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□ *Rice, grown on a wide range of soils with varying soil pH levels boron (B) availability, uptake and mobilization could be limiting hence may lead to lower productivity and rice yields has been tested at 11 locations on low yielding rice genotypes from, Initial Evaluation Trials (IET) of AICRIP viz.IET 20979, IET 21003, IET 21007, IET 21014, IET 21025 and Rasi as check variety. Active boron supplemented as foliar spray at anthesis stage at 0.2, 0.4 and 0.8 ppm. Grains with 1.20 (High density), and 1.06 (normal density) specific gravity (sp. gr.) and unfilled grains were determined. The results showed that application of boron resulted in increase in grain number (25–45) and reduced the number of unfilled spikelets. At majority of the locations, application of 0.4 ppm boron had resulted in significant increase in grain yield (4–8%). Cultures, IET 20979, IET 21007, and IET 21014 showed a positive response with the 0.4 ppm application at the majority of locations.*

Keywords: rice, boron, growth, phenology, spikelet sterility, yield

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most ancient crops, and is cultivated in 117 countries across the world and hence called as "global grain". In India, it is cultivated in an area of 44.8 million hectares with a total production of 93 million tons. In Andhra Pradesh, the crop is spread over an area of 4.3 million hectares with the production of 14.2 million tons and productivity of 3.248 tons ha^{-1} (CMIE, 2009). Rice being cultivated in various agro climatic situations across the country, the crop is subjected to various biotic and abiotic stresses. The productivity of the crop has been reported to decrease

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because of spikelet sterility. The reasons for spikelet sterility include incomplete panicle exertion, degenerative spikelets, presence of nonviable pollen and failure of anthesis. The problem of sterility can, however, be addressed by physiological or agronomic approaches like soil application or spray of nutrients. Boron (B) is an essential element for plants and boron availability in soil and irrigation water is an important determinant of agricultural production. The main functions of boron relate to cell wall strength and development, cell division, fruit and seed development, sugar transport, and hormone development (Marschner, 1986). Some functions of boron interrelate with those of nitrogen, phosphorous, potassium and calcium in plants. The boron requirement is much higher for reproductive growth than for vegetative growth in most plant species. Boron increases flower production and retention, pollen tube elongation and germination, seed and fruit development (Vaughan, 1977; De Wet et al., 1989).

Boron is associated with a wide range of morphological alterations, tissue differentiation, pollen germination and metabolite transfer which will greatly influence the yield and productivity. Rice, when grown on a wide range of soil types such as calcareous, clayey laterite, acid, etc., with varying soil pH levels, boron availability, uptake and mobilization become limiting and leads to reduced productivity and poor rice yields. In India Northern Bihar, part of Assam, West Bengal, Meghalaya and northern Orissa, all parts in North East India together with Karnataka and Gujarat soils show boron deficiency. In Andhra Pradesh rice varieties producing an average of 300 panicles m^{-2} and 100 spikelets per panicle showed spikelet sterility of 15% maturity indicating the scope for improving the spikelet fertility. Studies revealed that soil application of boron leads to fixation and unavailability. Boron, which is immobile in plant tissues, sprayed directly towards developing tissues such as flower buds and flowers ensures adequate supply at critical stages of development (Brown and Shelp, 1997). Thus, it has been understood that, boron application can reduce the spikelet sterility and improve fertility. Hence, boron application at different concentrations as foliar spray was assessed in selected rice cultures with an objective to assess its influence on enhancing spikelet fertility.

MATERIALS AND METHODS

Genotypes that have not been promoted to the Advanced Varietal Trials (AVT) due to their poor performance in terms of filled grains of 2008 Initial Varietal Trial (IET) viz. IET 20979, IET 21003, IET 21007, IET 21014, IET 21025 were selected for this study and grown at 11 locations varying in their soil characteristics (Table 1).

