Variability in bioavailable iron in hand-pounded traditional rice varieties from a highland village in northern Thailand

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Many have reported that iron (Fe) deficiency anemia is a worldwide problem (WHO 1996, IFPRI 1999). It has also been reported that most of the Fe intake of people comes from cereals (Senadhira et al 1998). To improve Fe nutrition of rice consumers, grain Fe concentration must not only be increased, it must also be in a form available to consumers of rice (Welch et al 2000, Glahn et al 2002). Glahn et al (2002) found that bioavailability of Fe in rice varied with genotype and that it was not correlated with grain Fe concentration. Furthermore, it has been reported that polishing increases the bioavailable Fe of rice grain in all varieties (Prom-u-thai et al 2004). Polished rice is more commonly consumed in urban areas, but hand-pounded rice is still eaten by people in remote highland villages. (Wooden mortar and pestle are used for pounding.) Therefore, useful information may be obtained by measuring bioavailable Fe in the rice that people actually eat.

This study set out to determine the bioavailability of Fe in hand-pounded rice from Tee Cha Village, Sob Moei District, Mae Hong Son Province, northern Thailand. Samples of six rice varieties were collected from seven individual households from the village. Exactly 1 g of each rice sample was evaluated for bioavailability of Fe by using in vitro digestion/CaCO$_2$ cell culture model in six replications, with unpolished rice variety Nishiki as the control (Glahn et al 2002). Ascorbic acid was added to the samples at 200 mM to increase the bioavailable Fe (Glahn et al 1999). Grain Fe concentration was analyzed by inductively coupled plasma (ICP) and phytate concentration was measured by high-performance liquid chromatography (HPLC) (Lehrfeld 1994).

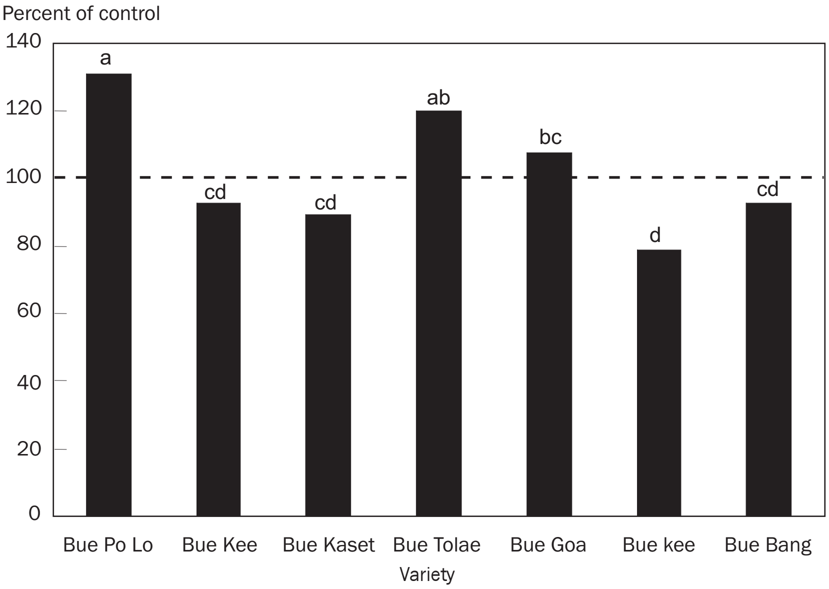
Grain Fe concentration of hand-pounded rice from Tee Cha was found to be highly variable (see table). The hand-pounded varieties with grain Fe concentration >10 mg g^{-1} were Bue Po Lo, Bue Kee (B), Bue Tolae, and Bue Kee (F). Bue Po Lo, Bue Kee (B), and Bue Kee (F) had a higher grain Fe concentration than Bue Tolae. On the other hand, grain Fe concentration of hand-pounded Bue Kaset, Bue Goa, and Bue Bang was <10 µg g^{-1}. Bue Goa and Bue Bang had a higher grain Fe concentration than Bue Kaset. Furthermore, phytate concentration of hand-pounded rice was also highly variable (see table). It was lowest in Bue Goa and Bue Bang and highest in Bue Po Lo, Bue Tolae, and Bue Kee (F). Others had intermediate values. However, there was no correlation between grain Fe and phytate concentration in all hand-pounded rice varieties.

Bioavailability of rice grain Fe in the village varied among different varieties (see figure). Three varieties (Bue Po Lo, Bue Tolae, and Bue Goa) had a higher Fe bioavailability than the standard Nishiki. It was highest in Bue Po Lo, lowest in Bue Goa, and intermediate in Bue Tolae. On the other hand, four varieties [Bue Kee (B), Bue Kaset, Bue Kee (F), and Bue Bang] had lower bioavailable Fe than Nishiki. There was no correlation between bioavailability of Fe and grain Fe as well as phytate concentration in rice grain.

Hand-pounded rice is in between unpolished and polished rice in terms of degree of polishing. Some of the aleurone layer is retained in the pounding

Iron and phytate concentrations of hand-pounded rice grains of six varieties from seven households, Tee Cha, northern Thailand.

Variety	Household	Iron concentration (µg g^{-1})	Phytate concentration (µ mol g^{-1})
Bue Po Lo	A	14.19 cd	7.47 e
Bue Kee (B)	B	16.45 d	4.64 b
Bue Kaset	C	7.64 a	5.73 c
Bue Tolae	D	13.62 c	7.26 de
Bue Goa	E	9.67 b	3.78 a
Bue Kee (F)	F	16.08 d	6.80 d
Bue Bang	G	9.76 b	3.66 a



Bioavailability of Fe in hand-pounded rice of six genotypes from seven households at Tee Cha Village, Sob Moei District, Mae Hong Son Province, relative to control variety Nishiki. Different letters indicate significant difference at *P* < 0.05.

process. It has been reported that unpolished rice contained high grain Fe concentration but low bioavailable Fe because of the presence of an inhibitor in unpolished grain (Glahn et al 2002). However, this study found that varieties Bue Po Lo and Bue Tolae had high grain Fe concentration and bioavailable Fe. Furthermore, Bue Goa had low grain Fe concentration but high bioavailable Fe. The rice eaten by people in the village was either Bue Po Lo (high Fe concentration and bioavailable Fe) or Bue Bang (low Fe concentration and bioavailable Fe). Bue Po Lo had almost three times the bioavailable Fe than Bue Bang. Therefore, those who eat this hand-pounded variety may have better Fe nutrition than those who eat Bue Bang. However, rice is normally eaten with side dishes that may affect the bioavailability of the Fe consumed. For example, consumption of a bioavailable Fe promoter substance, such as ascorbic acid, increases the bioavailability of Fe, but consumption of an inhibitory substance, such as phytic acid, decreases the bioavailability of Fe (Glahn et al 1999). Nevertheless, with everything else constant, eating rice with higher grain Fe content and higher Fe availability should contribute toward better Fe nutrition in people. The other rice variety that was almost as good as Bue Po Lo in this respect is Bue Tolae. Considerable variation exists in both concentration and bioavailability of Fe in rice normally eaten by people in the highland of northern Thailand. The high level of grain Fe and the high bioavailability of Fe in some local rice varieties may already be contributing toward improved Fe nutrition of some highland people.

References

Glahn RP, Zhiqiang Cheng, Ross MW, Gregorio GB. 2002. Comparison of iron bioavailability from 15 rice genotypes: studies using an in vitro digestion/Caco-2 cell culture model. J. Agric. Food Chem. 50:3586-3591.

Glahn RP, Lee OA, Miller DD. 1999. In vitro digestion/Caco-2 cell culture model to determine optimal ascorbic acid to Fe ratio in rice cereal. J. Food Sci. 64:925-928.

IFPRI (International Food Policy Research Institute). 1999. World food prospects: critical issue for the early twenty-first century. Washington, D.C: IFPRI.

Lehrfeld J. 1994. HPLC separation and quantification of phytic acid and some inositol phosphates in foods: problems and solutions. J. Agric. Food Chem. 42:2726-2731.

Prom-u-thai C, Glahn RP, Welch RM, Rerkasem B. 2004. Genotypic variation in bioavailability of iron in unpolished and polished rice. J. Food Chem. (in press)

Senadhira D, Gregorio G, Graham RD. 1998. Breeding iron- and zinc-dense rice. Paper presented at the International Workshop on Micronutrient Enhancement of Rice for Developing Countries, 3 September 1998, Rice Research and Extension Center, Stuttgart, Arkansas.

Welch RM, House WA, Beebe S, Senadhira D, Gregorio GB, Cheng Z. 2002. Testing iron and zinc bioavailability in genetically enriched bean (*Phaseolus vulgaris* L.) and rice (*Oryza sativa* L.) using a rat model. Food Nutr. Bull. 21:428-433.

WHO (World Health Organization). 1996. The world food summit: micronutrient malnutrition: half of the world affected. Geneva: WHO. p 1-4.

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Response of rice and wheat to organic and inorganic fertilizers and soil amendment under sodic water-irrigated conditions

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In many arid and semiarid regions of the world, sodic groundwater is the main or only source of irrigation and its use poses a threat to improved rice and wheat production. Application of gypsum as a soil or water amendment is commonly recommended to offset the deteriorating effects of these types of water. However, organic amendments have also been used to alleviate the adverse effects of soil sodicity on crop growth. Long-term nutrient management strategies developed so far for improving rice-wheat production on sodic lands are potentially applicable to areas having good-quality underground irrigation water. Since rice-wheat is the most commonly practiced crop rotation system in the Indo-Gangetic plains, improving its productivity, particularly in areas with poor-quality groundwater, is a major challenge. We investigated the long-term effects of sodic irrigation water (residual sodium carbonate [RSC] 8.5 meq L^{-1} and sodium absorption ratio [SAR] 8.8) with and without gypsum as a soil amendment and organic (farmyard manure [FYM] and pressmud) and inorganic fertilizer use (N, P, K, and Zn) on soil properties and yields of rice and wheat.

An 8-yr field experiment (1994-2001) with a wet-season rice (*Oryza sativa* L.) and winter-season wheat (*Triticum aestivum* L.) cropping system was conducted by CSSRI at the Bhaini Majra Experimental Farm, Kaithal. The experimental site (29.80° N, 76.45° E) is about 250 m above mean sea level. The experimental soil is classified as Aquic Natrustalfs with illite as a dominant mineral. Surface soil (0–15 cm) is sandy loam (52% sand, 25% silt, and 23% clay), with pH 8.6, SAR 29.0, organic carbon 0.4%, available P 14.8 kg ha^{-1}, available K 275 kg ha^{-1}, and CEC 10.2 cmol kg^{-1}. There were 10 treatments (Table 1) replicated four times in a randomized complete block design. The last two treatments with pressmud (T9 and T10) were included starting in 1997. The N, P, K, and Zn doses as per treatments (120 kg N, 26 kg P, 42 kg K, and 4.5 kg Zn ha^{-1}) were applied as urea, single superphosphate, muriate of potash, and zinc sulfate, respectively. The experiment was continued with the rice-wheat cropping sequence in the fixed layout each year during the 8-y period. The crops were irrigated with groundwater as and when required.

