Phosphorus requirements of *Azolla microphylla*

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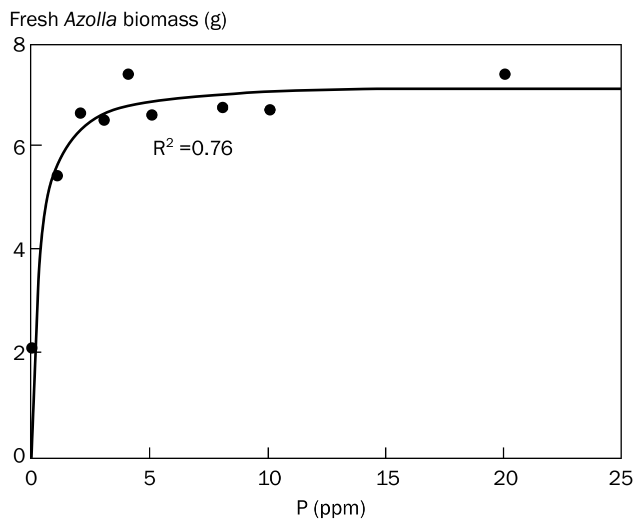
Azolla, a free-floating, N_2-fixing aquatic fern, is an established N biofertilizer for flooded rice. Phosphorus (P) is the most critical and limiting input for *Azolla*-rice cultivation (Majumdar et al 1993). *Azolla* absorbs P from the floodwater and makes it available to the plant. Different species of *Azolla* have different P requirements. An efficient P-scavenging strain is needed to ensure an adequate P supply.

We tested the P-scavenging ability of *A. microphylla*, the most efficient strain under north Indian climatic conditions. *A. microphylla* was obtained from germplasm collected at IARI. It was grown and maintained in N-free Espinas and Watanabe (E&W) medium in 8 × 10 × 2-in trays at 30 ± 2 ºC in a polyhouse (Watanabe et al 1977). To avoid drying, trays were topped with fresh medium every other day. The effect of P concentration on *A. microphylla* was studied using P-starved inoculum (*Azolla* fronds maintained in E&W medium minus P for 14 d). We also grew 0.5 g of P-starved fronds in 200-mL E&W media supplemented with different amounts of potassium dihydrogen phosphate to give 1–20 ppm P in 500 mL glass beakers.

Fronds, grown in E&W medium without P, served as the control. After 14 d, fresh biomass was harvested, blot-dried gently, and weighed. Samples were oven-dried at 60 °C and digested with triacid (nitric:perchloric:sulfuric, 9:2:1). P content was estimated using the ascorbic acid method (APHA 1992). The growth rate of *A. microphylla* increased when P concentration went from 0 to 2 ppm, but it stabilized at higher P concentrations (see figure). Thus, 2 ppm is the minimum P concentration needed to enable *A. microphylla* to achieve maximum growth. P deficiency affected *A. pinnata* growth the least among other species (Kushari and Watanabe 1992, Cary and Weerts 1992). These studies also showed that



Growth of *Azolla microphylla* at different P concentrations.

Growth of *Azolla microphylla* at different P levels and P content in dry biomass.

P in medium (ppm)	Doubling time (d)	RGR[a] ($g\ g^{-1}$)	Dry weight (g)	P(%) in dry biomass
Control	16.66	0.042	0.13	0.11
1	6.33	0.109	0.27	0.11
2	5.57	0.124	0.32	0.52
3	5.64	0.122	0.32	0.58
4	5.26	0.130	0.38	0.82
5	5.59	0.123	0.33	0.87
8	5.52	0.125	0.35	1.12
10	5.53	0.125	0.34	1.20
20	5.22	0.132	0.39	1.42
LSD at 0.05	11.07	0.03	0.035	1.39

[a]Relative growth rate = biomass produced per unit of biomass per unit of time, expressed as $g\ g^{-1}$ per day. Values represent mean of triplicates; experiment used complete randomized design.

5 ppm P was optimum for biomass production of *A. pinnata*. This strain of *A. microphylla* can grow well at all P levels, showing higher P levels in dry biomass compared with the four *Azolla* species described by Kushari and Watanabe (1991).

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Evaluating sodicity tolerance in rice hybrids

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Although rice cultivation is being pushed into marginal and saline lands because of urbanization and industrialization, increasing rice demand has to be met using these problem soils.

Increasing the productivity of rice in saline/sodic soils is a felt need inasmuch as rice is one crop that can grow relatively well in submerged conditions. This can be achieved either by breeding salt-tolerant rice varieties or applying suitable management practices. The first strategy, however, is sustainable and economically viable.

