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Root Phenology and Biochemical Changes in Rice Genotypes under Drought Stress

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A B S T R A C T

The Present study was carried out in the wire-netting house of the Krishi Vigyan Kendra, Kalahandi during Rabi 2014-15.The objective of the present endeavour was to screen 6 number of Paddy varieties (early group,75-85 days) for higher photosynthetic efficiency with higher productivity under simulated moisture stress conditions. The experiment was laid out in a factorial CRD with three stress treatments and three replications. The study revealed that moisture stress imposed root density in all the varieties. However, the variation among them has found to be statistically significant. Varieties like Kalinga-III (V3) (V4), Rudra (V5), Sankar, and Heera (V1) were found superior to other varieties, on the basis of their relative performance under stress prone environments. The study also evinced that moisture stress is highly detrimental to most of the physio-biochemical components investigated in the current search. Owing to imposition of stress the basic physiological process measured in terms of photosynthesis (Pn) significantly reduced. So also other parameters like stomatal conductance (Gs), transpiration rate (E) got affected, but the stress effect was almost negligible on photosynthetic active radiation (PAR).

Introduction

Rice, a seed of grass species (*Oryza sativa*, Asian rice) or (*Oryza glaberrima*, African rice) is a monocot and normally grown in the tropical environment. It can also survive as a perennial crop. It is grown worldwide in varied ecosystems ranging from flood to drought condition (Sheehy *et al.*, 2001) and consumed by 60 percent of the world population. It is the agricultural community with the third worldwide production after sugarcane and maize (FAOSTAT, 2012; Khush and Virk, 2000). It meets about 22 and 17 percent of the total calories and protein requirement respectively. Rice is one of the world's important staple food crop, not only provides food but also influences religions, cultures and life styles since vedic period. According to the food and agricultural organization (FAO, 2009-10) rice is cultivated over an area of 161.80 million hectares with the production of 678 million tons in the world with the average productivity of 4.3 tons per ha. About 45 % of the rice area is under rain fed condition which is mainly distributed in south and south-east Asia but contributes only 25 % of the total rice production. As per the statistics published by International rice research institute (IRRI)

estimated that 11 % of rice area in developing countries is under flood prone environment. With the advent of new technologies along with adoption of high yielding rice varieties coupled with improved agricultural management the rice production has been increased in last three decades enabling to reduce the chronic deficiency and excessive dependence of the imported food grains to period of self-sufficiency and surplus (Siddiq, 1997). Considering the population growth in India (2.72 percent / annum) our rice requirement ought to be increased to 25-30 million tons of milled rice in every decade. The pressure is likely to be accumulated in future and to achieve the targeted yield under reduced cultivable area, limitation of irrigation water and declined input efficiency and more over changing climate in all the major rice based cropping systems. This is a challenging task for our rice scientist to reduce the gap between the population growth rate and food production demand in forthcoming years. Rice production in India has increased during last 6 years by about 3.5 tons from 250.3 lakh tons during first five year plan period to 857.3 lakh tons during the tenth plan period. The average productivity of rice in India is 2.2 tons/ha which is far below than the global average of 2.7 tons/ha. India is expected to surpass the demand by the year 2030. Drought may be avoided by matching crop phenology with periods during the cropping season when water supply is abundant. This approach has been an effective tool for crops grown in monsoonal climates where they are sown at the beginning of wet season and mature before dry season (Purcell *et al.,* 2003). But the strategy often fails owing to the erratic monsoon during these days. Though attempts have been made by different scientists to study how the plants overcome the impact of stress (on growth and yield reduction) on account of drought or moisture deficit, there is lot to be understood as to the physiological and biochemical basis of drought tolerance in plants, rice in particular. This study has been taken up with the main objective to have a greater insight into this physiological and biochemical basis of drought tolerance in rice which would come in handy in designing the crop ideotypes for drought prone environments.

