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Study of genotype x environment interactions and genotypic adaptation for Physiological, Biochemical and Agro-morphological characters under Drought condition in Upland Rice (*Oryza sativa* L.)

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ABSTRACT: *The genotype x environment interactions played very important role in the expression of all the characters except plant height. The linear component G x E interaction assumed significance in case of all the characters except plant height. The non-linear component of G x E interaction assumed significance for all the characters except plant height, SOD at 3 days and soluble sugar at flowering. The lines identified as widely adapted lines having high mean performance, average or above linear response and stability were TN-1, DGI-138, Vandana, DGI-379 for tall stature; P-0090, NDR-97, DGI-21, DGI-75 and Saita for short stature, DSU-18-6, P-0088 and P-0397 for relative water content; TN-1, NDR-359, DGI-138 and DGI-21 for root length and P-0088 and P-0326 for root dry weight. In case of biochemical traits, the widely adapted genotypes were Moroberekan and IR-64 for proline content; DGI-138 for SOD at 3 days and P-0090 for soluble sugar at flowering. While, NDR-97, Vandana, DGI-152, DGI-138, Moroberekan, DSU-18-6 and DGI-21 produced high yield and these lines found suitable to un-favourable environments.*

Key words: *G x E, physiological & biochemical character, drought & upland rice*

INTRODUCTION

Drought is a major limitation for rice production in rainfed ecosystems. Drought is estimated to account for rice crop losses of 1.7 million tonnes per year in eastern India (Pandey *et al.*, 2000). On average, the estimated yield lost to drought is 144 kg ha^{-1} annually (Dey and Upadhyaya, 1996). The ''green revolution'' in rice improvement has benefited many farmers in irrigated rice production but has had limited impact on rain-fed production (Evenson and Gollin, 2003). Average yields of rainfed upland rice are 1.1 t ha^{-1} but this varies according to soil type, fertilizer use, rainfall and agronomic practices. Farmers tend to grow short duration varieties in order to escape late-season drought, but only a limited range of varieties exist for these conditions and all have relatively low yields (De Datta, 1984; Virk *et al.*, 2003).

Developing rice plants resistant to drought is considered a promising approach to help satisfy the increasing demand for food in both developing and underdeveloped countries. Genotype-environment (GE) interactions are extremely important in the development and evaluation of plant varieties because they reduce the genotypic-stability values under diverse environments. Developing crop cultivars that perform well across a wide range of environmental conditions has long been a major challenge to plant breeder. In practice, genotype by environment interaction complicates the identification of superior genotypes (Allard and Bradshaw, 1964).

The poorest farmers grow upland rainfed rice and have benefited little from high yielding green revolution varieties most are limited to growing local low yielding varieties (Bourai *et al.*, 2003).

MATERIALS AND METHODS

The present investigation was carried out in wet season at the Instructional Farm of Department of

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Crop Physiology, N. D. University of Agriculture & Technology Kumarganj (Faizabad), U.P., India. The genotypes of upland rice from different geographical regions were screened for reproductive stage drought tolerance in two years. The genotypes were seeded and seedling establishment was done in dry beds and transplanting was done 21 days after seeding. Each genotype was transplanted in Randomized Block Design with three replications in a 5 m length row. Row spacing was 20 x 15 cm and one seedling per hill was used. Recommended agronomic practices were followed. Pesticides and bird nets were used to protect the plants against pests. All other crop management practices were at the optimum level.

Management of Water Stress

The experiments were conducted with well defined protocol for water management under natural field conditions during wet season in both the years.

Irrigated (NS): The experimental field was left uncovered to receive natural rainfall. In addition to this, experimental plots were irrigated using well laid channels for supplying tube well water, as and when required, to maintain appropriate moisture levels as recommended for irrigated rice.