Hybrid rice technology offers much scope for increasing yield because of heterosis. Rice hybrids are known to have greater vegetative vigor and a stronger root system that enable them to tolerate salinity (Senadhira and Virmani 1987). Although hybrid rice is already under commercial cultivation in many parts of the world, only a few reports on its performance in sodic soils are available. Hence, screening of rice hybrids for sodicity tolerance needs more attention. This study was conducted to evaluate the performance of a set of rice hybrids in both sodic and normal soils.

The four rice hybrids were ADTRH 1 (released for cultivation by TNAU), ADTRH 15, TNRH 50 (being evaluated by TNAU), and DRRH 1 (released for cultivation by the Directorate of Rice Research). These hybrids were evaluated along with inbred check varieties during the dry season (June-September). The experiment used a randomized block design with three replications under both normal and sodic environments.

The sodic soils have an exchangeable sodium percentage (ESP) of around 20, with a sodium adsorption ratio of more than 10. The crop was completely irrigated with poor-quality underground water (10 meq L^{-1} residual sodium carbonate [RSC] and pH 9.8). The soil was designated as nonsaline sodic since its electrical conductivity value was less than 4 dS m^{-1}. On the other hand, under the favorable environment, ESP was less than 15 and pH was 7.4. Also, irrigation water was good (acceptable RSC and pH).

Days to maturity, spikelet fertility, grain yield, and grain type were recorded in both normal and sodic conditions. The data were subjected to analysis of variance and significant differences among the genotypes for the characters studied were observed (see table). Standard heterosis was expressed as a percent increase or decrease, calculated by comparing the hybrid's performance with that of TRY 2 (see table). (TRY 2 is an inbred variety recommended for growing in sodic soil.) The significance of standard heterosis was tested using the method of Wynne et al (1970). The effect of sodicity was evaluated by calculating the sodicity tolerance index (STI) (obtained by dividing grain yield in plots with sodic soil by grain yield in normal plots). Relatively higher values indicate sodicity tolerance (i.e., cultivars with values more than 0.5 were considered to have better sodicity tolerance).

DRRH 1 ranked first in both normal and sodic soils, recording a grain yield of 7.2 and 4.8 t ha^{-1}, respectively. This hybrid matures in 120 d and has long slender white grains. The standard heterosis of DRRH 1 in normal soil was 14.3%; it was 20.0% in sodic soil (see table).

Virmani and Kumar (2004) also reported higher standard heterosis values in saline soils (60.6%) than in normal soils (19.7%). Similar findings were reported by Madhan et al (2000) and Gregorio et al (2002). The STI of DRRH 1 was 0.67, which was the highest among the hybrids tested, thus proving its superiority over other hybrids. Its spikelet fertility was 79% under sodic conditions, which was also higher than that of other hybrids, and was the main reason for the increased grain yield. Although other hybrids showed higher heterotic effects in normal soil, their performance in sodic soil was not encouraging.

The rice hybrid DRRH 1 is a promising variety for cultivation in sodic soils. There is scope for exploiting hybrid vigor in sodic soil to boost overall rice production. With the development of sodicity-tolerant parental lines, the yield potential of rice hybrids in sodic soils could be further increased.

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Performance of rice hybrids and inbreds in normal and sodic soils, Anbil Dharmalingam Agricultural College and Research Institute, Trichy, India.

Entry	Parentage	Maturity (d)	Spikelet fertility under sodicity (%)	Grain yield (t ha^{-1})		STI	Grain type[a]
				Normal soil	Sodic soil		
ADTRH 1	IR58025A/IR66	110	72	7.1 (+12.7**)	3.5 (−12.5**)	0.44	LS, W
ADTRH 15	TS29A/ADRH 16R	115	66	6.5 (+3.17**)	2.7 (−33.3**)	0.41	MS, W
TNRH 50	IR58025A/IR65515	110	62	6.8 (+8.3**)	2.7 (−33.3**)	0.39	MS, W
DRRH 1	IR58025A/IR40750	120	79	7.2 (+14.3**)	4.8 (+20.0**)	0.67	LS, W
ADT 43	Inbred check variety	108	78	6.5	3.4	0.52	MS, W
MDU 5	Inbred check variety	105	65	5.2	2.6	0.50	MS, W
ADT 45	Inbred check variety	110	70	5.4	3.0	0.56	MS, W
TRY 2	Sodicity-tolerant commercial inbred variety	120	70	5.6	4.0	0.63	LS, W
SE		0.72	1.47	0.10	0.11	–	–
CD (5%)		1.54	3.16	0.23	0.24	–	–

[a]LS = long slender, MS = medium slender, W = white. Numbers in parentheses indicate standard heterosis. ** = significant at 1% level. STI = sodicity tolerance index.