The 5-d-old seedlings (three $hill^{-1}$) of rice cultivar Jaya were transplanted in standing water (5 ± 1 cm) in the first week of July each year at 20 × 15-cm spacing. One-third of N and full

Table 1. Effects of gypsum, farmyard manure (FYM), pressmud, and inorganic fertilizer use on rice yield, Karnal, India, 1994-2001.

Treatment		Grain yield (t ha^{-1})								Mean	Increase over control (%)
Rice	Wheat	1994	1995	1996	1997	1998	1999	2000	2001		
T_1 (control)	Control	3.42	3.15	2.11	2.20	2.25	2.76	2.71	2.78	2.67	–
T_2 (N_{120})	N_{120}	4.84	4.75	3.02	3.23	3.31	4.37	4.04	4.27	3.98	49.1
T_3 (N_{120} P_{26})	N_{120} P_{26}	5.58	5.76	4.16	4.10	4.16	5.07	4.33	4.79	4.74	77.5
T_4 (N_{120} P_{26} K_{42})	N_{120} P_{26} K_{42}	5.46	5.65	4.23	4.24	4.32	5.45	4.38	4.81	4.82	80.5
T_4 (N_{120} P_{26} K_{42} $Zn_{4.5}$)	N_{120} P_{26} K_{42}	5.45	5.81	4.25	4.84	4.73	5.49	4.53	4.94	5.01	87.6
T_6 (T_4 + FYM 10 t ha^{-1})	N_{120} P_{26} K_{42}	5.62	5.92	4.86	4.97	4.96	5.81	4.88	5.30	5.29	98.1
T_7 (T_4 + gypsum 5 t ha^{-1})	N_{120} P_{26} K_{42}	5.53	5.85	4.36	4.81	4.79	5.73	4.92	5.38	5.17	93.6
T_8 (T_4 FYM 10 t ha^{-1} + gypsum 5 t ha^{-1})	N_{120} P_{26} K_{42}	5.61	6.12	4.78	4.87	5.07	5.79	4.93	5.62	5.35	100.4
T_9 (T_4 + pressmud 10 t ha^{-1})	N_{120} P_{26} K_{42}	–	–	–	5.04	5.05	6.24	4.88	5.36	5.31	98.9
T_{10} (T_4 + pressmud 10 t ha^{-1}) + gypsum 5 t ha^{-1}	N_{120} P_{26} K_{42}	–	–	–	5.28	5.10	6.19	4.95	5.52	5.41	102.6
LSD P = 0.05		0.51	0.56	0.54	0.41	0.34	0.53	0.49	0.44	0.46	–
Av rainfall (mm)		691	1035	585	847	667	308	540	622	–	–

doses of P, K, Zn, gypsum, FYM, and pressmud were added at the time of transplanting. The remaining N was broadcast into equal splits at 3 and 6 wk after transplanting. The crop was harvested in the third week of October each year. Grain yield of rice was computed to 14% moisture content and straw yield on an oven-dry basis.

Wheat cultivar HD2329 was sown in the second week of November each year at a row spacing of 20 cm. One-third of N and full doses of P and K were applied during sowing. The remaining N was topdressed in two equal splits at 3 and 6 wk after sowing. The crop was harvested in the second week of April each year. Grain and straw yields of wheat were recorded on an oven-dry basis.

The continuous use of fertilizer N alone (120 kg ha^{-1}) significantly improved grain yield of rice and wheat over the control (no fertilizer, Tables 1 and 2). Mean yield increased by 49.1% for rice and 73.2% for wheat. Phosphorus applied at 26 kg ha^{-1} each to rice and wheat significantly improved yields, with the mean increase being 0.76 and 0.64 t ha^{-1}, respectively. Potassium applied at 42 kg ha^{-1} to both crops had no significant effect on yields. Zinc application improved the yield of rice but the effects were significant only in 1997 and 1998. The NPK fertilizer with either 10 t FYM ha^{-1} or 5 t pressmud ha^{-1} (T6, T7, and T9) recorded significantly higher yields over the years than NPK alone (T4). The residual effect of FYM, gypsum, and pressmud on wheat yield has been significant since 1997. Though yields of both crops improved further when gypsum was applied with FYM or pressmud (T8 and T10), the differences were not significant

Table 2. Effects of gypsum, farmyard manure (FYM), pressmud, and inorganic fertilizer use on wheat yield, Karnal, India, 1994-2002.

Treatment		Grain yield (t ha^{-1})								Mean	Increase over control
Rice	Wheat	1994-95	1995-96	1996-97	1997-98	1998-99	1999-2000	2000-01	2001-02		
T_1 (control)	Control	1.44	1.65	1.68	1.64	1.67	1.77	1.86	1.69	1.68	–
T_2 (N_{120})	N_{120}	2.47	2.85	2.84	2.79	2.65	3.24	3.25	3.17	2.91	73.2
T_3 (N_{120} P_{26})	N_{120} P_{26}	2.82	3.56	3.28	3.36	3.76	3.84	3.88	3.92	3.55	111.3
T_4 (N_{120} P_{26} K_{42})	N_{120} P_{26} K_{42}	2.88	3.55	3.38	3.44	3.91	3.92	4.09	1.00	3.65	117.3
T_4 (N_{120} P_{26} K_{42} $Zn_{4.5}$)	N_{120} P_{26} K_{42}	2.83	3.65	3.68	3.64	4.22	3.96	4.29	4.09	3.80	126.2
T_6 (T_4 + FYM 10 t ha^{-1})	N_{120} P_{26} K_{42}	2.92	3.71	3.80	3.82	4.44	4.47	4.78	4.58	4.07	142.3
T_7 (T_4 + gypsum 5 t ha^{-1})	N_{120} P_{26} K_{42}	2.90	3.65	3.73	3.72	4.36	4.33	4.65	4.62	4.01	138.7
T_8 (T_4 FYM 10 t ha^{-1} + gypsum 5 t ha^{-1})	N_{120} P_{26} K_{42}	3.03	3.72	3.85	3.90	4.48	4.40	4.82	4.80	4.13	145.8
T_9 (T_4 + pressmud 10 t ha^{-1})	N_{120} P_{26} K_{42}	–	–	–	3.92	4.43	4.39	4.81	4.64	4.44	98.9
T_{10} (T_4 + pressmud 10 t ha^{-1} + gypsum 5 t ha^{-1})	N_{120} P_{26} K_{42}	–	–	–	3.91	4.54	4.57	4.71	4.73	4.49	167.3
LSD P=0.05		0.32	0.45	0.33	0.33	0.31	0.27	0.29	0.32	0.32	–

Table 3. Physicochemical properties of surface soil (0–15) after 8 y of experimentation, Karnal, India, 1994-2001.

Treatment		pH	Organic C (%)	Available nutrients (kg ha^{-1})			DTPA extractable Zn (mg kg^{-1})	Increase over control (%)
				N	P	K		
Rice	Wheat			1999	2000	2001		
T^1 (control)	Control	8.50	0.26	90	11.0	220	0.64	18.4
T_2 (N_{120})	N_{120}	8.53	0.27	146	4.04	4.27	3.98	49.1
T_3 (N_{120} P_{26})	N_{120} P_{26}	8.48	0.27	146	18.5	240	0.65	13.5
T_4 (N_{120} P_{26} K_{42})	N_{120} P_{26} K_{42}	8.52	0.26	146	22.2	282	0.66	14.2
T_4 (N_{120} P_{26} K_{42} $Zn_{4.5}$)	N_{120} P_{26} K_{42}	8.50	0.26	144	20.5	279	1.12	14.1
T_6 (T_4 + FYM 10 t ha^{-1})	N_{120} P_{26} K_{42}	8.40	0.41	158	22.0	296	1.03	12.1
T_7 (T_4 +gypsum 5 t ha^{-1})	N_{120} P_{26} K_{42}	8.20	0.37	148	18.9	291	0.69	11.7
T_8 (T_4 FYM 10 t ha^{-1} + gypsum 5 t ha^{-1})	N_{120} P_{26} K_{42}	8.30	0.40	159	23.3	297	1.11	10.3
T_9 (T_4 + pressmud 10 t ha^{-1})	N_{120} P_{26} K_{42}	8.30	0.41	155	23.8	295	0.96	11.5
T_{10} (T_4 + pressmud 10 t ha^{-1} + gypsum 5 t ha^{-1})	N_{120} P_{26} K_{42}	8.30	0.40	157	23.2	292	0.95	10.1
CD (P=0.05)		0.09	0.05	8	3.1	22	0.14	0.8

over treatments T6, T7, and T9. The differences in rice and wheat yields over the years have risen primarily because of erratic rainfall and its impact on the SAR of the soil (Tables 1, 2, and 3). Continuous irrigation with sodic water and inorganic fertilizer use for 8 y slightly decreased soil pH and SAR from initial values of 8.6 and 29.0 to 8.50 and 18.7, respectively. However, treatments involving the use of gypsum, FYM, and pressmud significantly decreased soil pH and SAR and improved soil organic C and available N, P, K, and Zn over inorganic fertilizer treatments and the control (Table 3). The results suggest that rice and wheat productivity and soil fertility can be sustained by the integrated use of gypsum, FYM, or pressmud with the recommended NPK dose in areas having sodic underground water. Pressmud, a byproduct of sugar manufacture and a cheap alternative to gypsum, offers opportunities to Indo-Gangetic farmers to efficiently use poor-quality groundwater and improve rice-wheat productivity and soil fertility.

Comparison of different amendments for alleviating iron toxicity in rice

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Highly weathered soils that are acidic, deficient in nutrients, and rich in sesquioxides occur in 11.7 million ha in India (Prasad and Biswas 2000) and in 0.75 million ha in Orissa (Sahu 1993). Rice is grown in low- to medium-elevation land with this type of soil and crops adjacent to leached upland often suffer from Fe toxicity associated with interflow of water from the upland. The mechanism by which the interflow exhibits iron toxicity in rice is uncertain, but it appears to involve dilution of plant nutrients and upsetting of the plant's ability to exclude toxic Fe rather than an inflow of large amounts of dissolved Fe (Van Breemen and Moormann 1978). Amelioration of Fe toxicity in rice through different means has been studied elsewhere (Van Breemen and Moormann 1978, Sahu et al 2001, Sahrawat et al 2001).