Reproductive stage drought stress (RSS): The experiment field was covered by constructing temporary rainout shelter at a height of 10-12 feet using polythene sheets to exclude any possibility of natural rainfall falling in the experimental plots with proper drainage channel. Care was taken to check the inflow or seepage of water from the adjoining areas by making adequate bunds around the experiment and covered with polythene in drought condition. The heading stage drought was created by withholding the irrigation for 15 days up to 80 K Pa at 0-15 cm soil profile and 60 K Pa at 30 cm soil depth. Plants were exposed for two weeks (60-80 KPa.). Soil moisture content (SMC) during stress period was monitored through periodical soil sampling at 0-15, 15-30 cm soil depth. Drought was released by irrigation. Recovery was measured at 10^{th} days after released of drought. Genotypes were scored for leaf rolling and leaf drying at the peak stress period using the IRRI Standard Evaluation System (IRRI, 1996).

Observation and Evaluation

Observations were recorded on five competitive plants of the middle row of each plot for yield and biochemical traits. The biochemical traits estimated by protein content by Lowery *et al*. (1951), soluble sugar by Yemn and Willis (1954), proline content by Bates *et al*. (1973), superoxide dismutase activity (SOD) according to Asada *et al*. (1974). The data were analyzed by appropriate statistical analysis (Gomez and Gomez, 1984) using CropStat 7.2 (IRRI, 2009) programme. Pooled analyses of variance over four environments were estimated as per the models suggested by Eberhart and Russell (1966) to estimate the three stability parameters *viz*., mean, regression coefficient (bi) and mean squared deviation (S^2di) for each genotype.

RESULTS AND DISCUSSION

Study of G x E interaction was carried out following Eberhart and Russell (1966). The pooled analysis of variance in respect of different characters is set out in Table 1. The differences among the genotypes were highly significant for all the characters under study. The mean squares due to environments were also highly significant for all the characters. The differences, therefore, were present among the genotypes as well as environments. The G x E interaction component was highly significant for all the characters except plant height and test weight. The linear component of G x E interaction was also preponderant for all the characters except plant height. As for as non-linear component of G x E interaction was concerned, it assumed significance for all the characters except plant height.

Physio-morphological traits

Plant height ranged from 67.83 cm for Moroberekan to 103.83 cm for TN-1. The lines, TN-1 (103.83), DGI-138 (97.25), Vandana (94.92), DGI-379 (93.58)and P-0397 (93.50) were found to be statistically superior to general mean (83.33cm) for tall stature while, Moroberekan, P-0090, NDR-97, Saita DGI-75, DGI-21 were found to be significantly shorter in stature than general mean. Two entries, P-0080 and P-0397 possessed b>1 while remaining were entries characterized by b=1.The non-linear sensitivity coefficients of all the entries were equal to zero (Table 2). The taller genotypes, TN-1 DGI-138, Vandana, DGI379 had b=1 and s^2di=0. Similarly, the shorter genotypes, namely, Moroberekan, P-0090, NDR-97, DGI-21, DGI-75 and Saita were also characterized by b=1 and S^2di=0.

The relative water content (RWC) varied from 65.44% (DGI-21) to 80.58% (DSU-18-6), with a general mean of 73.28%. DSU-18-6 (80.58), Azucena (78.50), P-0397 (77.40) and TN-1 (76.38) were significantly superior in RWC than the general mean whereas, DGI-21, DGI-138, DGI-152 and Saita had below average RWC. The linear sensitivity coefficients of DSU-18-6, IR-64, Azucena, P-0088 and P-0397 were greater than unity while, NDR-97, NDR-359, DGI-152 and Vandana showed b<1. The other entries were characterized by b=1.The non-linear sensitivity coefficients of IR-64, Azucena, T.N-1 and DGI-75 were greater than Zero while, remaining fourteen lines emerged with s^2di=0. DSU-18-6, P-0088 and P-0397 showed high mean performance for RWC along with b>1 and S^2di=0. IR-64 and Azucena had high mean performance with b>1 and S^2di=0.