Can rhizobial inoculation promote rice growth through nitrogen fixation?

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The discovery of *Rhizobium leguminosarum* bv. *trifolii* and photosynthetic Bradyrhizobium as rice endophytes from Egypt and Africa has added a new paradigm in beneficial plant-microbe association with their role in plant growth promotion (Yanni et al 1997, Chaintreuil et al 2000).

These bacteria were capable of colonizing rice root interiors endophytically (in intercellular space) while promoting plant growth of certain rice cultivars. Earlier, other bacteria such as *Azospirillum and Herbaspirillum* were isolated from rice and they showed colonization and growth promotion (Okon and Labandera-Gonzales 1994, James et al 2002).

In India, where rice has been under cultivation for many decades, we looked at the possibility of such natural rhizobial endophytes occurring in Indian soils.

Rice root samples from two districts of Uttar Pradesh were collected from fields where rice has, for many decades, been grown in rotation with berseem (*Trifolium alexandrinum*). Root samples were washed thoroughly in running water to remove all soil particles and other materials. These were then surface-sterilized (using a method described by Yanni et al 1997) and cut into small pieces (about 3–5 cm). The surface-sterilized roots were then suspended in water. Streaking of water droplets from the suspension was done to check any contamination. The surface-sterilized root pieces were then macerated in a sterile pestle and mortar. Macerates were used to (1) inoculate rice seedlings (*Oryza sativa* L. cv Sarjoo 52) grown in pots filled with moist field soil, (2) inoculate nine different legume hosts, and (3) streak on yeast extract-mannitol plates containing Congo red dye to isolate single colonies of bacteria. This process was repeated for all collected macerates.

Surprisingly, of the nine legumes tested as a trap host, nodulation occurred only on French bean (*Phaseolus vulgaris* L.) plants. The rest were not nodulated. Molecular identification of bacteria was also done; analysis of their 16s rDNA sequences further confirmed them as rhizobia. At this level of identification, we could say that the bacteria obtained from the rice root macerate that nodulated the French bean plant were *Rhizobium leguminosarum* bv. *phaseoli.*

The six isolates were successfully isolated. Three out of the six isolates were used to observe the effect on rice plant growth promotion under gnotobiotic and glasshouse conditions. In the glasshouse experiment, rice plants were grown in pots filled with moist field soil. Very promising results on plant growth promotion with respect to dry weight of root and shoot, chlorophyll content, grain yield, and total plant N and P content were obtained (see table).

Another significant finding was the expression of nitrogenase activity by rice plants inoculated with these isolates. The amount

Effect of rhizobial inoculation on yield and yield components of rice variety Sarjoo 52 under greenhouse conditions.[a]

Strain	Plant height (cm)	Panicles (no. hill^{-1})	Chlorophyll content (SPAD reading)	Root dry weight (g hill^{-1})	Shoot dry weight (g hill^{-1})	Grain yield (g hill^{-1})	Plant N content (mg hill^{-1})	Plant P content (mg hill^{-1})
Control	89.8	6.4	24.5	1.56	20.76	12.98	669.53	63.00
BHUE3	96.0*	8.5**	24.5 ns	2.15**	28.65**	15.53**	1,015.60**	95.19**
BHUE5	94.6 ns	7.5*	26.8*	2.03**	26.72**	14.40*	965.52**	89.78**
BHUE6	95.8*	8.2**	25.0 ns	2.10**	28.13**	15.45**	997.76**	93.17**
USDA2695	90.5 ns	6.8 ns	23.7 ns	1.86*	23.93*	13.00 ns	787.06**	80.15**
ANU843	93.2 ns	7.5*	23.6 ns	1.90*	24.05*	14.10 ns	792.19**	80.85**
LSD (0.05)	4.92	1.11	2.18	0.25	2.879	1.706	12.268	3.170

[a]*, ** = values for inoculated plants that are significantly different from the control at P = 0.05 and 0.01 levels, respectively. ns = no significant difference between treatments and control. Values are means of six replicates.

of activity expressed by BHUE3 was 0.96 μmol C_2H_4 g^{-1} dry weight h^{-1}, that by BHUE5 was 0.81, and that by BHUE6 was 0.70. Under similar experiments, when *R. leguminosarum* bv. *trifolii* (ANU843) and *R. leguminosarum* bv. *phaseoli* (USDA2695) were used to inoculate the plants, no nitrogenase activity was detected. ANU843 is a known endophytic colonizer of rice, whereas USDA2695 is a well-established strain of *P. vulgaris* obtained from USDA, USA.