To study the comparative efficacy of various amendments for amelioration of Fe toxicity under these conditions and interactions with climate and genotypes, field experiments were conducted in the 1999, 2000, and 2001 wet seasons (WS) at the OUAT Central Research Station. The soil is an Aeric Haplaquept derived from highly weathered materials with pH 5.0, CEC 5.1 cmol (p+)- kg^{-1}, 0.39% organic C, 11 ppm Olsen's P, 58 ppm NH_4OAc K, 412 ppm DTPA-extractable Fe, 1.0 ppm Zn, and 35 ppm Mn. The treatments included eight amendments such as application of lime (0.5 and 0.25 lime requirement), fly ash (20 and 10 t ha^{-1}), K (66 kg ha^{-1}), Zn (10 and 5 kg ha^{-1}), and foliar spray of $MnSO_4$ (0.6%). One no-amendment treatment was included. Two rice varieties, Mahsuri (tolerant of Fe toxicity) and Jajati (susceptible to Fe toxicity), were used. The experimental design was a split plot with rice variety as the main plot and amendments as

Table 1. Effects of different amendments on Fe toxicity of susceptible and tolerant rice varieties.[a]

Treatment	Jajati (susceptible)				Mahsuri (tolerant)			
	1999	2000	2001	Mean	1999	2000	2001	Mean
No amendment	9	7	9	8.3	2	3	3	2.7
Lime (0.5 of LR[b])	3	3	5	3.7	1	2	2	1.7
Lime (0.25 of LR)	5	3	7	5.0	2	2	2	2.0
Fly ash (20 t ha^{-1})	5	5	7	5.7	3	2	1	2.0
Fly ash (10 t ha^{-1})	5	5	7	5.7	3	3	2	2.7
Potassium (80 kg ha^{-1})	5	5	6	5.3	3	3	2	2.7
Zn (10 kg ha^{-1})	3	3	5	3.7	2	2	1	1.3
Zn (5 kg ha^{-1})	3	3	7	4.3	3	3	2	2.3
$MnSO_4$ (0.6%) (foliar spray)	5	7	7	6.3	2	2	3	2.3

[a]1 = least severe, 9 = most severe (IRRI 1980). [b]LR = lime requirement.

subplots, replicated three times. All the treatments received 80 kg N, 18 kg P, and 33 kg K ha^{-1} applied in two equal splits at transplanting and 25 d after transplanting. Urea, single superphosphate, and muriate of potash were the sources of N, P, and K, respectively. Nitrogen was applied in three splits (25% at transplanting, 50% at mid-tillering, and 25% at panicle initiation). All the P was supplied at transplanting and a foliar spray of $MnSO_4$ was given at mid-tillering.

Symptoms of Fe toxicity appeared in the control treatment 25 d after planting the susceptible variety. Symptoms were reddish brown spots on the tips of the lower leaves, with bronzing spreading over the entire leaf.

Bronzing symptoms were scored at 40 DAT following the *Standard evaluation system for rice* (IRRI 1980). These symptoms decreased with the application of the different amendments (Table 1). Application of Zn and lime at higher doses resulted in minimum toxicity. Jajati gave higher toxicity values than Mahsuri.

Grain and straw yield (Tables 2 and 3) of both varieties increased with application of the different amendments. Application of Zn showed the highest yield because of antagonism between Zn and Fe.

Except for straw yield in 2001, Mahsuri produced higher yield than Jajati.

Fe concentration in leaves (Table 4) was higher in the control treatment. A minimum concen-tration of Fe in leaves was observed in the Zn treatment, followed by the lime treatment. Jajati showed a higher Fe concentration in leaves than did Mahsuri.

Table 2. Effects of different amendments on grain yield (t ha^{-1}) of susceptible and tolerant rice varieties grown in Fe-toxic soil, Orissa, India.

Treatment	Jajati				Mahsuri			
	1999	2000	2001	Mean	1999	2000	2001	Mean
No amendment	1.1	1.7	2.6	1.8	1.0	2.2	2.7	2.0
Lime (0.5 of LR)	1.4	2.4	3.0	2.3	2.2	2.7	3.3	2.7
Lime (0.25 of LR)	1.5	2.4	2.9	2.3	2.1	2.8	3.2	2.7
Fly ash (20 t ha^{-1})	1.6	2.2	3.3	2.4	1.8	2.5	4.1	2.8
Fly ash (10 t ha^{-1})	1.6	2.1	3.0	2.2	1.6	2.7	4.0	2.8
Potassium (80 kg ha^{-1})	1.6	2.6	3.5	2.6	1.9	2.6	4.5	3.0
Zn (10 kg ha^{-1})	1.9	2.7	3.9	2.8	2.2	2.9	4.7	3.3
Zn (5 kg ha^{-1})	1.6	2.7	3.4	2.6	2.1	2.7	4.2	3.0
$MnSO_4$ (0.6%) (foliar spray)	1.2	1.9	2.8	2.0	1.6	2.5	3.4	2.5
Mean CD (0.05)[a]	1.5	2.3	3.2	2.3	1.8	2.6	3.8	2.8
Variety (V)	0.09	0.02	0.03					
Amendment (A)	0.20	0.03	0.06					
V × A	0.28	0.04	ns					

[a]CD values refer to two varieties, nine treatments, and three replications in a split-plot design. ns = not significant.

Table 3. Effects of different amendments on straw yield (t ha^{-1}) of susceptible and tolerant rice varieties grown in Fe-toxic soil, Orissa, India.

Treatment	Jajati				Mahsuri			
	1999	2000	2001	Mean	1999	2000	2001	Mean
No amendment	1.4	1.4	2.7	1.8	1.6	2.1	2.8	2.2
Lime (0.5 of LR)	2.5	2.2	3.0	2.6	2.7	2.5	3.5	2.9
Lime (0.25 of LR)	2.5	2.3	3.2	2.7	2.8	2.3	3.5	2.9
Fly ash (20 t ha^{-1})	2.4	2.1	3.2	2.6	2.5	2.3	4.1	3.0
Fly ash (10 t ha^{-1})	2.4	1.9	3.6	2.6	2.2	2.3	3.8	2.8
Potassium (80 kg ha^{-1})	2.7	2.4	3.8	3.0	2.6	2.5	4.7	3.3
Zn (10 kg ha^{-1})	2.6	2.3	4.1	3.0	3.1	2.5	4.8	3.5
Zn (5 kg ha^{-1})	2.5	2.4	3.6	2.8	2.8	2.5	3.9	3.1
$MnSO_4$ (0.6%) (foliar spray)	2.1	1.8	2.8	2.2	2.2	2.3	3.5	2.7
Mean	2.3	2.1	3.3	2.6	2.5	2.4	3.8	2.9
CD (0.05)[a]								
Variety (V)	0.13	0.02	ns					
Amendment (A)	0.29	0.03	0.05					
V × A	0.40	0.04	ns					

[a]CD values refer to two varieties, nine treatments, and three replications in a split-plot design. ns = not significant.

Table 4. Effects of different amendments on Fe concentration (ppm) in leaves of susceptible and tolerant rice varieties grown in Fe-toxic soil, Orissa, India.

Treatment	Jajati				Mahsuri			
	1999	2000	2001	Mean	1999	2000	2001	Mean
No amendment	918	916	956	930	635	664	773	691
Lime (0.5 of LR)	489	526	652	556	377	374	395	382
Lime (0.25 of LR)	558	516	679	583	408	395	530	444
Fly ash (20 t ha^{-1})	533	576	701	603	471	490	450	472
Fly ash (10 t ha^{-1})	539	623	663	608	508	513	538	520
Potassium (80 kg ha^{-1})	620	655	734	670	523	528	480	510
Zn (10 kg ha^{-1})	430	503	605	513	345	467	414	409
Zn (5 kg ha^{-1})	473	582	625	560	350	465	568	461
$MnSO_4$ (0.6%) (foliar spray)	522	590	724	612	410	423	455	429
Mean	565	610	704	626	447	480	511	491
CD (0.05)[a]								
Variety (V)	13.140	1.789	1.203					
Amendment (A)	4.383	4.227	4.169					
V × A	6.199	5.978	5.896					

[a]CD values refer to two varieties, nine treatments, and three replications in a split-plot design.

References

IRRI (International Rice Research Institute). 1980. Standard evaluation system for rice. 2nd ed. International Rice Testing Program. Manila (Philippines): IRRI.

Prasad RN, Biswas PP. 2000. Land resources in sustainable agricultural development. Indian Farming 49:9-13.

Sahu SK. 1993. Soils of Orissa and their management. Orissa Rev. 49:10-13.

Sahu SK, Sandha B, Dev G. 2001. Relationship between applied potassium and iron toxicity in rice. Int. Rice Res. Notes 26(2):52-53.

Sahrawat KL, Diatta S, Singh BN. 2001. Nutrient application reduces iron toxicity in lowland rice. Int. Rice Res. Notes 26(2):51-52.

Van Breemen N, Moormann FR. 1978. Iron-toxic soils. In: Soils and rice. Manila (Philippines): International Rice Research Institute. p 781-800.

Evaluating nitrogen transfer efficiency of immobilized cyanobacteria to rice seedlings by ^{15}N technique

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The N_2-fixing cyanobacteria play a vital role in the maintenance of soil fertility and sustainability. Immobilization of these cyanobacteria in soil matrices could improve their growth, nitrogenase activity, and ammonia excretion level (Kannaiyan et al 1994). The present experiment aimed to quantify the amount of N transferred from immobilized cyanobacteria to rice seedlings using the ^{15}N dilution method.

The cyanobacteria cultures—*Anabaena azollae* (AS-DS-SK) and *Nostoc muscorum* (DOH)—were immobilized in polyurethane foam (PUF) and sugarcane waste (SCW) based on the physical entrapment principle. Two g of 10-cm-sided bits of PUFs, washed well in distilled water, were placed into a 250-mL conical flask containing 100 mL of N-free BG-11 medium and sterilized. The SCW (bagasse) was cut into 2.5-cm bits, soaked in 0.05% NaOH for 1 h, washed several times with distilled water until free of alkali, and finally soaked in distilled water. Ten grams of bits were placed into a 250-mL conical flask containing 100 mL of N-free BG-11 medium and sterilized. The actively growing cultures were inoculated to a final concentration of 0.05 OD at 750 mm. The flasks were incubated in a growth chamber at 3,000-lux light intensity with 12-h day/night cycle at 24 ± 1 ºC. The 1-mo-old immobilized and free-living cultures were used in this study.