The experiment was conducted in split plot design with three replications, 10 × 20 cm spacing with normal recommended package and practices that are being adopted, except for the application of active boron in the

TABLE 1 External application of boron on rice under different types of soils and their characteristics

Location & state	Soil type	pH	EC	Available N (kg ha^{-1})	Available P $_2O_5$ (kg ha^{-1})	Available K (kg ha^{-1})	O.C (%)
DRR, (AP)	Clay	8.1	0.55	220	75	450	0.72
MTU, (AP)	Clay	6.1	0.74	237	17.5	241	1.0
CBE, (TN)	Clay	7	0.7				0.56
PTB, (Kerala)	Sandy loam	4.6	0.023		16.5	90.7	0.96
KRK, (Pondi)	Sandy loam	7.6	0.22	121	31	175	0.43
BHU, (UP)	Sandy silty	7.2	0.32	128	34.5	118	0.38
PNG, (Uttaranchal)	Silty loam	8.0	0.63		21	290	
CTK, (Orissa)	Sandy clay loam	6.8		270	45	120	0.63
TTB, (Asssam)	Silty clay	5.5		390	9.8	112	0.9
HAT, (WB)		5.8	0.1	50	6	126	0.4
Umiam, (Meghalaya)	Sandy loam	5.2		350	27	240	

form of foliar spray at anthesis stage at 0.2, 0.4 and 0.8 ppm while control was sprayed with water alone. Phenological observations and yield and its components were recorded from tiller to maturity stages. Post-harvest observations on yield and its components were recorded.

Grains with 1.20 (High density), and 1.06 (normal density) specific gravity (sp. gr.) were determined as per the method described by Venkateswarlu et al. (1988) The number of filled and unfilled grains were recorded using an automated grain counter (Contador, Pfeuffer, Germany). The data was statistically analyzed as per Gomez and Gomez (1984).

RESULTS

Growth and Phenology

Treatment and genotypes means of the phenological information growth dynamics up to flowering stage such as leaf area index, tiller number, leaf weight, panicle weight, etc., are presented in Table 2. All these parameters recorded were before the application of boron as foliar spray and is expected to provide the information about the genotypes in relative terms of their physiological activity. Based on this, it can be realized that, IET 20979, IET 21003 and IET 21014 had better source potentials in terms of dry weights of culm and leaf. Mean sink potential is 248 gm^{-2} and genotypes IET 20979 and IET 21007 were found to be superior at this stage.

Yield and Its Components

The mean grain number per panicle 124 at nine locations with a minimum at Pattambhi (PTB) and maximum at Coimbatore (CBT) (184),

TABLE 2 Means for growth and phenology with boron application

						Tiller stage		Panicle initiation stage		Flowering stage			Grain weights (sp.gr)					
	DF (d)	Mat (d)	Pr.b (no)	sec.br (n0)	LAI	Culm wt (g m^{-2})	Leaf Wt (g m^{-2})	Culm wt (g m^{-2})	leaf wt (g m^{-2})	Culm wt (g m^{-2})	Leaf wt (g m^{-2})	Pan wt (g m^{-2}))	HDG (1.20 sp.gr) N0	Normal (1.06 sp.gr) No	Unfilled spikelets (no)	Pan. (No m^{-2})	G.no Pan^{-1}	Yield (g m^{-2})
Control	91	125	9	27	4	81	54	314	253	530	218	245	4	5	274	252	120	457
0.2 ppm	90	123	10	28	5	90	57	297	248	525	223	231	4	5	255	266	121	452
0.4 ppm	91	124	10	29	5	86	56	283	251	510	225	257	4	5	251	278	129	484
0.8 ppm	92	125	10	29	5	87	59	291	251	547	226	249	4	6	265	270	125	471
Genotype																		
IET 20979	103	133	9	26	5	87	56	322	226	584	247	288	5	5	233	297	120	497
IET 21003	104	135	11	40	5	90	57	305	266	622	285	207	4	7	432	256	179	473
IET 21007	83	116	9	26	4	83	56	267	232	461	181	257	5	4	189	261	113	461
IET 21014	86	119	9	24	5	95	62	293	248	430	199	233	5	4	193	254	105	416
IET 21025	88	125	10	31	4	75	53	289	262	570	230	242	3	6	256	249	116	510
Rasi	83	117	9	24	4	77	47	300	269	504	196	246	5	5	170	269	112	454
Expt. mean	93	124	10	28	5	86	56	267	286	498	222	248	4	5	253	264	130	467

followed by Titabar (TTB), Maruteru (MTU) and Pantnagar (PNR) in different genotypes (Table 3). The grain number recorded was lowest at PTB in all the genotypes. IET 21003 and IET 20979 genotypes irrespective of locations had higher grain number per panicles even higher to rasi, the check variety. Application of boron resulted in increase of grain number from 120 to 129 at 0.4 ppm. An average increase of 30 grains per panicle at TTB was the highest response obtained by boron treatment while such response was not noticed at Karaikal (KRK) and Umiam (UMM). At other locations the response was moderate.