The root length ranged from 36.22 cm in P-0090 to 90.45 cm in P-0326 with a general mean (49.83 cm), P-0326 (90.45) followed by DGI-21 (73.77), Vandana (64.02), TN-1 (60.03), NDR-359 (54.38) and DGI-138 (59.39) had above average root length while, IR-64 showed root length at par with the general mean. Remaining entries were found to have statistically lesser root length than general mean. Vandana, TN-1, NDR-97, P-0088, P-0090, DGI-138, DSU-18-6, NDR-359 had b>1 whereas, P-0326, JR-64, Azucena, DGI-379 and P-0397 had b<1. Saita possessed negative b value. Remaining entries showed b=1. P-0397, DGI-75, Vandana and DSU -18-6 exhibited s^2di>0 while, remaining entries had S^2di=0. TN-1, NDR-359 and DGI-138 possessed high mean performance, b>1 and S^2di=0 for root length. DGI-21 showed high mean performance with b=1 and S^2di=0. The line with highest root length P-0326 had b<1 and S^2di=0.

The general mean for root volume was 56.73 ml. and root volume varied from 35.98 ml (NDR-97) to 100.46 cm^3 (P-0326), P-0326, followed by Moroberekan (99.57), P-0088 (81.58) DGI-21 (70.68) and DSU-18-6 (68.6) showed statistically superior root volume than general mean while, Azucena, NDR-359, TN-1, Vandana and DGI-75 were statistically at par with the general mean in root volume. Remaining entries showed below average root volume. NDR-97, Moroberekan, P-0090 and DGI-379 showed b<1. DGI-138, Azucena, NDR-359, Vandana and P-0397 had b=1. Remaining entries had negative b values. The non-linear sensitivity coefficients of NDR-97, NDR-359, DGI-379 and Saita did not deviate significantly from zero while, remaining entries possessed s^2d^2>0. NDR-359 showed medium mean performance with b=1 and s^2di=0. P-0326 and DGI-21 had high mean performance with negative b value and s^2di=0. Moroberekan and P-0088 showed high mean performance with b=1 and s^2di=0.

Root dry weight varied 4.95 g in case of NDR-97 to 14.39 g in case of NDR- 359, with a general mean of 8.95 gm. NDR-39 (14.39), TN-1(13.78), P-0088 (13.46), P-0397(12.19) and P-0326 (11.42) possessed statistically higher root dry weight than general mean, while, NDR-97, DGI-21, DGI-138, DSU-18-6, DGI-379 and Saita were statistically inferior to the general mean. The remaining entries were at par with the general mean. The linear sensitivity coefficient of NDR-359 was b>1 while NDR-97, Moroberekan and DGI-75 have b>1. DGI-21, DGI-138, P-326, Azucena and P-0088 possessed b=1, while remaining entries had negative b values. The line having highest mean performance for root dry weight, NDR -359 possessed b>1 and s^2di>0. Among the other lines having high mean for root dry weight P-0088 and P-0326 had b=1 and s^2di=0.

Biochemical traits

The mean squares due to varieties were highly significant for all characters under study. The variances due to environments and environment linear component (E-L) were also highly significant in all the cases. This indicated that substantial variation existed among the genotypes as well as environments. The mean squares due to G x E interaction were found to be highly significant for all the characters. The linear component of G x E interaction was also highly significant for all the characters. The non-linear G x E component was highly significant for all the characters except SOD at 3 days and soluble sugar at flowering (Table 1).