The hydroponic rice culture (cultivar ADT36) in N-free medium (Watanabe 1977) was inoculated with 0.5 g cell equivalent of free-living, PUF-, and SCW-immobilized cyanobacterial cultures. The ^{15}N urea (10% ^{15}N atom excess) was applied at 5 mg L^{-1} at weekly intervals. The hydroponic rice culture was carried out in a growth chamber at 3,000-lux light intensity with 12-h day/night cycle at 24 ± 1 ºC. After 1 mo, the

Effect of inoculation of immobilized cyanobacteria on N content, N uptake, and ^{15}N atom % excess in ADT36 rice seedlings grown under hydroponic conditions.

Treatment[a]	Cyanobacterial N content[b] (%)	Rice seedlings after 30 d		
		Nitrogen (%)	N uptake (mg plant^{-1})	% ^{15}N atom[c] excess
A. azollae (AS-DS-SK) (free) +^{15}N urea	3.48	1.54	0.40	6.04
A. azollae (AS-DS-SK) (PUF) +^{15}N urea	3.77	2.29	0.68	5.90
A. azollae (AS-DS-SK) (SCW) +^{15}N urea	3.84	2.53	0.73	5.70
N. muscorum (DOH) (free) +^{15}N urea	3.51	1.58	0.41	5.93
N. muscorum (DOH) (PUF) +^{15}N urea	3.82	2.21	0.73	5.68
N. muscorum (DOH) (SCW) +^{15}N urea	3.80	2.36	0.92	5.09
^{15}N urea alone	–	1.43	0.37	7.09
CD (0.05)	ns	0.120	0.004	0.028

[a] Free = free-living condition, PUF = polyurethane foam immobilized condition, SCW = sugarcane waste immobilized condition. [b] N content of both free-living and immobilized cyanobacterial cultures at the time of inoculation. [c] %^{15}N atom excess was calculated following Proden et al (1985).

total N content of rice seedlings was estimated by the Kjeldahl method and $^{15}N/^{14}N$ was determined using the Micromass 622 VG ISO gas mass spectrometer. The percent N derived from fertilizer (^{15}Ndff) and cyanobacteria (^{15}Ndfc) was calculated following the procedure of Pruden et al (1985).

Inoculation of cyanobacteria, either as immobilized or free-living along with urea, significantly increased N content and N uptake of rice seedlings (see table). Among the cultures, *N. muscorum* (DOH) immobilized in SCW with ^{15}N urea recorded the highest N content and N uptake of rice seedlings. The rice seedlings receiving the immobilized culture have recorded higher N accumulation than the free-living cultures. In particular, the SCW-immobilized *N. muscorum* (DOH) contributed significantly higher N to rice seedlings (25.84%) than the other (see figure) by way of N_2 fixation, thereby recording a high N transfer efficiency. The results revealed that 16–28% of N can be added to rice seedlings by immobilized cyanobacteria in the presence of urea as fertilizer N (Valiente et al 2000).

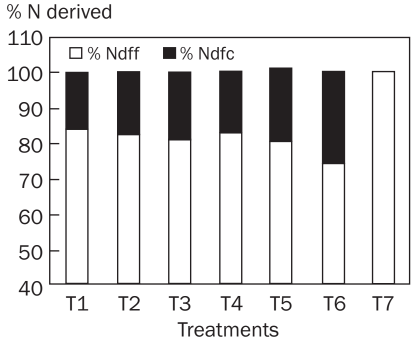
References

Kannaiyan S, Rao KK, Hall DO. 1994. Immobilization of *Anabaena azollae* from *Azolla filiculoides* in polyvinyl foam for ammonia production in a photobioreactor. World J. Microbiol. Biotechnol. 10:55-58.

Pruden G, Powson DS, Jenkinson DS. 1985. The measurement of ^{15}N in soil and plant materials. Fert. Res. 6:205-218.

Valiente EF, Ucha A, Quesoda A, Leganes F, Carreres R. 2000. Contribution of N_2-fixing cyanobacteria to rice production: availability of nitrogen from ^{15}N-labelled cyanobacteria and ammonium sulfate to rice. Plant Soil 221(1):107-112.

Watanabe I. 1977. *Azolla* utilization in rice culture. Int. Rice Res. Newsl. 2(3):10.



Nitrogen contribution by immobilized cyanobacteria to rice seedlings (cultivar ADT36) grown under hydroponic conditions.

T_1 = *A. azollae* (AS-DS-SK) (free); T_2 = *A. azollae* (AS-DS-SK) (PUF); T_3 = *A. azollae* (AS-DS-SK) (SCW); T_4 = *N. muscorum* (DOH) (free); T_5 = *N. muscorum* (DOH) (PUF); T_6 = *N. muscorum* (DOH) (SCW); T_7 = ^{15}N urea. (All treatments received ^{15}N urea uniformly as uninoculated control.)

% Ndff and %Ndfc were calculated as follows (Pruden et al 1985):

$$\%\ \text{Ndff} = \frac{\text{Percent } ^{15}\text{N atom excess in inoculated plant}}{\text{Percent } ^{15}\text{N atom excess in uninoculated plant}} \times 100$$

$$\%\ \text{Ndfc} = 100 - \%\text{Ndff}$$

Evaluation and identification of cold-tolerant rice genotypes by cold-water irrigation stress

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In temperate regions, rice is cultivated as a summer crop. However, several million hectares in temperate and high-altitude areas cannot be planted with modern rice varieties because of low-temperature stress at different stages of plant growth. Low temperatures below 15 °C during the vegetative stage cause leaf discoloration, reduce tillering, and delay heading (Rutger and Peterson 1979). During the reproductive stage, low night temperature causes sterility, leading to a 20% yield loss (Li et al 1997, Kwon et al 2002). In South Korea, low-temperature stress is the main limiting factor for rice productivity. The main challenge is to identify appropriate solutions to low-temperature stress in rice. This study has been undertaken to evaluate 69 advanced breeding lines of the International Rice Research Institute (IRRI) along with five Korean rice cultivars using the cold-water-temperature irrigation facility developed at the Chuncheon substation of NICS, RDA, Republic of Korea, to identify promising cold-tolerant genotypes for use as donors in their temperate rice improvement program through molecular genetics and breeding research.

The 69 IRRI lines consisted of 51 new plant types (NPT) and 18 bred for high-altitude areas (HAA) of the Philippines. Korean rice cultivars Jinbubyeo and Odaebyeo were used as cold-tolerant checks and Saesbeolbyeo was the cold-sensitive check. The IRRI breeding lines, along with Korean varieties, were planted in single rows each and consisted of 40 plants at a spacing of 30 cm × 15 cm. Irrigation water temperature was normal until tillering stage. Water temperature regimes ranging from 17, 18, 19, and 25 °C were set and continuous flowing water of 5-cm depth was maintained from tillering to maturity. Leaf discoloration was scored during the vegetative stage and data on four agronomic traits—culm length (cm), panicle exsertion (cm), panicle length (cm), and spikelet sterility (%)—were collected at the end of the stress period for the selected 12 breeding lines. Traits were evaluated using the *Standard evaluation methods of rice* (RDA 1995).

Of the 69 IRRI breeding lines tested at four temperature regimes, five NPT lines and two lines adapted to HAA did not express leaf discoloration. The plants stayed green throughout the growth period. The remaining 62 IRRI lines were highly

Genotypes and performance of four agronomic traits in each temperature regime.[a]

Variety/genotype	Culm length (cm)				Panicle length (cm)			
	17 °C	18 °C	19 °C	25 °C	17 °C	18 °C	19 °C	25 °C
Geumobyeo	51.0 ^{d}	54.0 ^{c}	57.0 ^{cd}	69.6 ^{de}	15.4 ^{ef}	16.6 ^{de}	16.8 ^{cd}	19.0 ^{f}
Sangjubyeo	49.2 ^{d}	49.2 ^{d}	55.4 ^{d}	67.4 ^{ef}	16.4 ^{de}	17.0 ^{d}	16.8 ^{cd}	19.0 ^{f}
Jinbubyeo	56.2 ^{c}	59.2 ^{b}	59.2 ^{cd}	72.4 ^{d}	14.6 ^{f}	15.4 ^{e}	15.2 ^{e}	17.6 ^{fg}
Odaebyeo	58.4 ^{c}	61.0 ^{b}	63.8 ^{b}	70.0 ^{de}	15.4 ^{ef}	16.8 ^{de}	15.8 ^{de}	16.6 ^{g}
Saesbeolbyeo	27.8 ^{h}	27.2 ^{h}	30.6 ^{h}	51.6 ^{g}	16.8 ^{de}	16.2 ^{de}	17.0 ^{cd}	18.8 ^{f}
IR61727-4B-1-1-1	73.6 ^{a}	76.6 ^{a}	84.0 ^{a}	113.0 ^{a}	19.4 ^{b}	20.6 ^{bc}	20.4 ^{b}	23.4 ^{cd}
IR64629-5-3-2-2	65.0 ^{b}	59.2 ^{b}	66.0 ^{b}	88.0 ^{b}	21.8 ^{a}	21.8 ^{ab}	22.4 ^{a}	27.6 ^{a}
IR66160-121-4-4-2	41.8 ^{e}	44.8 ^{e}	51.0 ^{e}	68.6 ^{de}	17.2 ^{cd}	17.4 ^{d}	18.0 ^{c}	21.4 ^{e}
IR69132-17-2-2-2	38.2 ^{f}	38.6 ^{fg}	43.2 ^{f}	77.4 ^{c}	19.4 ^{b}	20.6 ^{bc}	20.2 ^{b}	24.0 ^{bcd}
IR70554-48-1-2	31.2 ^{g}	40.6 ^{f}	41.4 ^{f}	69.2 ^{de}	18.8 ^{bc}	20.4 ^{bc}	20.8 ^{b}	23.0 ^{de}
IR71218-7-1-2	29.2 ^{gh}	36.4 ^{g}	35.2 ^{g}	62.6 ^{f}	20.0 ^{b}	20.0 ^{c}	20.4 ^{b}	25.0 ^{bc}
IR72225-20-3-2-3	31.6 ^{g}	39.0 ^{fg}	43.8 ^{f}	69.6 ^{de}	22.2 ^{a}	22.6 ^{a}	23.8 ^{a}	25.6 ^{b}
MSE	4.78	7.31	7.49	14.76	1.65	1.39	1.40	2.08
LSD	2.78	3.44	3.48	4.89	1.63	1.50	1.50	1.84