The average unfilled spikelet number is 266 with relatively higher numbers in IET 21003 and IET 21025 genotypes and are from the locations, UMM, PNR and KRK (Table 4). Except Hatwara (HAT) and PTB, in the remaining locations the reduction in unfilled spikelets ranged from 3 (MTU) to a maximum of 73 (UMM) followed by TTB (53) and KRK. The trend was found to be similar in case of panicle number m^{-2} which is higher in IET 20979 (297) and with 0.4 ppm boron treatment (278) (Table 5).

Genotypes, IET 20979 and IET 21003 irrespective of location had yields better than Rasi, (454 g m^{-2}) (Table 6). Leaving the yield performance of IET 21025 (510 g m^{-2}) at KRK location, and IET 21007 (461 g m^{-2}) were at par with check variety rasi and IET 21014 was inferior in terms of grain yield.

TABLE 3 Boron concentration and grain number panicle^{-1} at maturity at different locations Kh 2009

Boron conc.	CBT	DRR	KRK	MTU	PNR	PTB	UMM	HAT	TTB
Control	176	93	113	141	156	38	100	124	138
0.2 ppm	184	89	99	142	142	44	101	125	165
0.4 ppm	188	106	100	165	160	46	93	138	168
0.8 ppm	191	109	110	157	136	45	105	111	158
Genotype									
IET 20979	198	105	95	136	172	43	76	115	143
IET 21003	270	98	160	207	303	59	162	130	220
IET 21007	164	86	97	140	107	28		127	155
IET 21014	173	96	84	138	128	39	52	111	125
IET 21025	147	104	111	131	99	36	109	129	174
Rasi	155	105	85	156	81	52		135	127
Expt. mean	184	99	106	151	148	43	100	124	157
CD_Main	0.3	13.8	NS	NS	NS	2.7	NS	NS	19.2
CD_Sub	0.4	NS	28.4	18.9	36.6	2.8	467.4	NS	19.2
CD_MinS	NS	39.1	NS	NS	NS	5.8	NS	NS	NS
CD_SinM	NS	38.4	NS	NS	NS	5.6	NS	NS	NS
CV_Main	0.2	17.1	27.0	17.0	27.8	7.8	36.3	30.4	14.9
CV_SuB	0.3	23.4	32.6	15.2	29.9	7.9	55.6	36.6	14.8

TABLE 4 Boron concentration and 5 panicle unfilled spikelet number at different locations Kh 2009

Boron conc.	CBT	DRR	KRK	MTU	PNR	PTB	UMM	HAT	TTB
Control	124	189	219	260	315	261	614	206	283
0.2 ppm	115	207	211	242	227	224	652	157	265
0.4 ppm	104	179	165	257	260	321	531	206	232
0.8 ppm	96	307	180	266	225	280	636	165	230
Genotype									
IET 20979	66	269	239	195	357	246	387	167	173
IET 21003	201	231	396	276	696	253	1092	311	431
IET 21007	166	128	142	240	94	308		147	285
IET 21014	34	194	85	302	120	328	344	144	185
IET 21025	156	246	173	260	204	213	611	189	255
Rasi	33	256	125	265	69	282		141	186
Expt. mean	109	221	193	256	257	272	608	224	253
CD_Main	0.3	85.2	NS	NS	NS	NS	NS	NS	NS
CD_Sub	0.3	83.7	76.2	NS	85.9	NS	307.1	77.2	91.1
CD_MinS	0.7	173.5	NS	NS	177.4	360.6	NS	NS	NS
CD_SinM	0.7	167.3	NS	NS	171.9	338.4	NS	NS	NS
CV_Main	0.4	47.3	51.5	21.1	38.6	113.7	62.6	41.5	50.0
CV_SuB	0.4	46.0	47.7	37.1	40.6	75.5	59.9	51.1	43.7

TABLE 5 Boron concentration and panicle number m^{-2} at maturity at different locations Kh 2009