The proline content ranged from 22.16 mgg^1 fresh weight (DGI-152) to 35.91 mgg^{-1} fresh weight (Moroberekan). Moroberekan (35.91) had significantly higher proline content than remaining genotypes. Above average proline content was also shown by NDR-97 (33.80), DGI-379 (31.40), IR-64 (29.61) and Saita (29.28). DGI-138, P-0326, Azucena, NDR-359, DGI-152 TN-1, DGI-75 and P-0397 showed below average proline content. Remaining three genotypes had proline content at par with the general mean (28.36). The entries, DGI-21, DSU-18-6, IR-64, NDR-359, TN-1, DGI-75, P-0088, P-0397 and Saita had b>1, while NDR-97, Moroberekan, DGI-138, P-0090, DGI-379and Vandana possessed b>1. The linear sensitivity coefficients of remaining entries were equal to unity (b=1). The non-linear sensitivity coefficients (S^2di) were equal to zero for P-0326, IR-64, Azucena, NDR-359, Vandana and DGI-75. The genotype having highest proline content, Moroberekan, had b>1 and S^2di >0. The other lines following it for higher proline content, NDR-97, P-0090, DGI-379, Saita also showed b>1 and s^2di >0. Among the genotypes having high proline content, Vandana showed b<1 and s^2di = 0,

Table 1
Pooled analysis of variance for physio-morphological traits under target environments

SN	Source of variation	df	M.S.S. Characters PH	RWC	RL	RV	RDW	Proline	SOD 3 day	SS at F	GY
1.	V	17	407.81**	75.46**	875.91**	1726.74**	36.23**	58.40**	2501.90**	2889.52**	32205.93**
2.	E	3	591.80**	2370.64**	1584.72**	263.28**	2.89**	681.84**	1945745.6**	18694.44**	134383.88**
3.	VxE	51	29.00	24.79**	59.73**	185.14**	2.95**	6.792**	1648.76**	513.71**	2253.81**
4.	P. error	136	47.31	2.85	1.93	3.98	0.029	0.0695	8.44	13.18	9.49
5.	VxE	54	60.27**	155.11**	144.45**	189.49**	2.95**	44.29**	109654.14**	1523.75**	9594.37**
6.	E (Linear)	1	1775.34**	7112.01**	4754.18**	789.85**	8.68**	2045.52**	5837247.6**	56083.20**	403149.83**
7.	VxE (linear)	17	41.88	58.25**	167.93**	365.19**	4.59**	19.292**	2556.45**	1407.97**	3672.27**
8.	Pooled deviation	36	21.31	7.61	5.31	89.84	2.01	0.512	1128.23	62.89	1458.81

Table 2
Mean performance, coefficient of variability and stability parameters for grain yield of rice genotypes under target environment