Materials and Methods

Pot culture experiment was conducted in Rabi 2004-15 in a wire net house of the Krishi Vigyan Kendra, Kalahandi in completely randomized design (CRD). Sowing of seeds was done in cement pots containing Mixture of soil and FYM (4:1). The holes of pots were partially closed to ensure proper drainage during watering the pots. The soil was treated with chloropyriphos dust before sowing to protect the seeds against the white ants. Plant protection measures and irrigation schedules were taken as and when required. The sowing was done on 1st January, 2009 in the cement pots at a rate of 10 seeds per pot. After two weeks of sowing only 5 healthy seedlings were allowed to grow thinning the rest. Well decomposed farm yard manure and recommended doses of chemical fertilizers were applied to experimental pots. The various intercultural operations leading to loosening of soil, weeding and thinning were done 15 days after sowing of the crop followed by second weeding. Seeds were treated with Thiram at the rate of 3 gm/kg of seed before sowing in order to protect the crop from seed borne diseases. Recommended pesticides were applied as and when required.

Water stress level

No water stress (control) N_S

Stress (with holding irrigation at flowering stage) S_1

Stress at flowering S_2

Control pots were irrigated regularly maintaining soil moisture at field capacity throughout the cropping period.

S1: Water stress at tillering stage (Irrigation was withheld till the temporary wilting of the plants).

S2: Water stress at flowering stage (Irrigation was withheld at flowering stage to the same replication till the temporary wilting of the plants).

Morphological studies

Five hills were uprooted from each treatment at different growth stages and the following observations were recorded, computed and presented in tabulated form.

Root phenology (Root volume)

Roots were carefully extracted by uprooting the hills and washed thoroughly, cleaned by soft washing. The root volume was measured by water displacement technique in measuring cylinder.

Root density

The respective dry weights of the root samples were taken and the root (mass) density was calculated from the root volume according to the following formula.

$$\text{Root Density} = \frac{\text{Root dry weight}}{\text{Root volume}}$$

Portable Photosynthesis System (PP System)

A portable photosynthesis system (CIRAS-2) of version 2.02 is used in the experiment to take some critical observation on leaf parameters including stress to potted plants and also the following observations are taken by using the P.P. system and recorded in tables.

Biochemical studies

Different biochemical studies were taken up during the crop growth period as well as after the crop were harvested.

Chlorophyll fractions

The chlorophyll-a, chlorophyll-b and total chlorophyll content in the leaves were determined by using the method stated by Arnon (1949). The second leaf from the top was sampled for the purpose. The leaf samples were immediately kept in moist polythene bags to keep them turgid. 100 grams of fresh leaf was taken from the middle portion of the leaf and were cut into small pieces. The leaf discs were then put in 80 % v/v acetone solution and kept in dark for 24 hours. Then they were filtered by Whatman No.1 filter paper and the filterate was used to record the absorbance (OD) at 645 nm and 663 nm. The respective chlorophyll content was calculated using the following formulae and expressed as mg g – 1 FW leaf.

$$\text{Chlorophyll–a} = (12.7 \times OD663 - 2.69 \times OD645) \times \frac{V}{1000 \times W_F}$$

$$\text{Chlorophyll–b} = (22.9 \times OD645 - 4.68 \times OD663) \times \frac{V}{1000 \times W_F}$$

$$\text{Total Chlorophyll} = (20.2 \times OD645 + 8.02 \times OD663) \times \frac{V}{1000 \times W_F}$$

Where,

OD645 = OD value at 645 nm

OD663 = OD value at 663 nm
V = Volume of the extract
WF = Fresh weight of leaf in gram

Chlorophyll stability index (%)

Chlorophyll Stability Index (CSI) was calculated by taking leaf samples of control as untreated and those imposed with drought stress as treated and using the formula given below (Kar *et al.,* 2005).

$$CSI\ (\%) = \frac{\text{Total chlorophyll l content (stress)}}{\textit{Total chlorophyll l content (non - stress)}} \times 100$$

Total nitrogen

Total nitrogen content of different plant parts viz. stem, leaf and root, were determined following the procedure of AOAC (1970) and Yosida *et al.,* (1976). 200 mg of powdered dry plant samples were taken in digestion tubes and 4ml of concentrated sulphuric acid were added to each. The digestion tubes were kept as such for an hour and then put in digestion chamber for digestion. The digestion unit was heated slowly till frothing occurred. Two beads of sodium thiosulphate were added to each tube to check frothing. Digestion was continued till the contents tuned into clear blue syrupy liquid without any bubbling. Then 10ml of distilled water was added after cooling the tubes. The contents were then diluted to 25 ml with distilled water. The digested plant samples were analysed by micro-Kjeldahl distillation apparatus. Ten ml of digested sample was put into the micro-Kjeldahl flask followed by 10 ml of 40 % (w/w) NaOH. Simultaneously, a flask containing 10 ml of 4% boric acid and 2-3 drops of mixed indicator was kept under the condenser to absorb the ammonia gas liberated during the course of distillation and the distillation continued for 10 minutes. After completion of the distillation process the distillate were titrated against 0.02 N HCl.