Boron conc.	CBT	DRR	KRK	MTU	PNR	PTB	UMM	HAT	TTB	CRRI
Control	246	339	273	273	237	215	281	267	198	189
0.2 ppm	254	345	319	272	234	238	329	249	224	194
0.4 ppm	262	316	349	279	232	260	292	274	236	-
0.8 ppm	270	294	365	269	229	260	307	272	236	198
Genotype										
IET 20979	323	328	361	320	254	222	410	292	252	208
IET 21003	302	306	291	262	196	268	237	290	259	153
IET 21007	236	353	324	259	229	217	316	273	237	170
IET 21014	228	328	319	260	235	243	270	239	191	222
IET 21025	234	320	341	252	242	180	265	241	208	209
Rasi	223	305	322	286	243	328	314	258	193	220
Expt. mean	258	323	326	273	233	243	302	195	223	197
CD_Main	0.5	24.5	NS	NS	NS	12.3	NS	2.5	19.1	
CD_Sub	6.5	NS	NS	34.3	30.0	14.2	NS	6.0	41.0	
CD_MinS	NS	96.7	NS	NS	NS	29.1	NS	12.1	NS	
CD_SinM	NS	95.7	NS	NS	NS	28.3	NS	12.0	NS	
CV_Main	0.2	9.3	38.3	13.5	10.1	6.2	23.6	1.2	10.5	
CV_SuB	3.0	17.9	27.2	15.2	15.6	7.1	107.0	2.7	22.3	

TABLE 6 Boron concentration and grain yield (g m^{-2}) at different locations Kh 2009

Boron conc.	CBT	DRR	KRK	MTU	PNR	PTB	UMM	HAT	TTB	CRRI	BHU
Control	556	654	656	381	651	306	157	583	313	311	717
0.2 ppm	572	614	500	458	625	307	187	567	363	324	771
0.4 ppm	589	648	601	515	618	291	172	541	384	—	792
0.8 ppm	606	531	608	396	603	551	185	542	349	339	812
Genotype											
IET 20979	666	612	391	466	651	471	306	645	451	311	619
IET 21003	653	559	432	563	671	391	243	573	273	370	591
IET 21007	553	633	594	394	604	401	340	561	268	263	786
IET 21014	528	620	594	376	599	294	77	468	302	304	854
IET 21025	556	635	802	401	639	374	322	575	419	373	880
Rasi	530	613	734	427	580	251	67	527	400	411	908
Expt. mean	581	612	591	438	624	364	175	558	352	339	773
CD_Main	6.6	55.6	NS	89.7	NS	54.9	NS	NS	38.3		
CD_Sub	10.7	NS	146.6	80.2	NS	58.4	4.4	NS	51.0		
CD_MinS	NS	158.0	299.0	NS	NS	120.5	NS	NS	NS		
CD_SinM	NS	154.9	293.1	NS	NS	116.7	NS	NS	NS		
CV_Main	1.4	11.1	21.8	25.1	9.1	18.5	32.6	35.2	13.3		
CV_SuB	2.2	15.3	30.0	22.2	16.9	19.5	30.2	24.2	17.6		

DISCUSSION

Boron deficiency results in reduced yields (Carpena et al., 2000) particularly at the flowering stage (Goldbach, 1997; Hemantha Ranjan, 2000). As shown in Table 1, rice is being grown on a wide range of soil types, such as clay, sandy loam, silty loam, clayey laterite, acid etc., with varying soil pH levels which would influence boron availability (Eguchi and Yamada, 1997). Large number of rice test cultures when grown across the country and the differences in yield could arise due to variation in soil characteristics, poor management practices and experimental errors. Therefore, the possibility of genotypes with good characteristics sometimes escape the advanced trials. Additionally in the current IPR regimes, the valuable material generated by breeding program needs to be preserved for future which may turn out to be useful genetic materials before being discarded due to the poor yields which is nothing but a genotype X environment interaction.

Increased grain number on application of Boron at 0.4 ppm and increase of 30 grains per panicle at TTB and no such response at KRK and UMM, in spite of being similar soils type but differed in soil PH, available nitrogen and phosphorus conditions. Such type of response in grain number would possibly arise due to tissue differentiation (i.e., increased panicle numbers), pollen viability (Garg et al., 1979) and more number of spikelets fertilized (conversely a reduction in the unfilled spikelets) which increases productivity, while an increase in grain weight largely contribute to enhance the yield. Earlier it was shown that under high soil PH boron availability becomes limiting (Lehto, 1995), in sandy soils (Shaaban et al., 2006).