S. No.	Genotypes	Plant height (cm)			Relative water content (%)			Root length (cm)			Root volume (cm³)			Root dry weight (g)		
		Mean	Reg. Coef. (B)	Mean Sq. Dev. (SD)	Mean	Reg. Coef. (B)	Mean Sq. Dev. (SD)	Mean	Reg. Coef. (B)	Mean Sq. Dev. (SD)	Mean	Reg. Coef. (B)	Mean Sq. Dev. (SD)	Mean	Reg. Coef. (B)	Mean Sq. Dev. (SD)
1.	DGI-21	77.50	0.42	-15.58	65.44	1.21	1.54	73.77	1.19	1.42	70.68	-4.74	329.25	7.15	3.95	2.37
2.	NDR-97	72.75	0.80	-10.56	70.25	0.34	0.97	41.27	1.50	0.47	35.98	3.80	100.83	4.95	2.80	1.63
3.	Moroberekan	67.83	0.42	-15.01	71.27	0.98	1.25	42.17	1.04	2.80	99.57	4.64	91.95	7.42	2.38	0.88
4.	DGI-138	97.25	0.70	-14.47	69.62	0.67	0.34	59.53	1.79	3.55	44.75	2.15	31.34	5.10	3.16	1.65
5.	DSU-18-6	82.25	1.43	-13.23	80.55	1.75	5.58	41.69	1.47	7.06	68.78	1.35	15.15	5.98	-1.05	0.09
6.	P-0326	84.50	1.65	-15.53	75.86	0.85	2.19	90.45	0.71	2.59	100.46	-6.12	586.16	11.42	4.28	1.07
7.	IR-64	80.25	1.66	-14.49	77.86	1.44	14.72	50.91	0.38	3.62	42.52	0.18	6.26	8.12	-2.00	2.62
8.	Azocena	85.00	0.54	-13.16	78.00	1.33	20.90	38.69	0.64	-0.04	52.23	1.95	24.83	10.17	4.43	0.54
9.	NDR-359	82.83	0.65	-13.24	71.89	0.46	7.24	54.39	1.35	3.06	64.72	3.15	2.24	14.39	6.90	4.34
10.	DGI-152	81.17	-0.01	-8.61	68.32	0.59	2.89	40.50	0.79	-0.13	32.39	1.43	12.36	8.51	-2.15	0.56
11.	P-0090	68.75	1.12	36.33	76.50	1.19	1.36	36.22	1.28	-0.26	43.57	1.09	71.75	9.50	-1.00	6.70
12.	TN-1	103.83	1.16	58.53	76.38	1.06	13.02	60.03	1.92	1.74	53.48	-0.77	46.83	13.78	-1.95	6.56
13.	DGI-379	93.58	1.30	-7.86	74.79	0.87	1.38	46.78	-0.56	4.95	41.04	1.49	4.10	6.92	-0.24	0.61
14.	Vandana	94.92	0.61	11.79	69.93	0.46	2.21	64.02	2.51	7.48	53.68	2.20	66.34	8.49	-3.35	2.55
15.	DGI-75	75.08	0.56	53.33	75.21	1.21	44.68	38.77	0.77	15.07	60.36	-0.81	26.04	7.97	1.20	0.48
16.	P-0088	85.00	2.45	-9.78	73.49	1.31	4.95	42.26	1.39	0.51	81.58	5.19	140.32	13.46	4.35	2.08
17.	P-00397	93.50	2.07	103.84	77.40	1.27	7.31	36.98	0.49	30.25	36.98	2.19	28.36	12.19	-2.92	1.29
18.	Saita	74.00	0.46	-12.49	66.26	1.00	4.38	38.48	-0.67	-0.13	38.33	-0.35	9.14	5.63	-0.81	0.10

Table 3
Mean performance, coefficient of variability and stability parameters for grain yield of rice genotypes under target environment

SN	Genotypes		Proline		SOD 3 days			Soluble sugar at F			Grain yield		
		Mean	Mean	Reg. Coef. (B)	Mean	Reg. Coef. (B)	Mean Sq. Dev. (SD)	Mean Sq. Dev. (SD)	Reg. Coef. (B)	Mean	Mean Sq. Dev. (SD)	Reg. Coef. (B)	Mean Sq. Dev. (SD)
1.	DGI-21	28.68	165.75	1.05	493.33	1.44	343.10	363.67	0.67	746.17	5.64	1.37	0.24
2.	NDR-97	33.80	172.50	1.06	589.92	0.52	312.77	489.64	0.49	745.25	7.25	0.37	0.22
3.	Moroberekan	35.91	222.50	1.05	519.00	0.56	62.34	199.55	0.53	743.83	20.45	0.37	0.85
4.	DGI-138	25.72	143.50	1.11	522.83	1.29	241.57	7.80	2.32	765.08	142.47	0.64	0.47
5.	DSU-18-6	27.82	172.25	1.02	518.25	1.08	543.43	133.25	0.55	733.67	-0.86	1.14	0.28
6.	P-0326	25.26	159.42	1.09	380.92	056	140.45	59.58	0.23	759.25	51.40	1.04	0.05
7.	IR-64	29.61	157.92	0.98	358.25	1.28	140.06	2071.35	1.19	722.33	-2.46	1.62	0.09
8.	Azocena	24.85	199.17	1.04	422.92	0.49	82.86	111.67	0.56	744.75	1.09	1.01	0.12
9.	NDR-359	25.48	163.83	1.01	432.50	0.35	31.27	133.65	0.48	738.08	437.58	1.19	-0.02
10.	DGI-152	22.16	154.17	0.97	530.08	1.79	232.2	718.84	1.72	730.33	22.78	0.96	0.73
11.	P-0090	33.49	187.67	0.92	335.83	1.04	340.00	468.74	0.01	712.92	2.70	0.61	0.25
12.	TN-1	25.50	231.42	1.02	494.83	0.83	52476	110.94	0.47	740.00	8.90	1.38	0.49
13.	DGI-379	31.40	134.25	1.72	623.58	1.41	1029.20	13634.02	1.58	751.42	13.69	0.62	0.74
14.	Vandana	32.59	197.58	1.01	586.67	0.74	17322.55	227.92	0.27	742.08	3.48	0.39	0.00
15.	DGI-75	26.31	191.83	1.09	440.33	1.46	1295.00	201.38	0.49	760.08	46.63	1.20	0.00
16.	P-0088	28.37	156.83	0.99	335.33	1.10	33.50	28.21	1.09	737.17	253.46	1.09	3.22
17.	P-00397	24.36	165.17	0.93	336.33	1.01	35.00	1008.46	1.48	720.17	29.90	1.39	0.77
18.	Saita	29.28	142.00	0.94	309.50	1.05	2229.60	288.88	1.91	720.00	9.41	1.61	0.31