The nitrogen content was calculated using the following formula.

$$\%\ N = \frac{(ST - BT) \times \text{Normality of HCl} \times 14 \times 100 \times DF}{\textit{Sample weight}\ (g) \times 1000}$$

Where,

ST = Sample titer value
BT = Blank titer value
DF = Dilution Factor (in this case 2.5)

Results and Discussion

The study entitled "Morphological and biochemical responses in rice genotypes under drought stress" was conducted in wire netting house of the Krishi Vigyan Kendra in the district of Kalahandi, Odisha. The various morpho-physiological and biochemical observations recorded during the ontogeny of rice crops were tabulated, analysed and presented in the following heads and subheads.

Physiological and biochemical traits

Photosynthesis (P_n)

Photosynthetic rate was measured as four different stages *viz.,* tillering P.I, flowering & harvesting (Table 5). In general, there was decrease in photosynthesis in all the varieties irrespective of stages due to imposition of water stress. Most decrease was recorded at flowering and least at PI stage. The varieties like Rudra(V_5), Sneha(V_2) and Kalinga-III(V_3) exhibited their excellence in most of the stages in respect of the character under stress as compared to other varieties. Varieties like Sneha(V_2), Rudra(V5) and Kalinga-III(V_3) had higher photosynthesis under non

stress failed to achieve the target under stress. The variation in photosynthetic effect at different stages followed the following trend.

Since long, It has been known drought injury is manifested both at zone of cell turgor and zone of cell flaccidity. This is chiefly attributed to stomatal closure, increased mesophyl résistance, decreased diffusion and Metabolic shift which concomitantly inhibit growth and development of plant leading to its productivity (Levitt, 1980). The close relation between leaf water potential and rate of photosynthesis has long been explained by the partial or complete stomatal closure.

Root phenology

In the present investigation the root density presented in Table 3 drastically reduced in all most all varieties due to stress at both tillering and flowering stages. Varieties namely Sankar (V_6), Heera (V_1), Subhadra (V_4) at tillering and Heera (V_1), Subhadra (V4) and Rudra (V_5) at flowering registered minimum reduction of root mass when subject to water stress, while Kalinga-III (V_3), Sneha (V_2) and Sankar (V_6) suffered a great deal under the adverse conditions. Analysing the overall mean values water stress resulted in decreasing root density at tillering and flowering stages by a margin of 36 and 42 % respectively. Present study is in consonance with the research findings of (Zhao *et al.*, 2001, Sadasivam *et al.*, 2000).

Stomatal conductance (Gs)

The value pertaining to stomatal conductance was presented in Table 6. The large variation was observed among the varieties in respect of their characters under non-stress and stress condition in all the stages studied. The tabulated values made to implicate Heera (V_1), Rudra (V_5) and Subhadra (V_4) varieties maintained higher stomatal conductance at different stages under adverse condition. The lowest stomatal conductance (G_S) was obtained in Sankar (V_6) at tillering and PI stage, whereas Subhadra (V_4) and Heera (V_1) at flowering and Sankar (V_6) at harvesting stages. The overall mean values indicated that stress imposed at flowering (24%) stage resulted in maximum decrease of Gs followed by PI (25%), tillering (51%) and harvesting (76%). The decrease in stomatal conductance (G_S) are increase in stomatal resistance is chiefly attributed to drought injury caused at zone of cell turgor (Levitt, 1980). The varieties having higher GS are supposed to maintain higher photosynthetic trite as compared to other varieties.

Photosynthetic active radiation (PAR)

Photosynthetic active radiation (PAR) in response to water stress was recorded at different growth stages in all the varieties presented in Table 6. No variability was obtained in respect of this characters neither among the varieties nor any of the growth stage studied in the present investigation. Moreover, no supporting evidence was encountered from the various literatures available in this regard.