Interestingly, the mean unfilled spikelets in control reduced from 274 to 251 under the influence of 0.4ppm boron suggesting that, boron enhanced the fertility of the spikelets (Table 4). In wheat, boron deficiency resulted in male sterility (Rerkasem, 1995) in sunflower and rice also boron deficiency resulted in reduced yields (Blamey et al., 1997; Li and Liang, 1997). As a result of boron application an increase of 45% yield in wheat was obtained (Halder et al., 2007). Apart from the fertility factor, boron is known to conjugate with sugar moieties (Lewis, 1980; Agarwala and Chatterjee, 1996) for assimilate mobilization. Under such type of situations, grain density is supposed to be influenced which has been studied in the present context. The results presented in Tables 7 and 8, where in high density grains (1.20 sp. gr.) and normal density grains (1.06 sp. gr.) appears to be not very much influenced in spite of the existence of genotypic differences. The individual response of all these factors culminated in achieving a mean grain yield of 463 g $m^{-2.}$

IET 20979 except at HAT, IET 21003 except at PTB and UMM did gain yield supremacy with boron application compared to the marginal to no improvement in rest of the genotypes. It appears from Figure 1 that boron did not influenced the yield components of any of the genotypes across the locations. However, the performance of genotypes analyzed by genotype

TABLE 7 Boron concentration and 5 panicle grain wt (g) HDG (1.20 sp gr) at different locations Kh 2009

Boron conc.	BHU	DRR	KRK	MTU	PNR	PTB	UMM	TTB
Control	1.82	8.62	2.95	7.21	3.98	3.85	2.27	2.57
0.2 ppm	1.82	8.05	2.37	8.09	2.72	5.04	1.85	3.49
0.4 ppm	1.84	8.81	2.99	8.36	4.69	3.69	1.73	3.79
0.8 ppm	1.87	6.63	2.86	9.79	4.15	4.70	1.99	3.82
Genotype								
IET 20979	1.75	8.45	1.47	9.59	5.55	3.43	3.02	6.45
IET 21003	1.63	6.19	2.57	11.80	0.31	4.12	1.40	1.51
IET 21007	1.73	9.24	2.43	7.79	4.82	4.59		2.33
IET 21014	1.83	8.23	4.91	6.45	6.71	5.15	1.75	5.32
IET 21025	2.08	7.94	1.08	6.79	3.09	4.54	1.67	0.76
Rasi	2.00	8.10	4.30	7.76	2.86	4.09		4.15
Expt. mean	1.84	8.03	2.79	8.36	3.89	4.32	1.96	3.42
CD_Main	NS	NS	NS	NS	0.6	NS	NS	NS
CD_Sub	0.0	NS	1.4	NS	1.2	NS	NS	1.7
CD_MinS	0.1	6.6	NS	NS	2.4	NS	NS	NS
CD_SinM	0.1	6.4	NS	NS	2.4	NS	NS	NS
CV_Main	3.2	38.3	82.2	89.9	17.6	74.6	74.6	50.4
CV_SuB	2.6	48.3	60.0	54.9	36.8	89.5	5760.6	60.8

TABLE 8 Boron concentration and 5 panicle grain wt. (g) normal grain (1.06 sp. Gr.) at different locations Kh 2009

Boron conc.	BHU	DRR	KRK	MTU	PNR	PTB	UMM	TTB
Control	0.72	4.76	5.47	6.31	4.38	6.15	7.07	6.43
0.2 ppm	0.77	5.58	4.68	6.33	6.22	5.88	6.27	6.95
0.4 ppm	0.79	7.03	4.66	5.06	5.65	5.26	6.87	7.98
0.8 ppm	0.81	8.01	4.95	5.14	5.81	5.04	7.42	7.74
Genotype								
IET 20979	0.62	7.07	3.12	4.29	4.08	6.38	5.71	10.29
IET 21003	0.59	8.35	6.04	8.70	12.86	5.91	8.89	8.32
IET 21007	0.79	3.05	6.25	5.09	2.82	6.32		4.95
IET 21014	0.85	4.13	2.70	5.26	4.45	5.00	3.17	7.32
IET 21025	0.88	7.54	8.22	5.70	4.78	4.86	9.86	6.78
Rasi	0.91	7.93	3.31	5.21	4.10	5.01		5.97
Expt. mean	0.77	6.35	4.94	5.71	5.51	5.58	6.91	7.27
CD_Main	0.0	NS	NS	NS	NS	NS	NS	NS
CD_Sub	0.0	3.9	2.2	1.9	1.6	NS	NS	1.8
CD_MinS	0.0	8.0	NS	NS	3.3	3.5	NS	NS
CD_SinM	0.0	7.7	NS	NS	3.1	3.4	NS	NS
CV_Main	3.7	83.1	38.8	42.0	39.6	27.6	26.4	19.9
CV_SuB	2.3	73.6	53.1	39.5	34.3	37.1	119.1	30.6

wise (Figure 2) indicated otherwise. The mean grain yield improvement due to 0.4 ppm boron treatment irrespective of locations is an increase of 43 g m^{-2} (447 g m^{-2}- 484 g m^{-2}) and the locations benefited with statistically significant under clay soils (CBT, DRR, MTU), sandy loam soils (PTB, CTK) and silty clay (TTB). Most of these soils also are characterized by pH <7.0 (Table 6). Above pH 7, availability of soil boron reduced (Dunn et al., 2005). In the present investigation though there was a general increase in yield which is not statistically significant; probably due to less availability of