To show that these bacteria can colonize the root interiors, two of these isolates were tagged with markers of antibiotic (ciprofloxacin) resistance and the *GUS* reporter gene to detect the site and path of bacterial entry. From these experiments, we can say that these bacteria do enter and colonize through lateral root cracks in the intercellular spaces of the roots. However, the best way to confirm this is to tag the isolates with *gfp* genes and observe them under a fluorescent microscope. Currently, we are in the process of procuring that equipment.

It can be concluded (1) that the bacteria isolated from these rice roots are *R. leguminosarum* bv. *phaseoli*; (2) that when these bacteria are used as a source of inoculation, a significant increase in plant growth and productivity (in terms of dry matter) is achieved; (3) that, apart from other possible mechanisms, biological N_2 fixation may contribute to growth promotion by the isolates; and (4) that, based on available evidence, the cells of the isolates enter through the root cracks, where lateral roots are attached to the main root, and colonize the intercellular region. More experiments have to be conducted to better understand the mechanism involved.

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Quality of shallow water table as affected by long-term fertilizer use in the rice-wheat system

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In India, the increase in foodgrain production from 50.8 million t (1951-52) to 203.6 million t (1998-99) is mainly attributed to the adoption of high-yielding crop varieties and use of fertilizers. Consequently, fertilizer consumption during the corresponding period increased from a mere 0.55 kg ha^{-1} to 90.04 kg ha^{-1} (FAI 1999). The increased use and/or misuse of fertilizers had frequently been cited as the cause of water quality deterioration (Miller 1979). Nitrate leaching can occur in intensively cultivated areas with a shallow water table (Bajwa et al 1992). In the face of increasing food demand of the burgeoning population, efficient fertilizer use in crops and the prevention of groundwater pollution are critical (Singh and Sekhon 1976). In the tarai region of Uttaranchal, the water table is shallow (about 1 m deep) and rice-wheat is the predominant cropping system. Since the inception of this long-term experiment, no study on groundwater quality has so far been conducted. This study aimed to monitor the impact of continuous fertilizer use (more than 30 y) under intensive cropping on the nutrient enrichment of groundwater.

Conducted in the 30th year of a long-term fertilizer experiment initiated in 1971, the study used a rice-wheat-cowpea sequence (Nand Ram 1995) on a Mollisol with silty clay loam texture at Pantnagar (latitude 29° N; longitude 79° 3′ E), Uttaranchal, north India.

The selected fertilizer treatments shown in Table 1 were continuously applied for three decades, only in rice and wheat. Cowpea fodder, on the other hand, was grown without using any nutrient input since the start of the experiment. Based on initial soil tests, the treatments with four replications under a randomized block design (individual plot size of 25 m × 12 m) consisted of 50%, 100%, and 150% NPK. These correspond to suboptimal, optimal, and superoptimal fertilizer doses, respectively. For rice and wheat, annual NPK rates at optimal dose (100%) were 240 kg N ha^{-1}, 52 kg P ha^{-1} (single superphosphate), and 70 kg K ha^{-1} (muriate of potash). In the 100% NPK + farmyard manure (FYM) treatment, FYM was incorporated at 15 t ha^{-1} y^{-1} before wheat sowing.

In October 2000, samples of groundwater were taken from each plot immediately after the rice harvest. To get samples, holes were bored with a 7.5-cm auger to groundwater level at 1-m depth. Water samples were obtained by applying suction using a piece of rubber tubing. After filtration, the groundwater samples were immediately stored in a freezer for chemical analysis later. The concentration of NO_3-N in groundwater samples was estimated (2-d sampling) by the chromotropic acid method (Sims and Jackson 1971). PO_4-P concentration was indicated by a blue color developed with the use of ammonium molybdate, potassium antimony tartarate, and ascorbic acid (Murphy and Riley 1962). The concentration of K was measured by a flame photometer.

The NO_3-N, PO_4-P, and K concentrations in groundwater as affected by the continuous use of fertilizers and FYM under intensive cropping are shown in Table 2.

