the growth rates and increase in photosynthetic rates resulted in increase in the yield. Maximum cob length, the highest no of rows per cob, highest number of seeds per cob and also grain yield per plant was highest in e-CO_2 treatment due to substantial increase in yield in elevated climate change treatments.

Table 5a : Effect of elevated CO_2 and temperature regimes on yield components

Treatments	Yield components											
	Cob length (cm)						No of rows per cob					
	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean
T_1	13.31	10.75	11.56	13.38	14.44	12.69	11.88	12.50	12.50	12.25	14.00	12.63
T_2	12.25	10.88	9.69	9.69	12.00	10.90	11.25	11.75	11.63	11.50	11.13	11.45
T_3	16.00	14.69	14.13	13.00	15.13	14.59	14.88	15.13	13.00	14.25	12.75	14.00
T_4	15.63	12.94	12.63	14.81	13.75	13.95	13.38	13.00	12.88	12.50	12.50	12.85
T_5	15.38	13.31	10.69	12.25	12.50	12.83	12.50	12.25	11.38	11.88	10.25	11.65
Mean	14.51	12.51	11.74	12.63	13.56		12.78	12.93	12.28	12.48	12.13	
		S.E.±		C.D. (P=0.01)				S.E.±		C.D. (P=0.01)		
A		0.349		1.303				0.378		1.412		
B		0.349		1.303				0.378		NS		
A x B		0.780		NS				0.844		NS		

T_1 = Ambient CO_2 (390 ppm) T_2 = 390 ppm CO_2+ 2^0 C in temperature A= Treatments
T_3 = Elevated CO_2 (550 ppm) with normal temperature T_4 = 550 ppm CO_2+ 2^0 C in temperature B=Genotypes
T_5 = Reference plot (open field) NS=Non-signficant

Table 5b : Effect of elevated CO_2 and temperature regimes on yield components

Treatments	Yield components											
	No of seeds per cob (number)						Grain yield per plant (g)					
	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean	HTMR-1	HTMR-2	ARJUN	900 M GOLD	NK 6240	Mean
T_1	296	312	304	312	283	301	97.26	92.99	91.56	92.69	85.35	91.97
T_2	172	154	167	147	190	166	64.56	59.63	63.13	56.40	64.71	61.68
T_3	484	463	409	412	417	437	163.00	154.00	139.50	139.63	139.88	147.20
T_4	388	391	343	347	341	362	127.75	127.75	116.20	118.65	117.33	121.54
T_5	260	242	230	267	242	248	86.38	80.88	76.95	82.44	72.96	79.92
Mean	320	312	290	297	294		107.79	103.05	97.47	97.96	96.05	
		S.E.±		C.D. (P=0.01)				S.E.±		C.D. (P=0.01)		
A		12.379		46.268				3.183		11.896		
B		12.379		NS				3.183		NS		
A x B		27.679		NS				7.117		NS		

T_1 = Ambient CO_2 (390 ppm) T_2 = 390 ppm CO_2+ 2^0 C in temperature A= Treatments
T_3 = Elevated CO_2 (550 ppm) with normal temperature T_4 = 550 ppm CO_2+ 2^0 C in temperature B=Genotypes
T_5 = Reference plot (open field) NS=Non-significant

Likewise, the combination of increasing CO_2 concentration and air temperature resulted in reduced grain yield and declining harvest index compared to increased CO_2 alone. (Moya *et al*., 1998). Similarly Mishra and Agrawal (2014) reported that in Mung bean crop under elevated CO_2 700 ppm increased total chlorophyll, photosynthetic rate, growth and yield parameters.Higher temperature decrease the plant biomass and yield by decreasing photosynthesis and increasing transpiration and stomatal conductance (Nobel, 2005). Also, plants mitigate overheating by leaf rolling and drooping and vertical leaf orientation (Larcher, 2003 and Nobel, 2005) or by transient wilting (Chiariello *et al*., 1987 and Nobel, 2005). Such adaptive mechanisms likely reduce leaf exposure to incident light and in turn, may lead to decreased photosynthesis.

Conclusion :

The exposure of the crop elevated CO_2 and temperature regime resulted in the significant decrease in the photosynthetic rates. The minimum reduction was observed in HTMR-1, HTMR-2 and NK 6240 and the maximum in ARJUN and 900M-GOLD. Among the genotypes NK 6240, HTMR-1 and 900 M-GOLD genotype recorded maximum transpiration rate and stomatal conductance whereas, the genotypes HTMR-

2 and ARJUN had least transpiration rate and stomatal conductance.The exposure of the crop to elevated CO_2 and temperature regime resulted in significant increase in leaf temperature in HTMR-2, 900M-GOLD and HTMR-1 and least leaf temperature was noticed in ARJUN and NK 6240 genotype. Among five maize genotypes studied the good response to NDVI was observed in HTMR-2, HTMR-1 and 900M-GOLD whereas, poor response to NDVI was observed in ARJUN and NK 6240 genotypes.

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