Chlorophyll content and chlorophyll stability index (CSI)

The chlorophyll content & CSI index in general decrease in response to moisture stress in all the varieties both at tillering and flowering stage (Table 4). The decrease in chlorophyll content in response to stress was to the tune of 30-40%. The overall mean values implied that water stress decreased the chlorophyll content by a margin of 40% and 47% at tillering and flowering respectively. Varieties like Subhadra (V_4), Rudra (V_5) and Sankar (V_6) maintain high CSI whereas variety Kalinga-III(V_3) had the lowest value at tillering and at flowering followed by

Subhadra (V_4), Rudra (V_5) and Sankar (V_6) at tillering and flowering respectively. The mean values indicated that the values of CSI at tillering 60%, at flowering 54%. Yamane *et al.,* (2003) and Das *et al.,* (2005) revealed similar reduction in chlorophyll content in rice genotypes which is in agreement with the present finding. In respect of CSI Agarie *et al.,* (1995) reported decrease in CSI with imposition of moisture stress in rice genotypes by a margin of 12 %. However in the present finding the decrease in CSI was to the tune at 50% to 60% might be due to variation in macro and micro environments.

Table.1 Details of varieties used

Symbol	Varieties
V_1	**Heera(V1)**
V_2	**Sneha(V2)**
V_3	**Kalinga-III(V3)(V4)**
V_4	**Subhadra(V4)**
V_5	**Rudra(V5)**
V_6	**Sankar**

Table.2 Photosynthetic and ancilliary parameters

Sl.No.	Name of the parameter	Notation	Unit
1	Reference carbon dioxide	CO2R	Ppm
2	Photosynthetic active radiation	PAR	M mol m2 S-1
3	Reference humidity	MBR	Millibar
4	Cuvette Air temperature	TC	0oC
5	Transpiration Rate/Evaporation	E	M mol m2S-1
6	Stomatal conductance	Gs	M mol m2S-1
7	Photosynthesis Rate	Pn	M mol m2S-1
8	Internal CO_2 concentration	CI	ppm

Table.3 Effect of drought stress on root density (g cc^{-1}) of paddy

Varieties	Tillering			Flowering		
	Non stress	Stress	Mean	Non stress	Stress	Mean
V1	0.446	0.362	0.404	0.502	0.494	0.581
V2	0.863	0.577	0.720	0.977	0.839	0.908
V3	0.554	0.189	0.372	0.751	0.964	0.858
V4	0.667	0.498	0.583	0.701	0.659	0.680
V5	0.454	0.137	0.295	0.884	0.856	0.870
V6	0.558	0.500	0.529	0.685	0.557	0.621
Mean	0.590	0.377		0.750	0.728	
	V	**S**	**V x S**	**V**	**S**	**V x S**
Sem	0.002	0.001	0.003	0.209	0.117	0.296
CD 5%	0.007	0.004	0.010	0.651	0.365	0.921

Table.4 Effect of drought stress on chlorophyll content and transpiration rate of paddy

	CSI		Chlorophyll content (mg g^{-1} FW leaf)						Transpiration rate (µ mol m^2 S^{-1})											
			Tillering stage			PI Stage			Tillering			PI			Flowering			Harvesting		
Varieties	Tillering	Flowering	NS	Stress	Mean	NS	Stress	Mean	NS	Stress	Mean	NS	Stress	Mean	NS	Stress	Mean	NS	Stress	Mean
V1	58.28	37.74	2.76	1.60	2.18	2.26	0.85	1.56	3.56	3.45	3.51	2.16	1.67	1.91	1.95	0.88	1.42	6.64	1.11	3.88
V2	54.49	48.95	2.86	1.56	2.21	2.07	1.01	1.54	3.24	2.24	2.74	2.33	1.86	2.10	2.06	1.94	2.00	3.12	0.98	2.05
V3	51.26	46.24	2.93	1.50	2.22	2.40	1.11	1.76	4.40	3.01	3.71	2.73	2.08	2.41	1.81	1.77	1.79	3.41	0.76	2.08
V4	69.74	71.10	2.05	1.43	1.74	1.52	1.08	1.30	2.64	2.53	2.59	2.41	1.92	2.17	2.67	1.85	2.26	2.01	1.19	1.60
V5	66.20	64.61	2.09	1.38	1.74	1.61	1.04	1.33	4.12	3.47	3.80	2.93	1.95	2.44	2.35	2.18	2.27	0.72	1.80	1.26
V6	62.46	59.92	2.13	1.33	1.73	1.69	1.01	1.35	6.31	1.14	3.73	2.83	1.76	2.30	2.27	2.17	2.22	2.08	0.98	1.53
Mean	60.41	54.76	2.471	1.47		1.93	1.02		4.05	2.64		2.57	1.87		2.19	1.80		3.00	1.14	
	V	V	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S
Sem	0.824	1.146	0.026	0.015	0.036	0.024	0.014	0.034	0.073	0.042	0.103	0.023	0.013	0.032	0.019	0.011	0.026	0.021	0.012	0.029
CD 5%	2.565	3.566	0.080	0.046	0.113	0.075	0.043	0.106	0.226	0.131	0.320	0.071	0.041	0.100	0.058	0.033	0.082	0.065	0.037	0.091