to emerge as most desirable line for proline content having high proline content with stability. IR-64 had high proline content with b>1 and $s^2di=0$ (Table 3).

The super oxide dismutase (SOD) at 3 days ranged from 651.42 in case of DGI-379 to 765.08 for DGI-138.All the entries, except DGI-379 were found to be statistically at par with the general mean which was 733.86. DGI-138 had b>1 and $s^2di=0$, besides having highest SOD at 3 days.DGT-379 possessed b>1 but it had low mean and $s^2di>0$. All the entries except DGI-138 showed $s^2di>0$. The b values of all the entries except DGI-138 and DGI-379 were equal to unity.

The soluble sugar at flowering varied from 134.25 (DGI-379) to 231.42 (T.N-1). Moroberekan (222.50), P.0090 (187.67), Vandana (197.58) and DGI-75 (191.83) along with TN-1 (231.42) were found to be significantly superior than the general mean (173.20). DGI-138, P-0326, IR-64, NDR-359, DGI-152, DGI-379, P-088 and Saita showed below average means for this character. DGI-138, DGI-152, P-0090, DGI-379, P.0397 and Saita emerged with b>1, while DGI-21, NDR-97, Moroberekan, DSU-18-6, P-0326, Azucena, NDR-359, TN-1, Vandana and DGI-75 had b<1. All the entries showed $s^2di=0$ except DGI-138, P-0326, NDR-359, DGI-75 and P-0088 having $s^2di>0$. Among the lines having high mean performance for soluble sugar at flowering stages, TN-1, Moroberekan, Azucena and Vandana had b<1 and $s^2di=O$.P-0090 combined high soluble sugar at flowering with b>1 and $s^2di=0$ while, DGI-75 had high mean performance with b<1 and $s^2di>0$.

The grain yield ranged from 309.5 g per plant in case of Saita to 589.92 for NDR-97. In addition to NDR-97 (589.92), Vandana (586.67), DGI-152 (530.08), DGI-138 (522.83), Moroberekan (519.00), DSU-18-6 (518.25) and DGI-21 (493.33) also produced significantly superior grain yield than general mean (446.13). Azucena, NDR-359, TN-1 DGI-379 and DGI-75 were statistically at par with the general mean while, remaining entries were below average in mean performance.DGI-152 had b>1 and characterizes with b=1. The non-linear sensitivity coefficients of all the eighteen characters were greater than zero ($s^2di=0$).