Variety/genotype	Panicle exsertion (cm)				Sterility (%)			
	17 °C	18 °C	19 °C	25 °C	17 °C	18 °C	19 °C	25 °C
Geumobyeo	2.6 ^{a}	3.8 ^{a}	4.6 ^{ab}	5.8 ^{bc}	40.5 ^{c}	8.1 ^{e}	7.0 ^{de}	4.2 ^{d}
Sangjubyeo	1.6 ^{a}	2.6 ^{ab}	2.8 ^{c}	6.2 ^{bc}	23.7 ^{d}	12.0 ^{de}	5.2 ^{e}	4.7 ^{d}
Jinbubyeo	2.2 ^{a}	3.8 ^{a}	3.2 ^{bc}	5.0 ^{cd}	12.4 ^{e}	8.0 ^{e}	5.7 ^{e}	2.5 ^{d}
Odaebyeo	1.6 ^{a}	2.6 ^{ab}	5.0 ^{ab}	4.4 ^{cd}	33.0 ^{cd}	28.4 ^{c}	16.7 ^{cd}	3.7 ^{d}
Saesbeolbyeo	-9.0 ^{c}	-9.8 ^{d}	-6.8 ^{f}	-1.2 ^{e}	100.0 ^{a}	100.0 ^{a}	98.8 ^{a}	10.1 ^{cd}
IR61727-4B-1-1-1	2.6 ^{a}	1.2 ^{b}	6.6 ^{a}	11.0 ^{a}	28.5 ^{d}	20.1 ^{cd}	13.4 ^{cde}	10.8 ^{cd}
IR64629-5-3-2-2	2.2 ^{a}	1.8 ^{ab}	3.2 ^{bc}	12.8 ^{a}	98.2 ^{a}	95.1 ^{a}	76.3 ^{b}	12.3 ^{cd}
IR66160-121-4-4-2	-2.8 ^{b}	-2.2 ^{c}	0.4 ^{d}	4.6 ^{cd}	86.9 ^{b}	57.2 ^{b}	21.4 ^{c}	6.8 ^{d}
IR69132-17-2-2-2	-9.0 ^{c}	-8.2 ^{d}	-9.4 ^{g}	5.6 ^{bcd}	100.0 ^{a}	100.0 ^{a}	99.6 ^{a}	66.8 ^{a}
IR70554-48-1-2	-7.2 ^{c}	-4.2 ^{c}	-4.4 ^{e}	8.2 ^{b}	100.0 ^{a}	99.1 ^{a}	97.6 ^{a}	33.8 ^{b}
IR71218-7-1-2	-12.4 ^{d}	-12.4 ^{e}	-8.4 ^{fg}	3.0 ^{d}	100.0 ^{a}	99.1 ^{a}	99.9 ^{a}	26.3 ^{bc}
IR72225-20-3-2-3	-13.6 ^{d}	-9.4 ^{d}	-13.2 ^{h}	-1.4 ^{e}	99.3 ^{a}	99.6 ^{a}	99.6 ^{a}	73.1 ^{a}
MSE	4.34	3.73	2.90	4.31	57.4	56.4	67.1	209.3
LSD	2.64	2.46	2.17	2.64	9.63	9.55	10.4	18.4

[a] Means followed by the same letter are not significant at the 5% level by least significant difference test.

sensitive to low temperature, showing leaf discoloration and poor agronomic traits, and were not considered for data analysis. The performance of the four agronomic traits showed direct correlation with temperature regime. The temperature regimes of 17 °C and 18 °C had severely affected the normal expression of agronomic traits on all rice genotypes. Therefore, we have considered 19 °C water temperature as the critical temperature for the identification of cold-tolerant genotypes. In this temperature regime, the breeding lines IR61727-4B-1-1-1 and IR61660-121-4-4-2 did not show a significant reduction in the traits during the stress period (see table). The reproductive-stage low-temperature stress caused high sterility of spikelets in all lines, except IR61727-4B-1-1-1 and IR66160-121-4-4-2, which had 13% and 21% sterility, respectively, compared with the cold-tolerant japonica varieties Jinbubyeo (6%) and Odaebyeo (17%) (see table). Low temperature had a negative effect on the development of panicles. As a result of low-temperature stress, 62 IRRI breeding lines had degenerated panicles (see figure). The breeding lines IR61727-4B-1-1-1 and IR66160-121-4-4-2 were identified as the most promising genotypes for cold tolerance. The results demonstrated that these breeding lines represent a new source of tolerance for low-temperature stress that could broaden the genetic base of temperate rice cultivars grown in Korea. These two genotypes may also be suitable for boro rice cultivation in the eastern regions of India and Bangladesh.

Degenerate panicles of a low-temperature-sensitive line at the time of flowering.

References

Kwon SJ, Ahn SN, Jeong EG, Jeon YH, Hwang HG, Choi HC, Moon HP. 2002. Relationship between genetic divergence and hybrid performance in japonica rice grown in a cold water-irrigated field. Euphytica 128:389-396.

Li HB, Wang J, Liu AM, Liu KD, Zhang Q, Zou JS. 1997. Genetic basis of low-temperature-sensitive sterility in indica-japonica hybrids of rice as determined by RFLP analysis. Theor. Appl. Genet. 95:1092-1097.

RDA (Rural Development Administration). 1995. Manual for standard evaluation method in agricultural experiment and research. Suwon (Korea): RDA.

Rutger JN, Peterson ML. 1979. Cold tolerance of rice in California. In: Proceedings of rice cold tolerance workshop. Los Baños (Philippines): International Rice Research Institute.

Benefits of growing azolla under a space-sharing method

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In present-day agriculture, even though yield of cereals has increased in harmony with population growth (Bockman 1997), long-term productivity of the soil, particularly in rice fields, has been neglected. To cope with this situation, an attempt was made to replenish the depleted soil N in every season by growing azolla with rice. Under a space-sharing method, a separate space is allotted for rice and azolla. The aim is to offer enough space for the simultaneous growth of azolla in the field and to realize benefits from this approach—effective nutrient turnover, weed control, and more sunlight for rice.

The field experiments were conducted during the wet season (Oct 2001-Jan 2002) in the wetlands of TNAU. The experimental soil (Vertic Ustochrept) was clay (68.6%) and has a pH of 8.2, electrical conductivity 0.66 dS m^{-1}, organic C 0.62%, 242 kg available N ha^{-1}, and 1,440 kg total N ha^{-1}.

Medium-duration cultivar CO 43 (derivative of Dasal and IR20) was raised using four methods of space sharing (see Table 1 for details) and four levels of N (0, 112.5, 150, and 187.5 kg ha^{-1} as urea) in a split-plot design. Fertilizer N was applied in four equal splits (0, 25, 45, and 65 d after transplanting) (DAT). Azolla (*A. pinnata*) was inoculated at 3 DAT and maintained in floodwater until a week before harvest. No herbicide was used. Hand weeding was done at 25 and 45 DAT. Core samples of surface soil (7.5-cm-diam core up to 15-cm depth) were analyzed by procedures outlined for organic carbon by Walkley and Black (1934), for available N by Subbiah and Asija (1956), and for Kjeldahl N by Bremner (1965).

At harvest, when compared with the rice-azolla dual-culture method (M_1), the 2:1 space-sharing method with high rice density (M_3) exhibited a significant improvement in N uptake and, consequently, grain and straw yield (Table 2). Furthermore, there was greater buildup of organic C (+ 0.10%), available N (+10 kg ha^{-1}), and total N (+ 53 kg ha^{-1}) in the postharvest soil over M_1.

The beneficial effects of azolla observed in this study can be attributed to its preferred adaptability in the rice ecosystem and capability to fix substantial biological N_2 (Shrestha and Ladha

Table 1. Details of space-sharing methods.

	Sharing methods (rice space : azolla space)	Space transplanted(%)	Rice population density in plot, including the space for *Azolla* (hills m^{-2} [no.])
M1	No space sharing: azolla within rice as dual culture (20 ´ 10 cm spacing)	100	50
M2	2 : 1 space sharing with low rice density: azolla in 0.5-m space with every five rows of rice (20 ´ 10 cm spacing)	67	35
M3	2 : 1 space sharing with high rice density: azolla in 0.5-m space with every seven rows of rice (15 ´ 10 cm spacing)	67	48
M4	3 :1 space sharing with high rice density: azolla in 0.5-m space with every 10 rows of rice (15 10 cm spacing)	75	52

Table 2. Grain and straw yield, N uptake, and postharvest soil status.

Treatment		Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	N uptake (grain + straw) (kg ha^{-1})	Postharvest soil status		
Method of space sharing	N levels (kg ha^{-1})				Organic C (%) (kg ha^{-1})	KmnO$_4$-N (available N) (kg ha^{-1})	Kjeldahl N (total N)
M1	0	3.51	6.14	82.2	0.74	235	1481
	112.5	4.46	6.82	115.8	0.89	258	1497
	150	4.87	7.52	124.9	0.84	249	1502
	187.5	5.12	8.32	133.3	0.79	258	1499
	Mean	4.49	7.18	114.0	0.83	250	1495
M2	0	3.21	5.28	74.0	0.93	244	1557
	112.5	3.91	5.84	101.4	1.09	268	1561
	150	4.31	6.60	114.5	1.04	273	1579
	187.5	4.52	7.24	120.8	0.97	260	1585
	Mean	3.98	6.24	102.7	0.96	261	1570
M3	0	3.82	6.22	88.2	0.84	264	1528
	112.5	4.73	7.50	118.4	0.97	266	1555
	150	5.27	8.22	130.5	0.93	258	1564
	187.5	5.31	8.92	136.5	0.92	252	1544
	Mean	4.78	7.71	118.4	0.92	260	1548
M4	0	3.57	5.92	81.0	0.81	228	1512
	112.5	4.70	7.02	109.7	0.88	257	1514
	150	4.86	7.56	117.9	0.87	251	1505
	187.5	5.02	8.44	131.7	0.81	249	1529
	Mean	4.54	7.23	110.1	0.87	246	1515
CD[a]							
Methods		0.11**	0.24**	3.94**	0.02**	7.7**	42*
N levels at method		0.18**	0.32**	ns	ns	12.4**	ns

[a] Significance at 5% (*) and 1% (**) levels; ns – not significant.

1996). The azolla biomass would have also decomposed rapidly and supplied N to the rice crop (Roger and Ladha 1992, Kumar and Kannaiyan 2001).