Table.5 Effect of drought stress on photosynthetic rate and root density of paddy

	photosynthetic rate (Pn) µ mol m^2 S^{-1}												**Root Density (g cc^{-1})**					
	Tillering			PI			Flowering			Harvesting			Tillering			PI		
Varieties	NS	S	M	NS	S	M	NS	S	M	NS	S	M	NS	S	M	NS	S	M
V1	3.0	2.16	2.58	18.8	2.28	10.54	2.38	1.87	2.13	26.91	5.31	16.11	0.446	0.362	0.404	0.502	0.494	0.581
V2	31.3	5.42	18.37	34.6	8.72	21.70	2.32	1.00	1.66	12.66	3.18	7.92	0.863	0.577	0.720	0.977	0.839	0.908
V3	19.6	4.47	12.04	17.6	5.87	11.75	1.76	0.37	1.07	11.33	3.37	7.35	0.554	0.189	0.372	0.751	0.964	0.858
V4	3.08	0.63	1.85	8.87	5.91	7.39	7.63	3.30	5.47	8.08	2.27	5.18	0.667	0.498	0.583	0.701	0.659	0.680
V5	16.7	3.21	9.96	18.8	11.3	15.12	8.39	4.03	6.21	4.43	2.05	3.24	0.454	0.137	0.295	0.884	0.856	0.870
V6	11.2	2.02	6.65	11.5	3.71	7.61	3.89	1.38	2.64	6.15	1.73	3.94	0.558	0.500	0.529	0.685	0.557	0.621
Mean	14.1	2.99		18.3	6.31		4.40	1.99		11.60	2.99		0.590	0.377		0.750	0.728	
	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S
Sem	7.034	4.061	9.947	0.022	0.013	0.032	0.338	0.195	0.478	0.047	0.027	0.066	0.002	0.001	0.003	0.209	0.117	0.296
CD 5%	21.891	12.639	30.958	0.070	0.040	0.099	1.052	0.607	1.487	0.145	0.084	0.205	0.007	0.004	0.010	0.651	0.365	0.921

Table.6 Effect of drought stress on stomatal conductance and photosynthetic active radiation of paddy

	Stomatal conductance (Gs) (µ mol m^2 S^{-1})												Photosynthetic active radiation (PAR) (m mol m^2S^{-1})											
	Tillering			PI			Flowering			Harvesting			Tillering			PI			Flowering			Harvesting		
Varieties	**NS**	**S**	**M**	**NS**	**S**	**M**	**NS**	**S**	**M**	**NS**	**S**	**M**	**NS**	**S**	**M**	**NS**	**S**	**M**	**NS**	**S**	**M**	**NS**	**S**	**M**
V1	117.40	77.93	97.66	44.04	42.13	43.09	36.55	17.91	27.23	55.96	10.15	33.06	10	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
V2	55.27	44.81	50.04	50.87	32.70	41.79	40.76	36.32	38.54	64.77	6.95	35.86	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
V3	132.25	62.17	97.21	52.00	42.13	47.07	35.85	32.43	34.14	21.36	15.42	18.39	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
V4	78.68	50.00	64.34	65.56	32.49	49.03	50.55	33.95	42.25	37.52	8.08	22.80	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
V5	122.86	73.37	98.11	60.15	55.98	58.07	56.66	40.64	48.65	44.54	20.18	32.36	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
V6	177.07	23.46	100.27	52.64	38.42	45.53	44.35	39.45	41.90	60.95	6.39	33.67	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Mean	113.91	55.29		54.21	40.643		44.12	33.45		47.51	11.19		10.0	10.0		10.0	10.0		10.0	10.0		10.0	10.0	
	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S	V	S	V x S
Sem	4.365	2.520	6.173	4.932	2.848	6.975	4.391	2.535	6.21	2.241	1.29	3.16	0	0	0	0	0	0	0	0	0	0	0	0
CD 5%	13.58	7.84	19.21	15.35	8.862	21.708	13.66	7.890	19.32	6.97	4.02	9.86	0	0	0	0	0	0	0	0	0	0	0	0