The results of this study indicated that grain yield was significantly influenced by changes in environmental conditions because there were significant variations in grain yields of the genotypes tested in response to the environment. The tested genotypes *viz.*, TN-1, DGI-138, Vandana, DGI-379 for tall stature; P-0090, NDR-97, DGI-21, DGI-75 and Saita for short stature, DSU-18-6, P-0088 and P-0397 for relative water content; TN-1, NDR-359, DGI-138 and DGI-21 for root length and P-0088 and P-0326 for root dry weight. In case of biochemical traits, the widely adapted genotypes were Moroberekan and IR-64 for proline content; DGI-138 for SOD at 3 days and P-0090 for soluble sugar at flowering represented stability trends. In case of grain yield per plant, NDR-97 (589.92) followed by Vandana (587.6), DGI-152 (530.08), DGI-138 (522.83), Moroberekan (519.00), DSU-18-6 (518.25) and DGI-21 (493.33) produced high grain yield per plant. These lines had average response (bi=1) indicating suitability to unfavorable environments. Therefore, breeding studies should be continued for high yielding drought tolerant varieties.

REFERENCES

Allard, R.W. and A.D. Bradshaw: Implications of genotype environment interactions. *Crop Science*, **4**, 503-507 (1964).

Asada, K., S.M. Takahasi, and M. Nagate: Assay and inhibition of spinach Superoxide dismutase. *Agric. Biol. Chem.*, **38(2)**, 171-173 (1974).

Bates, L.S., R.P. Warden and I.D. Teare: Rapid determination of free proline for water stress studies. *Plant and Soil.*, **39**, 205-207 (1973).

Bourai, V.A., A. Choudary and M. Misra: Participatory crop improvement in Eastern India: A first impact assessment. Plant Sciences Research Programme Annual Report (2003).

De Datta, S.K.: Strategies for improving rice production in eastern India. *Outlook Agric.*, **13**, 185–194 (1984).

Dey, M.M., H.K. Upadhyaya: Yield loss due to drought, cold and submergence in Asia. In: Evenson, R.E., Herdt, R.W., Hossain, M. (Eds.), Rice Research in Asia: Progress and Priorities. Oxford University Press, Cary, NC, pp. 231–242 (1996).

Eberhart, S.A. and W.A. Russell: Stability parameters for comparing varieties. *Crop Science*, **6**, 36-40 (1966).

Evenson, R.E. and Gollin, D., Assessing the impact of the green revolution, 1960 to 2000. *Science*, **300**, 758–762 (2003).

Gomez, K.A., and A.A. Gomez: Statistical Procedures for Agricultural Research (2nd Edition). New York (USA) *John Wiley & Sons*. Inc. 680 p (1984).

I.R.R.I.: CropStat 7.2 for Windows. Crop Research Informatics Laboratory, International Rice Research Institute, Los Banos, Philippines (2009).

I.R.R.I.: Standard Evaluation System for Rice (4th Edition). International Rice Testing Programme, International Rice Research institute, Los Banos, Philippines (1996).

Lowery, O.H., N.J. Rosenbrough, A.L. Farr and R.J. Randall: Protein measurement with proline phenol reagent. *J. Biol. Chem.*, **193**, 265-275 (1951).

Pandey, S., D.D. Behura, R. Villano and D. Naik: Economic costs of drought farmers' coping mechanisms: a study of rainfed rice system in eastern india. IRRI Discussion Paper Series 39. Los Banos (Philippines): International Rice Research Institute. 35 p (2000).

Virk, D.S., D.N. Singh, R. Kumar, S.C. Prasad, J.S. Gangwar, J.R. Witcombe: Collaborative and consultative participatory plant breeding of rice for the rainfed uplands of eastern India. *Euphytica*, **132**, 95–108 (2003).

Yemm, E.W. and A.J. Willis: The estimation of carbohydrates in plant extracts by anthrone. *Biochemistry Journal*, **57**, 508-514 (1954).