Azolla grown in an exclusive 0.5-m strip alternating with a 1-m strip of rice in the 2:1 rice-azolla space-sharing method benefited the crop and soil more than did the dual system. It has increased soil available N, total N, and organic C at the end of the crop season. This may have resulted from the continuous deposition of senescing tissues of azolla from the azolla mat that has covered the entire floodwater space well before panicle initiation. As a consequence of this fertility enhancement, nutrient uptake of rice was hastened substantially, enabling the crop to adequately respond to applied N even at low levels.

Thus, a large grain yield was achieved at the 150 kg N ha^{-1} level itself (5.27 t ha^{-1}) under M_3, which could otherwise be obtained only by applying 187.5 kg N ha^{-1} under the conventional M_1. With this, a saving of 37.5 kg fertilizer N ha^{-1} has been realized. The 400-kg yield increase recorded under M_3 over the M_1 yield of 4.9 t ha^{-1} at 150 kg N ha^{-1} level was purely the effect of azolla growth in the exclusive space.

These space-sharing methods have shown some scope for bringing about an effective biological N_2 fixation and a soil N enrichment system by allowing adequate and exclusive space for azolla in the rice-growing season itself. For the most part of the crop-growing period, azolla that covers the floodwater surface as a thick mat would help reduce weed growth. This translates into increased rice yield with no additional cost to farmers.

Reference

Bockman OC. 1997. Fertilizers and biological nitrogen fixation as sources of plant nutrients: perspectives for future agriculture. Plant Soil 194:11-14.

Bremner JM. 1965. Methods of soil analysis. Part 2. Madison, Wis. (USA): American Society of Agronomy.

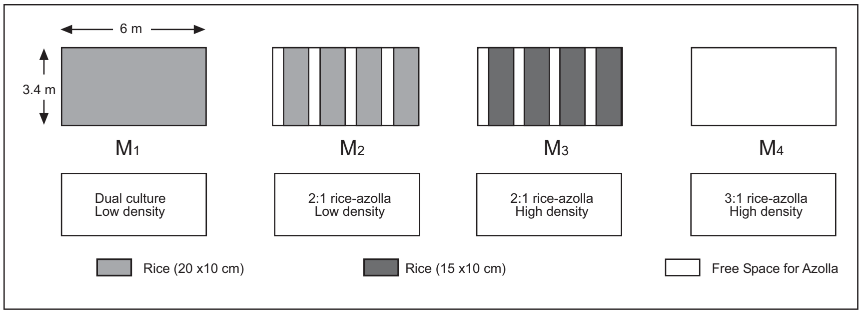
Kumar K, Kannaiyan S. 2001. Potential use of azolla biofertilizer in sustainable rice production. In: Yadav AK, Talukdar NC, editors. Proceedings of the North Eastern Regional Conference on Biofertilizers. Regional Biofertilizer Development Centre, Imphal. p 121.

Roger PA, Ladha JK. 1992. Biological N_2 fixation in wetland rice fields: estimation and contribution to nitrogen balance. Plant Soil 141:41-55.

Shrestha RK, Ladha JK. 1996. Genotypic variation in promotion of rice nitrogen fixation as determined by nitrogen–^{15}N dilution. Soil Sci. Soc. Am. J. 60:1815-1821.

Subbiah BV, Asija GL. 1956. A rapid procedure for estimation of available nitrogen in soils. Curr. Sci. 25:259-260.

Walkley A, Black IA. 1934. An examination of the Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.



Layout of space-sharing methods.

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Boron deficiency in calcareous soil reduces rice yield and impairs grain quality

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In spite of being tolerant of boron (B) deficiency (Savithri et al 1999), flooded rice suffers from this nutritional disorder in Pakistan (Chaudhry et al 1977) and elsewhere (Shorrocks 1997). Though appreciable rice yield increases with B application in Pakistan were initially observed about three decades ago (Chaudhry et al 1977), it is only recently that this micronutrient

Table 1. Yield, agronomic traits, and plant B concentration in Basmati rices as affected by B application to B-deficient calcareous soils in Pakistan.

Cultivar	B applied (kg ha^{-1})	Yield (t ha^{-1})		Panicle sterility (%)	Plant height (cm)	Productive tillers hill^{-1} (no.)	1,000-grain weight (g)	B concentration (mg kg^{-1})		B uptake (g ha^{-1})	B use efficiency (%)
		Grain	Straw					Leaves	Grain		
Basmati 385	0	3.77 a	5.43 a	28 a	134 a	14.3	19.4 a	5.3 a	1.33 a	17.4 a	
LSD (0.05)	1	4.72 b	6.63 b	16 b	140 b	16.1	20.1b	8.2b	2.49b	35.2b	1.78
		0.45	0.29	8	5		0.6	0.5	0.18	1.5	
Super Basmati	0	3.23	5.15a	23a	116a	18.4	19.0a	5.5a	1.73	17.2a	
	1	3.89	5.88b	14b	122b	20.1	20.2b	8.5b	2.51b	34.0B	1.68
LSD (0.05)			0.41	4	2		0.8	0.6	0.29	1.4	

Table 2. Impact of boron application on grain quality of two dominant Basmati varieties.[a]

Grain characteristic			Basmati 385		Super Basmati	
	Control	+ B	LSD (0.05)	Control	+ B	LSD (0.05)
Total milled rice (%)	71.1 a	73.1 b	1.4	70.4 b	72.0 a	
Head rice (%)	54.3 a	57.6 b	0.4	52.9 a	56.5 b	0.9
Kernel length (L) (mm)	6.67 b	6.68 b		7.18	7.36	
Kernel breadth (B) (mm)	1.61	1.62		1.61	1.61	
Kernel thickness (T) (mm)	1.52	1.53		1.53	1.54	
Kernel L:B	4.13	4.15		4.56	4.53	
Quality index (L/B T)	2.70	2.69		2.97	2.94	
Elongation ratio upon cooking	1.94	1.98 a		1.97	2.00	
Bursting upon cooking (%)	11 a	8 b	1	10 a	7 b	1
Alkali spreading value (1–7)[b]	4.5 a	4.8 b	0.2	4.7 a	5.0 b	0.1

[a]Means followed by different letters are statistically different at LSD 0.05. [b]Alkali spreading value: 4–5 score = intermediate gelatinization temperature.

disorder has received attention. In 2002, we studied the relative response to B application of the two most popular Basmati rice cultivars grown in the country.

Five multilocation, non-replicated field experiments (treated as five replications) were carried out in a randomized complete block design in the traditional rice-growing areas of Punjab Province, using Basmati 385 and Super Basmati. Soil in the experimental field was alkaline (pH 7.9–8.8), calcareous ($CaCO_3$ equivalent, 1.5–5.7%), nonsaline (EC, 0.3–1.5 dS m^{-1}), and low in organic matter (0.8–1.8%). Extractable nutrients were 7.8–14.0 mg P kg^{-1}, 102–200 mg K kg^{-1}, and 0.7–2.5 mg Zn kg^{-1}. Available B in the soil ranged from 0.21 to 0.42 mg kg^{-1}.

The experimental treatments consisted of the control (no B application) and 1.0 kg B ha^{-1} as borax, applied before transplanting. In all experiments, basal fertilization—120 kg N ha^{-1} (urea), 44 kg P ha^{-1} (diammonium phosphate), and 10 kg Zn ha^{-1} (zinc sulfate)—was done. Crop management was the same in all treatments. The experimental data collected were plant height, number of productive tillers, number of filled grains panicle^{-1}, B concentration in flag leaves at heading and in mature grain, and grain and straw yields. Total milled rice and head rice were determined and rice grains were analyzed for kernel length, breadth, and thickness; elongation upon cooking and bursting upon cooking; and alkali spreading value.

Boron application substantially increased grain yield in both cultivars (Table 1). The yield increase of Basmati 385 was 25% over that of the control and 20% in Super Basmati but the difference was not statistically significant for the better cultivar. Plant height, number of productive tillers, and grain weight of both cultivars increased with B application; the yield increase was primarily the consequence of reduced panicle sterility (Table 1). Boron concentration in control plant leaves of both cultivars was less than the critical B level of 6 mg kg^{-1} (Jones et al 1991). Moreover, B concentration in the mature grain appeared to be a good indicator of the B nutritional status of plants. Total B uptake by both rice cultivars was doubled with B fertilization, but B-use efficiency (i.e., the fraction of fertilizer B taken up by the aboveground plant parts) was <2% (Table 1).

Milling return and head rice recovery greatly improved with B application in both cultivars (Table 2). Desirable cooking traits such as elongation ratio, bursting on cooking, and alkali spreading value were likewise attained (Table 2). Thus, adequate B supply appears to be a prerequisite for obtaining optimum yields of good-quality Basmati rice. Considering grain yield increases alone, B use was highly cost-effective, with a value-cost ratio of 55:1 in Bamati 385 and 41:1 in Super Basmati. Improvements in milling return and grain quality were added advantages of economic significance.

This study shows that B deficiency-induced panicle sterility is a major cause of yield reduction in B-deficient soils. Boron application not only enhances crop productivity but also improves grain quality. Therefore, in B-deficient situations, rice growers are encouraged to include B in their fertilizer use program.

References

Chaudhry FM, Latif A, Rashid A, Alam SM. 1977. Response of rice varieties to field application of micronutrient fertilizer. Pakistan J. Sci. Ind. Res. 19:134-139.

Jones JB Jr, Wolf R, Mills HA. 1991. Plant analysis handbook. Athens, Georgia (USA): Micro-Macro Publishing. 213 p.

Savithri P, Perumal R, Nagarajan R. 1999. Soil and crop management technologies for enhancing rice production under micronutrient constraints. In: Balasubramanian V et al, editors. Resource management in rice systems: nutrients. Dordrecht (Netherlands): Kluwer Academic Publishers. p 121-135.

Shorrocks VM. 1997. The occurrence and correction of boron defiency. Plant Soil 193:121-148.

Comparative performance of leaf color chart with other nitrogen scheduling practices

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The high N deficiency of Indian soils and the concomitant high N requirement of the rice crop make recovery of applied N crucial. Only 18–40% of N is recovered because of heavy losses through various means and lack of synchronization of crop requirement with N application, resulting in lower physiological efficiency (Natarajan and Pushpavalli 1994). To match N supply with crop demand, a leaf color chart (LCC) based on leaf chlorophyll content and leaf N content has been used, along with fertilizer application dictated by soil nutrient status and what has been recommended. Testing of these types of technologies requires farmers' participation. This study aimed to evaluate different N scheduling practices in rice.