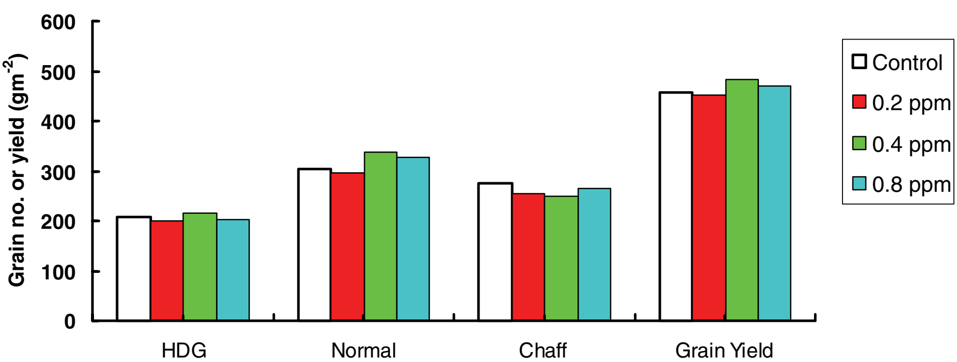

FIGURE 1 Boron response irrespective of genotypes on HDG, normal, chaff and grain yield in rice (Color figure available online).

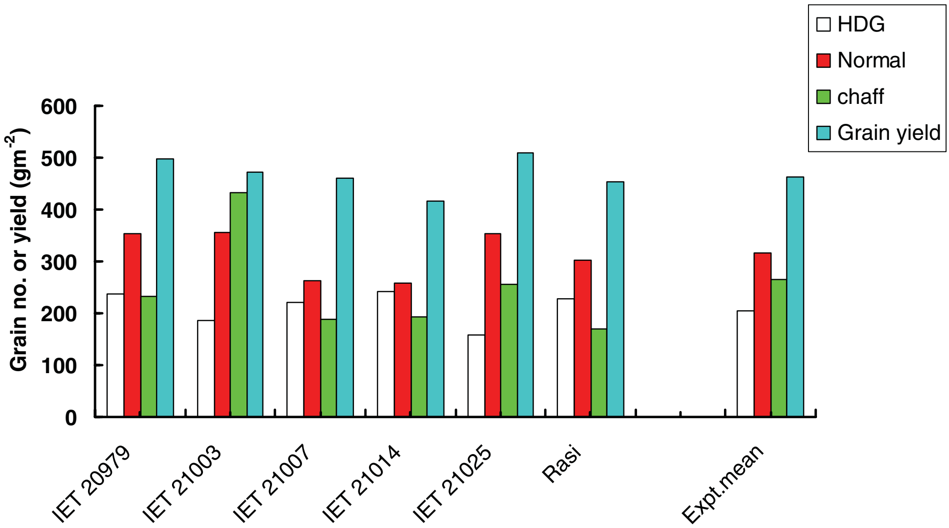

FIGURE 2 Genotype response irrespective of boron levels on HDG, normal, chaff and grain yield in rice (Color figure available online).

boron, In the remaining four centers a general improvement in yield was observed. On the contrary application of boron in acidic type of soils helps to reduce the boron deficiency (Yu and Beel, 2002) and thereby increase yields. Boron application on these genotypes at the 11 locations tested had differential impact on rice yield components in terms of both grain density and grain number. The results indicated that, at four locations most of the parameters studied were found to be consistent and statistically significant while in the remaining locations the results were encouraging though not significant.

In summary, Boron application 5–9% increase in fertility in genotypes IET 20979, IET 21007, IET 21014 and 0.4 ppm active boron foliar application had a positive influence at 60% of the locations where the trial was conducted. The usefulness of boron application for improving yield observed in the present study is worth further study as a management practice to improve rice productivity and yield.

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