The NO_3-N concentration in groundwater ranged from 0.31 to 0.43 ppm. Since the start of the experiment, the lowest concentration level of NO_3-N was noted in the control, in which neither fertilizers nor FYM were added. The addition of optimal N alone (100% N) significantly enriched groundwater NO_3-N content by 16% over the control. Compared with the control, 6%, 22%, and 32% enrichment with NO_3-N was noticed when applying NPK fertilizers at 50%, 100%, and 150%, respectively. The data revealed a significant increase in NO_3-N at both optimal (100% NPK) and superoptimal (150% NPK) doses applied continuously to rice and wheat for about three decades. Culvert (1975) also reported an increase in NO_3-N in drainage water after fertilization. Maximum enrichment of groundwater with NO_3-N was noticed with the simultaneous use of optimal NPK fertilizers and FYM (100% NPK + FYM). Compared with the 100% NPK treatment alone, the latter treatment enhanced the NO_3-N status in groundwater by 13%. This increase in NO_3-N may be attributed to FYM mineralization into NO_3-N. It is also interesting to note that the NO_3-N concentration in groundwater under all fertilizer treatments in this study was far below the permissible limit (10 ppm).

On the other hand, the PO_4-P concentration in groundwater samples ranged from 0.039 to 0.055 ppm. The addition of P fertilizers, even at either superoptimal or optimal rates, along with FYM (100% NPK + FYM), had no influence on PO_4-P concentration in groundwater (results were nonsignificant). This PO_4-P concentration was less than those of NO_3-N and K. This resulted from the several reactions that occurred to fix PO_4-P in soils (Larsen

Table 1. Rates of fertilizer addition under different treatments in rice and wheat.

Treatment	Crops	Fertilizer rate (kg ha^{-1})		
		N	P	K
Control	Rice	0	0	0
	Wheat	0	0	0
100% N	Rice	120	0	0
	Wheat	120	0	0
100% NP	Rice	120	26	0
	Wheat	120	26	0
100% NPK	Rice	120	26	33
	Wheat	120	26	37
100% NPK + FYM	Rice	120	26	33
	Wheat	156	35	68
50% NPK	Rice	60	13	16.5
	Wheat	60	13	18.5
150% NPK	Rice	180	39	55.5
	Wheat	180	39	55.5

Table 2. NO_3-N, PO_4-P, and K concentrations (ppm) in groundwater.

Treatment	NO_3-N	PO_4-P	K
Control	0.31	0.039	0.26
100% N	0.36	0.039	0.27
100% NP	0.37	0.043	0.28
100% NPK	0.38	0.046	0.45
100% NPK + FYM	0.43	0.052	0.48
50% NPK	0.33	0.043	0.35
150% NPK	0.41	0.055	0.53
CD (0.05)	0.04	ns[a]	0.04

[a]ns = nonsignificant.

1967). Consequently, a very small amount of PO_4-P leached down to the groundwater.

A range of 0.26–0.53 ppm K in groundwater was observed under the various treatments. The K concentration in groundwater decreased when no K was added to the crops. This was evident in the control treatments (100% N and NP [0.26–0.28 ppm K]). In these treatments, K has not been applied since the very beginning.

On the other hand, by adding K (at rates of 50%, 100%, and 150% NPK), its concentration in groundwater increased significantly by 34%, 73%, and 103%, respectively, over that of the control. This may have resulted from a greater amount of K leaching downward in the soil.

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Phosphorus nutrition reduces brown spot incidence in rainfed upland rice

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Brown spot, caused by *Helminthosporium oryzae* (Breda de Haan), is a disease in upland rice that markedly reduces yield. The disease is exacerbated by nutritional imbalance in the soil (Shukla 2002). Low phosphorus (P) and potassium (K) content contributes to infection (Chattopadhyay and Chakrabarty 1965). Also, the disease has higher incidence in dry soil than in wet soil and is therefore more severe in rainfed fields than in irrigated/flooded ones (Kulkarni et al 1979). In the rainfed upland, nutrient availability depends not only on the potential nutrient amount but also on rainfall pattern during crop growth.

A long-term P experiment (LTPE), begun in 1996 under the Upland Rice Research Consortium, aimed to evaluate the effect of P nutrition on rice productivity. This study shows the effect of P nutrition on brown spot incidence and rice productivity in 2 years: 1999, a normal year, and 2000, a drought year. Although the average rainfall at the site was 888.6 mm (based on 31 y of data), there was 971.7 mm of rainfall in 1999 and 783.8 mm in 2000. Rainfall distribution was 10.6% and 5.4% less than normal in August and October 2000, respectively. Also, the crop experienced drought for 10 d during panicle initiation, 8 d at flowering, and 9 d at maturity.