Field experiments were conducted during 2002 kharif in the predominantly rice-growing areas of Haryana. There were three different sites—Teek village, Kaithal District (site I); Krishi Vigyan Kendra, Kaithal (site II); and Rampur Thery, Sirsa (site III). Soil in the experimental fields was sandy clay loam, slightly alkaline (pH 8.0–8.6), low in available N (148–175 kg N ha^{-1}), medium in available P (10.6–12.8 kg P ha^{-1}), and high in available K (315.4–415 kg K ha^{-1}) at all sites. Sixteen treatment combinations comprising four N scheduling practices (recommended practice, soil test-based, farmers' practice, and LCC-based) and four varieties (IR64, HKR126, PR114, and PR106) were laid out in a randomized block design with three replications. For recommended and soil test-based fertilizer application practices, 150-26.4-49.8 kg NPK and 150-17.6-0 kg NPK ha^{-1} were applied in each plot as full P and K and with 1/3 N before transplanting and 1/3 N each at 3 and 6 wk after transplanting (WAT). A survey on existing farmers' practices showed that most farmers used 195 kg N and 25.3 kg P ha^{-1} and this was used as a base in this study (full P; 22.5 kg N basal and 57.5 kg N each at 15, 30, and 45 DAT). In LCC-based fertilizer application (14–54 DAT), a critical value of 4.0 was taken as a signal for applying N. If the means of all LCC readings remain <4.0, then 23 kg N ha^{-1} as urea was applied. In this practice, 26.4 kg P as single superphosphate and 49.8 kg K ha^{-1} as muriate of potash were applied as a basal dose in each plot before transplanting. At 44 DAT, an LCC value of >4.0 was recorded in HKR126 and PR106 at all sites (Table 1); hence, a fertilizer dose of 23 kg N ha^{-1} was omitted. Therefore, total N applied was 92 kg ha^{-1} in HKR126 and PR106 and 115 kg ha^{-1} in PR114 and IR64.

Nitrogen scheduling as per the farmers' practice recorded the highest grain yield, followed by

Table 1. Leaf color chart values recorded at different sites and amount of fertilizer N applied.

Treatment	14 DAT[a]			24 DAT			34 DAT			44 DAT			54 DAT			Total amount of N applied (kg ha^{-1})
	S_1[b]	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	
IR64	2.0	2.0	2.0	3.0	2.8	3.0	3.5	3.0	3.0	3.6	3.4	3.5	3.5	3.3	3.0	115.0
HKR126	2.5	2.4	2.5	3.5	3.6	3.5	3.9	3.7	3.6	4.1	4.3	4.0	3.8	3.8	3.7	92.0
PR114	2.7	2.8	2.5	3.0	3.5	3.5	3.5	3.3	3.5	3.5	3.7	3.7	3.4	3.4	3.5	115.0
PR106	3.0	2.7	2.5	3.8	3.7	3.6	3.8	3.6	3.5	4.2	4.1	4.2	3.8	3.6	3.8	92.0

[a]DAT = days after transplanting. [b]S_1 = Site I, S_2 = Site II, S_3 = Site III.

Table 2. Effect of N scheduling practices and varieties on yield-attributing characters and yield of rice at different sites.

Treatment	Panicles m^{-2} (no.)			Grains panicle^{-1} (no.)			Test weight (g)			Grain yield(t ha^{-1})		
	S_1[a]	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
N scheduling practices												
Recommendation basis	312	293	303	99	91	97	25.7	25.6	25.4	7.2	6.6	6.9
Soil test basis	311	289	300	100	91	98	25.7	25.6	25.3	7.1	6.5	6.9
Farmers' practice	322	301	312	100	91	97	26.0	26.5	26.0	7.6	6.7	7.0
Leaf color chart basis	284	264	274	94	88	93	24.3	24.0	23.8	6.4	5.3	6.0
CD at 5%	15.6	16.5	14.2	4.2	2.8	3.0	1.1	1.2	1.2	0.6	0.2	0.2
Varieties												
IR64	282	265	274	103	95	100	24.8	24.3	24.3	6.4	5.2	5.7
HKR126	309	287	298	100	93	100	26.0	26.1	25.7	7.6	6.9	7.1
PR114	316	295	306	95	88	94	25.3	25.4	25.1	7.2	6.6	6.9
PR106	322	300	312	94	86	91	25.5	25.9	25.4	7.1	6.5	7.1
CD at 5%	15.6	16.5	14.2	4.2	2.8	3.0	1.1	1.2	1.2	0.6	0.2	0.2

[a]S_1 = Site I, S_2 = Site II, S_3 = Site III.

recommended and soil test-based fertilizer application, but all these practices were statistically on a par with each other and found to be significantly superior to LCC-based fertilizer application at all three sites (Table 2). The percent increase in grain yield under the farmers' practice, recommended, and soil test-based fertilizer application over LCC-based fertilizer application was 16.0, 12.2, and 10.8 at site I; 21.8, 20.2, and 19.2 at site II; and 15.1, 14.0, and 13.2 at site III, respectively.

HKR126, PR114, and PR 106 were statistically on a par with each other and significantly superior to IR64 at all sites (Table 2). At site I, HKR126 recorded a 15.7%, 5.9%, and 7.1% increase in grain yield over IR64, PR114, and PR106, respectively, while that at site II was 23.8%, 4.4%, and 5.0%. At site III, PR106 produced 19.6%, 0.8%, and 3.4% higher grain yield than did IR64, HKR126, and PR114, respectively.

Results indicated that, although the N dose under the farmers' practice was 45 kg ha^{-1} higher than the recommended and soil test-based fertilizer application, this increased N level did not have any significant beneficial effect on the growth and yield of the rice crop. The slower growth and lower yield associated with LCC-based N application suggest that a basal dose of N may have a distinct advantage and must be applied for better tillering, faster growth, and ultimately higher yield. Further, the use of the LCC for scheduling N application may not be uniformly applicable to all varieties that differ in inherent leaf color, thereby necessitating individual/group standardization.

Reference

Natarajan K, Pushpavalli R. 1994. Strategies for higher nitrogen use efficiency in lowland rice. Indian Fert. Sci. Ann. p 93-103.

New rice cultivars tolerant of complete submergence

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Flash flooding affects more than 30 million ha of rainfed lowland rice area in South and Southeast Asia, of which 6.2 million ha are in India alone. Partial to complete submergence can be experienced any time during the growing season. The majority of rice germplasm cannot tolerate complete submergence and, if any survives, it tends to elongate and push its leaf tips above the water surface to avoid submergence. However, this mechanism is not suited for flash-flood conditions because excessive elongation causes the stem to become weak and to lodge. The situation worsens if the land becomes inundated within a week or so after the first inundation. Identification of nonelongating, submergence-tolerant cultivars with better agronomic traits is useful for breeding to develop new varieties and for direct use by farmers if these cultivars produce comparatively higher and more stable grain yield.

During the last 3 years, we had screened more than 6,000 rice germplasm accessions collected from different parts of India. In addition, improved germplasm provided through collaborative projects between CRRI and the International Rice Research Institute was also screened for submergence tolerance. The objective was to identify submergence-tolerant rice cultivars comparable with international check FR13A (locally known as Dhalaputia). Though FR13A was identified as a submergence-tolerant cultivar a few decades ago, varietal development using it as a donor has not, so far, been successful because of its poor combining ability in hybridization. Identifying new materials with tolerance for submergence but with a better plant type would be useful for breeding and for other purposes, so that farmers in this fragile environment could improve their living conditions.

The experiments were carried out during the wet seasons of 2001 and 2002. Genotypes were direct-seeded with a spacing of 20 × 15 cm. Three seedlings hill^{-1} were maintained by thinning 10 d after germi-nation. Twenty-one-day-old seedlings were submerged for 12 d under 80 cm of water, followed by normal conditions with 5–10 cm of standing water. Survival counts were taken visually after 10 d of withdrawal of submergence. Floodwater pH, temperature, dissolved oxygen and carbon dioxide concentration, and light penetration were determined at 30 and 60 cm of water depth.

To determine the yield potential of selected lines, an experiment was conducted under shallow rainfed lowland conditions where water depth varied from 0 to 40 cm. The experiment was conducted using transplanted seedlings with 20 × 15-cm spacing. N, P, and K fertilizers were applied at 60-30-30 kg ha^{-1} in the form of urea, single superphosphate, and muriate of potash.

Light intensity at 30- and 60-cm water depth varied from 58% to 63% and 41% to 45%, respectively. Oxygen concentration at the same water depth was 2.2–3.0 ppm at 0600 h and 4.9–7.2 ppm at 1730 h, whereas the concentration of carbon dioxide was 0.016–0.024 mol m^{-3} and 0.011–0.015 mol m^{-3} at 0600 h and 1730 h, respectively. The temperature did not vary greatly; it was 26.8–32.0 °C throughout the experiment. The pH of the water was about 7.00 ± 0.18.

Survival percentage was 0–10% for susceptible rice cultivars IR42, Sarala, Durga, and Tulasi. However, % survival varied from 75% to 88% for tolerant cultivars. In general, elongation due to submergence was more in susceptible cultivars (see table).

To compare the yields of the selected submergence-tolerant cultivars under normal conditions, another experiment was conducted under favorable rainfed lowland conditions with seven photoperiod-sensitive rice cultivars, plus three checks. Check cultivar Durga outyielded the other cultivars (see figure). However, the survival of this cultivar was only 10%. On the other hand, grain yield of the other two check varieties, Sarala and Tulasi, was below or equal to that of submergence-tolerant lines CR2006-7 and CR2003-13. The submergence-tolerant traditional lines FR13A and Kalaputia gave lower yields.