Table.7 Effect of drought stress on yield and nitrogen content of paddy

	Yield q ha^{-1}			Nitrogen content (% dry weight)					
				Tillering			Flowering		
Varieties	NS	S	DI	NS	S	M	NS	S	M
V1	39.80	31.31	0.78	2.363	1.830	2.097	1.753	1.573	1.30
V2	38.20	28.85	0.75	1.753	1.663	1.708	1.487	1.400	1.35
V3	43.93	37.07	0.84	1.660	1.480	1.570	1.130	0.962	1.48
V4	45.54	35.40	1.28	2.107	1.570	1.838	1.660	1.303	1.50
V5	38.58	32.05	0.83	1.920	1.660	1.790	1.570	1.483	1.36
V6	47.83	38.80	1.23	1.830	1.573	1.702	1.570	1.400	1.63
Mean				1.939	1.629		1.528	1.354	
				V	S	V x S	V	S	V x S
Sem				0.050	0.029	0.071	0.080	0.046	0.113
CD 5%				0.155	0.090	0.219	0.249	0.144	0.353

Physiological and biochemical traits

Tillring		PI		Flowering		Harvesting	
NS	S	NS	S	NS	S	NS	S
14.16 (100)	2.99 (21)	18.39 (100)	6.31 (34)	4.40 (100)	1.99 (45)	11.60 (100)	2.99 (25)

Transpiration rate (E)

Tillring		PI		Flowering		Harvesting	
NS	S	NS	S	NS	S	NS	S
6.31-2.64	3.45-1.14	2.93-2.16	2.08-1.67	2.67-1.81	2.18-0.88	6.64-0.72	1.80-0.76

Among the stages a sharp decline was noticed in respect of transpiration rate (E %). At harvesting stage in response to stresses.

Stages	**Non-stress**	**Stress**	**Reduction**
Tillering	100	65	35%
P.I	100	73	27%
Flowering	100	82	18%
Harvesting	100	38	62%

Transpiration rate (E)

In general transpiration rate is directly proportional to the vapour pressure deficit (VPD) and inversely to the leaf diffusion resistance. Within the zone of leaf turgor diffusion resistance is directly related to stomatal closure, however, when the soil dried changes in water vapour conductance of the stomata were linearly related to the changes in soil water potential from -0.1 to -2.0 mega pascal. In the present investigation all the rice varieties closed their stomata irrespective of growth stage as was evident from the decrease in transpiration rate (E) under stress (Table 4). Close analysis of the data revealed the transpiration rate which maintained the following trend.

Stomatal closure which causes decreased in transpiration rate has been attributed to either hormonal control or hydro passive control. Weather due to hormonal or to a hydro passive the role of stomatal control in water stress avoidance is highly complicated (Hall *et al.*, 1976).

Yield

Keeping the above facts in mind the grain yield was computed and presented in Table 7. It was noticed that the significant variation existed among the varieties under favourable conditions (non-stress). Which might be due to relative difference in their genetic potential; when all these varieties were subjected to moisture stress condition the grain yield reduced significantly. However, the magnitude of reduction among the varieties was different. Varieties like Rudra, Kalinga-III, and Heera suffered least; while the varieties like Subhadra, Sankar and Sneha suffered most due to adverse stress condition. In general, there was about 42 % reduction in yield (per plant basis) and Similarly, expression of yield loss on unit area basis (kg/ha) the same was found to be 19 % at flowering. The reduction in grain yield was due to stress attributed to reduction in panicle length, panicle weight and weight of the grain. Hence the above mentioned yield attributing character should primarily be taken as selection criteria for drought tolerance of rice cultivars. More over selection for drought tolerance by any

selection index require a rigorous control over the stress environment and needs to address moisture stress in terms of growth stage and stress intensity along with temperature gradient and radiation. Explicitly speaking drought tolerance is an interactive result of different morphological, physiological, biochemical and molecular traits and thus these different components could be used as selection of criteria for screening appropriate plant type. Further a combination of different traits of direct relevance, rather than a single trait, should be used as screening criteria (Johnson, 1980).