In 1999 and 2000, short-duration (105 d) upland rice variety Annada was seeded in clay loam soil (pH 5.8, 0.78% organic C, 0.09% total N, and 7.53 mg extractable P (Mehlich 1) kg^{-1}. The crop was sown in the first week of July and harvested in the third week of October. N, K, Zn, and Mg were applied uniformly in all plots at these rates: 75 kg urea ha^{-1}, 100 kg muriate of potash ha^{-1}, 15 kg $ZnSO_4$ ha^{-1}, and 25 kg Mg SO_4 ha^{-1}. P was applied at 0, 12, 24, 48, and 96 kg ha^{-1}. The experiment was laid out in a randomized complete block design and treatments were replicated four times. The intensity of leaf brown spot disease was recorded at flowering using the SES 0–9 scale (IRRI 1980). Grain yield at harvest was recorded on an oven dry-weight basis. P concentration in the soil at harvest as well as rice grain and straw P contents were estimated following double acid extraction for the soil and the vanadomolybdophosphoric yellow color method for the plant.

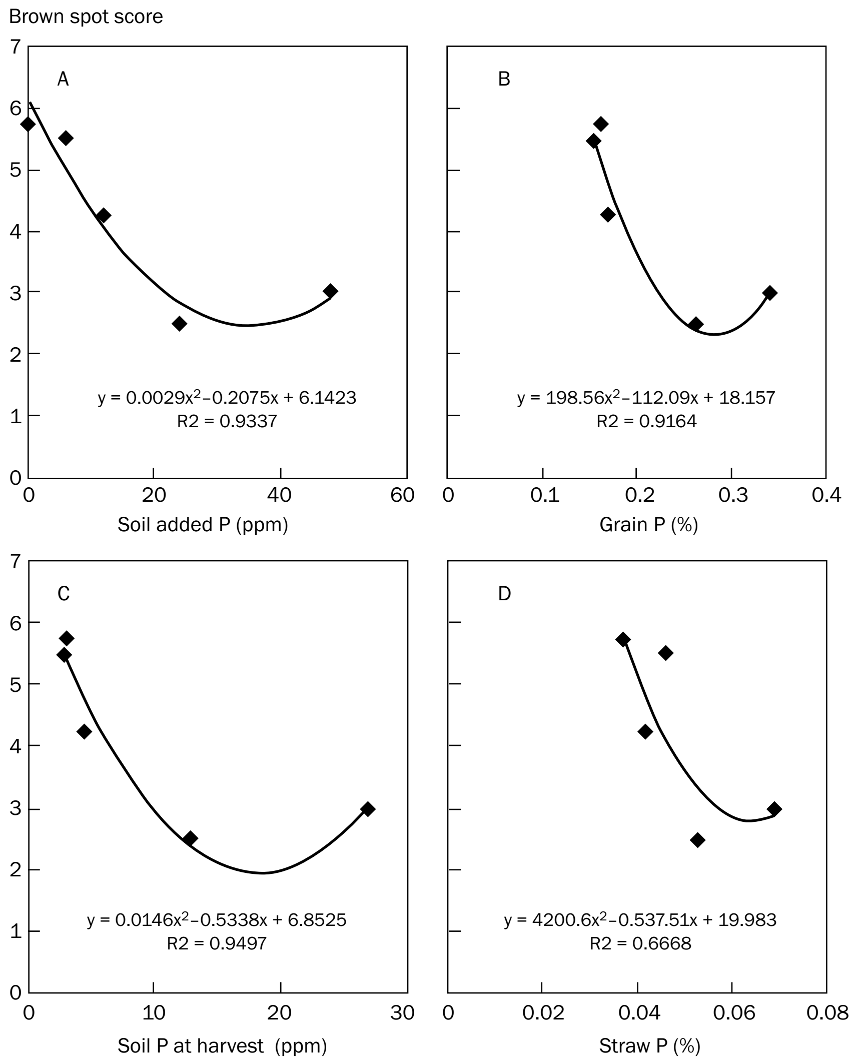
It was found that brown spot incidence was affected significantly by P nutrition in the drought year. The disease declined drastically with an increase in P concentration from 0 to 96 kg ha^{-1}. The minimum brown spot incidence was noted at 48 kg P ha^{-1} applied in soil. Results also showed that P nutrition not only reduced brown spot incidence but also maintained grain yield level. P concentration in grain and straw in a drought year was on a par with that in a normal year (see table). Brown spot was not observed in years with normal rainfall.

Correlation studies between P content and brown spot incidence showed that high P concentration in the soil, grain, and straw helped reduce brown spot incidence and increase rice productivity under drought conditions (see figure). Further, results indicated that P application at 48 kg ha^{-1} was optimal and that any additional increase would have negative effects in a drought year.