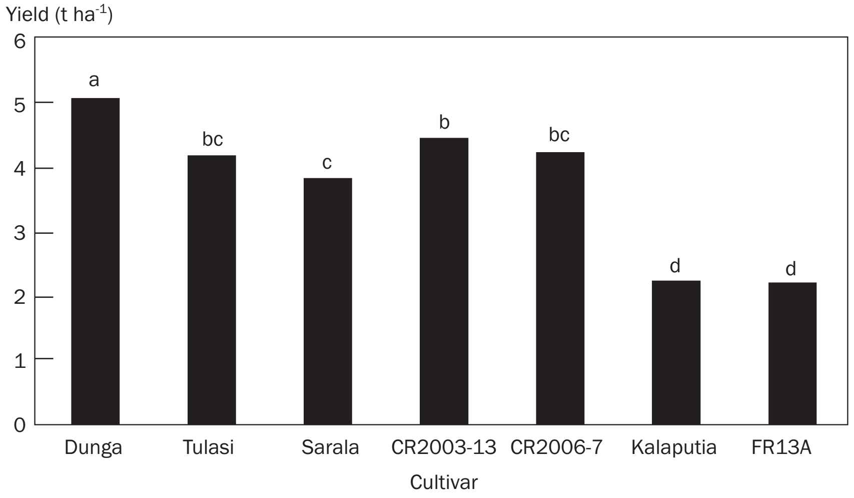
CR2003-13 and CR2006-7 were selected from breeding materials provided under the

CRRI-IRRI collaborative shuttle breeding program for eastern India and are being tested in farmers' fields and in national coordinated trials. Both lines have IR53508-B2-4-1-3-3 as one of the parents, which inherited its submergence tolerance from FR13A through BKNFR76106-16-0-1. In rainfed lowland flash-flood-prone areas, yields were low, ranging from 0.5 to 1.0 t ha^{-1}. These two cultivars could help increase and stabilize rice productivity. Unlike FR13A, the three landraces—Khoda, Khadara, and Kusuma—are awnless. The regeneration capacity of Khoda and Khadara is better than that of FR13A. The new submergence-tolerant landraces would be useful for breeding new cultivars tolerant of submergence.

Elongation and survival % of different genotypes due to submergence.

Cultivar	Characteristic	Plant height (cm)			Survival (%)^b
		BS^a	AS^a	Elongation	
Khoda	Traditional	32abc	58cde	26cd	84 ab
Khadara	Traditional	33abc	61a-d	28cd	78 ab
Kalaputia	Traditional	27e	50e	23d	88 a
Kusuma	Traditional	34ab	66abc	32abc	75 b
CR2003-13 (IR67638-15-CR6-1-10-1)	Improved	30cde	56de	26cd	77 ab
CR2006-7 (IR67632-4-CR1-3-3-2)	Improved	31bcd	60bcd	29bcd	79 ab
Durga	Improved	35a	70a	35ab	10 c
Sarala	Improved	28de	58cde	30bc	0
Tulasi	Improved	34ab	69ab	35ab	0
FR13A (tolerant check)	Traditional	33abc	64a-d	31abc	82 ab
IR42 (susceptible check)	Improved	28de	65a-d	37a	0

^{a}BS = before submergence, AS = after submergence. Means followed by a common letter are not significantly different at the 5% level by DMRT. ^{b}Sarala, Tulasi, and IR42 were not included in the analysis because of nonvariation in replicated data.



Grain yield of different cultivars under favorable rainfed lowland conditions. (Means followed by a common letter are not significantly different at the 5% level by DMRT.) Cultivars Durga, Tulasi, and Sarala are susceptible; the rest are tolerant.

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Performance of transplanted Basmati rice in different cropping systems as affected by N application

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Basmati rice varieties are in demand because of their long, slender, aromatic grains with intermediate level of amylose, which upon cooking exhibit high volume expansion. India has established a monopoly in exporting Basmati rice, which fetches a price two to three times higher than that of regular rice. In 1999, about 0.5 million t of Basmati was exported, giving the country Rs 30 million in foreign exchange earnings.

The cropping sequence Basmati rice-wheat is common but Basmati rice-sunflower was found to be more remunerative. To achieve high yield and to improve quality, N is a major factor considered in all types of environment. Low N may not lead to realization of maximum yield potential, and high N may lead to lodging, increased incidence of insect pest attack, and lower quality. N is usually applied at 60 kg ha^{-1}, but research shows that Basmati tends to lodge at this level of applied N. Green manuring (GM) is likewise a common practice, but data on the response of Basmati rice to different levels of N with or without GM in different cropping sequences are scanty.

Field studies were conducted from 1997 to 2001 at the PAU research farm to establish the optimum N requirement of Basmati rice in different cropping sequences. The experiment, laid out in a split-plot design, studied three cropping systems (fallow-Basmati rice-wheat, GM-Basmati rice-wheat, and GM-Basmati rice-sunflower [main plots] and four N levels (0, 20, 40, and 60 kg ha^{-1}) [subplots]). Treatments were replicated three times. Green manuring was achieved by incorporating exactly 50-d-old *Sesbania aculeata* (dhaincha) and 30-d-old seedlings of Basmati 386 were used for transplanting. All other recommended practices were followed for growing Basmati and the other crops. Soil was sandy loam, with pH 7.22, EC 0.11 dS m^{-1}, OC 0.27% (Walkley and Black 1934), available N 106.5 kg ha^{-1} (Subbiah and Asija 1956), P (Olsen et al 1954) 51.5 kg ha^{-1}, and K (Merwin and Peech 1950) 128.1 kg ha^{-1}. Yield of Basmati (adjusted at 18% moisture content) was recorded at harvest. Lodging percentage was also recorded in the different treatments.

Nitrogen application substantially increased the mean grain yield (1997-2000) of Basmati up to 40 kg N ha^{-1} in the fallow-Basmati-wheat sequence, but application of 60 kg N ha^{-1} reduced Basmati yield (Table 1). Compared with the 0 N treatment, the mean grain yield of Basmati increased by 0.31, 0.40, and 0.23 t ha^{-1} at doses of 20, 40, and 60 kg N ha^{-1}, respectively. But, in the GM-Basmati-wheat and GM-Basmati-sunflower sequences, application of N at all levels substantially reduced grain yield of Basmati. Across seasons, it decreased from 2.6 t ha^{-1} (control) to 2.1 t ha^{-1} at 60 kg N ha^{-1} in the former and from 2.7 t ha^{-1} (control) to 2.1 t ha^{-1} at 60 kg N ha^{-1} in the latter. When main yield was considered, irrespective of cropping sequence, application of N at 20 kg ha^{-1} increased the grain yield of Basmati, but application of N at a level higher than this decreased it. When yield of Basmati was considered, regardless of N application, it was found that maximum yield was obtained in the fallow-Basmati rice-wheat, followed by GM-Basmati-sunflower and GM-Basmati-wheat cropping. The increase in grain yield with N application in the first sequence was associated with the increase in yield-attributing characters—

Table 1. Mean yield of Basmati as influenced by level of N application in different cropping sequences, 1997-2000.[a]

N level (kg ha^{-1})	Fallow-Basmati-wheat	Green manure-Basmati-wheat	Green manure-Basmati-sunflower	Mean
		Grain yield of Basmati (t ha^{-1}) (1997)		
0	3.18	2.53	2.50	2.74
20	3.67	2.24	2.53	2.82
40	3.43	1.86	2.16	2.48
60	3.09	1.83	1.75	2.23
Mean	3.34	2.12	2.24	
		1998		
0	2.20	1.79	1.86	1.94
20	3.00	2.53	2.72	2.15
40	3.09	2.32	2.58	2.00
60	2.92	2.09	2.38	1.88
Mean	2.93	2.39	2.44	
		1999		
0	2.38	3.23	3.28	2.96
20	2.50	3.41	3.17	3.03
40	3.04	3.03	3.15	3.07
60	3.01	2.44	3.04	2.84
Mean	2.73	3.03	3.16	
		2000		
0	3.01	2.83	3.03	2.96
20	3.29	2.55	2.79	2.88
40	3.46	2.52	2.27	2.75
60	3.32	2.19	2.24	2.58
Mean	3.27	2.52	2.58	
CD 5%	1997	1998	1999	2000
Crop sequence	0.23	0.38	ns	0.22
N level	0.18	ns	ns	0.17
Interaction	0.31	ns	0.34	0.30
		Mean yield (1997-2000)		
0	2.69	2.60	2.65	
20	3.00	2.53	2.72	
40	3.09	2.32	2.58	
60	2.92	2.09	2.38	
Mean	2.93 (4.47)*	2.39 (4.77)*	2.44 (2.58)*	

[a]Numbers in parentheses are values of mean yield of wheat* and sunflower**.

grains per panicle, panicle weight, test weight of grains, and low lodging percentage. The decrease in Basmati yield in the other two cropping systems was mainly attributed to lodging of Basmati (Table 2). Chopra et al (2000) reported that Basmati seed yield increased with N application up to 40 kg ha^{-1}; thereafter, it decreased with an increase in N application. Similar results were reported by Singh and Pillai (1994). The incorporation of GM in the GM-Basmati-wheat sequence improved the yield of wheat. The mean yield of wheat increased from 4.47 t ha^{-1} in fallow-Basmati-wheat to 4.77 t ha^{-1} in the GM-Basmati-wheat system. This could be due to the addition of N and the mobilization of other nutrients from the soil to the plant.

Table 2. Lodging (%) of Basmati rice as influenced by different levels of N application in different cropping sequences, 1997-2000.

N level (kg ha^{-1})	Fallow-Basmati-wheat	Green manure-Basmati-wheat	Green manure-Basmati-sunflower
0	14.3	76.3	70.3
20	26.0	77.7	79.3
40	47.7	88.7	91.7
60	80.3	92.7	92.7
Mean	42.1	83.9	83.5

With N application, lodging increased from 14.3% to 80.3% in fallow-Basmati-wheat, from 76.3% to 92.7% in GM-Basmati-wheat cropping, and from 70.3% to 92.7% in GM-Basmati-sunflower when N was increased from 0 to 60 kg ha^{-1}. Incorporation of GM added about 60 kg N ha^{-1}, increasing the height of Basmati plants and making the crop more succulent. Lodging occurred and resulted in low yields in both cropping sequences where GM was used.

It may therefore be concluded that beneficial response to N application in Basmati rice may be expected only up to 20 kg N ha^{-1} in the fallow-Basmati-wheat cropping sequence and that, where GM is used, there is no need to provide N to Basmati rice.

References

Chopra NK, Chopra N, Chopra N. 2000. Effect of row spacing and nitrogen level on growth, yield and seed quality of scented rice (*Oryza sativa*) under transplanted conditions. Indian J. Agron. 45(2):304-308.

Merwin HD, Peech M. 1950. Exchangeability of soil potassium in the sand, silt and clay fractions as influenced by the nature of the complementary exchangeable cations. Soil Sci. Soc. Am. Proc. 15:125-128.

Olsen SR, Cole CV, Watanabe FS, Dean LA. 1954. Estimation of available phosphorus by extraction with sodium bicarbonate. Circular no. 939. Washington, D.C.: United States Department of Agriculture. p 19.

Singh SP, Pillai KG. 1994. Response of nitrogen in semidwarf scented rice varieties. Int. Rice Res. Notes 19(4):16-17.

Subbiah BV, Asija GL. 1956. A rapid procedure for estimation of available nitrogen in soils. Curr. Sci. 25: 259-260.

Wackley A, Black IA. 1934. An examination of the Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.