Nitrogen content

The impact of water stress was investigated on nitrogen assimilation, the lone nutrient, in all the varieties both at tillering and flowering stages (Table 7). Recorded data revealed that there is no definite trend so far as the Nitrogen content of the plant tissue was concerned. However, in some varieties the content decreased while it was maintained in many varieties. Although statistical difference was noticed among all the varieties the variation was found to be subtle. The maximum and the minimum values at tillering stage were (2.36%) (Heera) and 1.66% (Subhadra) under non-stress and 1.83 (Heera) and 1.48% (Kalinga-III) in stress. On the other hand at flowering stage the values were in an order of 1.75 and 1.13 and 1.57 and 0.96% at non stress and stress respectively. The decrease in Nitrogen content at tillering was 16 % and at flowering it was 11 %. Available literature suggests that nitrogen acquisition is significantly affected under various environmental causes i.e. water drought in particular. The Reason being the principal enzyme nitrate reductase (N_R) is highly susceptible to dehydration stress. More over the decreased soil water potential might be another cause of nutrient acquisition due to lower uptake of a particular nutrient. In this regard, many authors explicitly opine that Nitrogen absorption; translocation and assimilation are severely affected leading to an accumulation of Nitrogenous compound NO^{-3}, NO^{-2} and NH_3 (Hwang *et al.*, 1989; Baruah *et al.*, 1988). From the present finding the stress impact was found to be more at tillering than that of flowering stage.

In general there was decrease in photosynthesis (P_n) in all the varieties irrespective of stages due to imposition of water stress, most decrease was recorded at tillering and least at PI stage. Varieties like Rudra (V_5), Sneha (V_2) and Kalinga-III (V_3) exhibited higher photosynthesis in most of the stages in respect of the character under stress as compared to other varieties. The variety like Sneha (V_2) had higher photosynthesis under non-stress failed to achieve the target under stress. The varieties namely Heera (V_1), Rudra (V_5) and Subhadra (V_4) maintained higher stomatal conductance at different growth stages under adverse condition, the lowest in Sankar (V_6) and Subhadra (V_4) at tillering and PI whereas Heera (V_1) and Sankar (V_6) both at flowering and harvesting stage respectively. Comparison of photosynthetic active radiation (PAR) among different varieties indicated that no variability was obtained in respect of the characters neither among the varieties nor any of the growth stages studied in the present investigation. Among the stages a sharp decline was noticed in respect of transpiration rate at harvesting stage (62 %) in response to stress. The transpiration rate in other stages were in tillering (35 %), PI (27 %) and in flowering (18 %) under stress condition. The chlorophyll content and the CSI in general decreased in response to moisture stress in all the varieties at both the stages and the decrease in chlorophyll content in response to stress was to the tune of 30 - 40 %. Varieties like Subhadra (V_4), Rudra (V_5) and Sankar (V_6) maintain high CSI whereas variety Kalinga-III (V_3) had the lowest value at tillering and at flowering followed by Subhadra (V_4), Rudra (V_5) and Sankar (V_6) at tillering and flowering

respectively. Irrespective of the varieties, there is no definite trend so far as the nitrogen content of the plant tissue was maintained. The maximum and the minimum values at tillering stage were (2.36%) (Heera) and 1.66% (Subhadra) under non-stress and 1.83 (Heera) and 1.48% (Kalinga-III) in stress. On the other hand at flowering stage the values were in an order of 1.75 and 1.13 and 1.57 and 0.96% at non stress and stress respectively. The decrease in Nitrogen content at tillering was 16 % and at flowering it was 11 %.

As regards, yield the varieties like Rudra, Kalinga-III and Sneha suffered least while the varieties like Subhadra, Sankar and Sneha suffered most due to adverse stress condition. In general, there was about 42 % g plant^{-1} reduction in yield was obtained, when subjected to stress. Similarly the yield loss on unit area basis (kg/ha) was found to be 19 % at flowering.

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