Effect of P nutrition on grain yield, grain and straw P content, and brown spot incidence during drought (DY) and normal rainfall years (NY).

P nutrition (kg ha^{-1})	Grain yield (t ha^{-1})		Grain P (%)		Straw P (%)		Brown spot score[a]	
	NY	DY	NY	DY	NY	DY	NY	DY
0	2.74	1.27	0.35	0.16	0.07	0.04	0	6
12	3.27	1.64	0.32	0.16	0.07	0.05	0	6
24	3.24	2.87	0.30	0.17	0.07	0.04	0	4
48	3.35	3.27	0.35	0.26	0.07	0.05	0	3
96	3.42	3.49	0.35	0.34	0.07	0.07	0	3
LSD (5%)	ns[b]	0.81	ns	0.05	ns	0.02	–	2

[a]Rated according to SES: 0 = no incidence, 9 = 70–100%. [b]ns = nonsignificant.



Response curves for A) soil added P vs brown spot score, B) grain P vs brown spot score, and C) soil P at harvest vs brown spot score, D) straw P vs brown spot score.

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Basal N fertilization increases productivity of rainfed upland rice

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Under rainfed upland situations, rice grows in an environment prone to N losses due to volatilization and runoff. Farmers in eastern India hesitate to invest more in N inputs because of stress (biotic and abiotic)-related risks. Earlier studies (Sinha et al 1994, Singh et al 2002) recommended N application in two splits (20 and 40 d after rice emergence) in upland rice. We compared the response of upland rice variety Vandana to two split N applications: two N splits with basal and two N splits only during four consecutive wet seasons (2000-03).

The on-farm experiment used a randomized complete block design involving 11 farmers' fields under rainfed conditions in villages Khorahar, Handio, and Sakhia in Hazaribag, Jharkhand, India. The 11 fields were treated as replications. Soil in farmers' fields varied from silt loam to sandy loam, with pH 5.9–6.1, 0.22–0.39% organic C, 2.67–5.31 ppm double acid-soluble P, and 131–176 ppm available K. Fields were plowed once in the off-season (December-April) and three times before seeding. The recommended levels of P (13 kg ha^{-1}) and K (16 kg ha^{-1}) were applied in the form of single superphosphate and muriate of potash, respectively. Short-duration (95 d) variety Vandana was used as the test variety.

Nitrogen was applied at 40 kg ha^{-1} under two schedules: (1) basal + two splits (10 kg N at seeding as basal, 20 kg N at 20 d after rice emergence [DARE], and 10 kg N ha^{-1} at 40 DARE) and (2) two splits only (20 kg N ha^{-1} each at 20 and 40 DARE). Rice was seeded in the last week of June using 100 kg seed ha^{-1} in furrows 20 cm apart. Grain and straw yield and yield attributes of rice were recorded at harvest.

Basal N application substantially increased plant height, tiller number per plant, number of leaves and leaf area per plant, number of adventitious roots, and root length per plant at the seedling stage (Table 1). The SPAD values at tillering were >35 in plants under treatment 1 and <30 in those under treatment 2. The results indicated a positive effect of basal N application on early rice growth, which ultimately helps in achieving high productivity.

At harvest, plant height, panicle length, total number of tillers and ear-bearing tillers, and grain and straw yield of crops under treatment 1 were substantially higher than those in treatment 2 (Table 2). Variation in number of productive tillers m^{-2} because of the N schedule ranged from 2% to 9.2%, with a mean value of 6.1%. In the first year, grain and straw yields increased by 39.5% and 51.4%, respectively, with treatment 1. Yield increase was sustained in the next 3 y also; the magnitude of yield increase, however, declined compared with that of the first year. The overall increase in grain and straw yields attributed to treatment 1 over the 4 y was 24.6% and 26.9%, respectively. The increase in grain and straw yield in plots with basal N application was attributed to more ear-bearing tillers and a higher number of tillers, respectively (Fageria and Baligar 2001).

It may therefore be concluded that basal + two split applications of N can improve rice grain and straw yields under rainfed upland conditions.

Table 1. Agronomic traits of direct-seeded upland rice at the seedling stage as affected by N split application treatments.

Character	Basal + two splits	Two splits only	LSD% (5%)	Increase over two splits
Plant height (cm)	35.9	27.2	2.81	32.0
Tillers $plant^{-1}$ (no.)	2.4	1.1	0.54	18.0
Leaves $plant^{-1}$ (no.)	6.8	4.4	ns[a]	54.5
Leaf area (cm^2)	27.8	19.9	ns	39.6
Adventitious roots $plant^{-1}$ (no.)	24.0	17.0	1.8	41.2
SPAD values	35.9	28.6	0.90	25.5

[a]ns = nonsignificant.

Table 2. Yield and yield attributes of direct-seeded upland rice as affected by N split application.

N application method	Plant height (cm)	Panicle length (cm)	Total tillers m^{-2} (no.)	Productive tillers m^{-2} (no.)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
2000						
Basal + two splits	81.1	19.5	319	296	1.74	2.52
Two splits only	78.0	18.6	311	276	1.25	1.67
LSD (5%)	2.4	ns[a]	ns	16	0.29	0.43
2001						
Basal + two splits	100.7	19.6	369	322	1.95	2.57
Two splits only	97.0	18.3	313	273	1.65	2.08
LSD (5%)	ns	0.91	45	24	0.16	0.44
2002						
Basal + two splits	104.0	16.8	317	270	2.16	2.83
Two splits only	101.9	15.4	299	295	1.79	2.57
LSD (5%)	ns	0.99	ns	ns	ns	ns
2003						
Basal + two splits	96.9	17.1	374	358	1.95	4.21
Two splits only	88.3	16.4	356	345	1.59	3.43
LSD (5%)	5.4	ns	14	ns	0.20	ns

[a]ns = nonsignificant.

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Short-duration rice varieties adaptable to sodicity

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Sodicity is one of the most widespread problems in irrigated agriculture. Rice is best suited for growing in problem soils since it can be cultivated under flooded conditions. Although rice strongly tolerates sodicity, reduction in grain yield varies quite a lot compared with that under favorable environments. Growing the most sodicity-tolerant rice varieties is a long-term strategy that can ensure better economic returns. Because of the complexity in the inheritance pattern of sodicity tolerance and because of screening problems, only a few rice varieties are released for commercial cultivation in sodic conditions (Gregorio et al 2002). Though there are reports on cultivar differences in sodicity tolerance, studies on screening for adaptability of popular rice varieties to sodic conditions are scanty. Some crop varieties, although not bred for unfavorable environments, fared well under abiotic stresses. (IR64, which was developed for irrigated conditions, was later observed to possess drought tolerance.)

This experiment aimed to study the nature and magnitude of interaction of rice varieties under sodic and normal conditions. The rice varieties were tested in three environments: (1) normal soil with good-quality irrigation water (E1), (2) normal soil with poor-quality irrigation water (E2), and (3) sodic soil irrigated with sodic water (E3). Sodicity tolerance is assessed in terms of absolute or relative yield inasmuch as yield is the ultimate goal in unfavorable conditions (Shanon 1984). The study also regarded grain yield as a parameter for assessing adaptability.

A set of 24 rice genotypes was raised in a randomized block design in three replications each under three environments during the dry season (Jun-Sep). In E1, soil pH was 7.4, exchangeable sodium percentage (ESP) was <15, and the quality of irrigation water was good, that is, with acceptable values of residual sodium carbonate (RSC), sodium absorption ratio (SAR), and pH. E2, on the other hand, had normal pH (8.0) and ESP <15. However, the irrigation water had a pH of 9.2 and RSC >10. In E3, both the soil and irrigation water were sodic (pH 9.5, ESP >15, SAR >10, RSC > 10). Grain yield was assessed in all three environments for comparison and statistical analysis. The recommended agronomic practices were adopted. The stability parameter of different parameters was assessed as per the method of Eberhert and Russel (1966).

Results of ANOVA revealed significant differences in grain yield among the genotypes in all three different environments (Table 1). The pooled ANOVA for mean data also indicated variance due to genotypes, which confirmed the variability among the genotypes. Further, the variance due to environment was also significant, indicating the effect of sodicity in soil and water on grain yield. A significant genotype × environment interaction also showed the differential response of genotypes under different stress environments.

Normal soil with good-quality irrigation water is the most favorable environment (Table 2). This is because the genotypes selected for this study were originally developed for a favorable environment.

Table 1. Pooled ANOVA of mean data (for grain yield).

Source	Degrees of freedom	Mean square
Genotype (G)	23	1.711**
Environment (E)	2	38.191**
G × E (linear)	23	0.521**
Environment (linear)	1	38.194**
Pooled deviation	24	0.031**
Pooled error	72	

Table 2. Environmental index of tested environments.

Environment	Environmental index
Normal soil and water	0.9771
Normal soil and poor-quality water	–0.2062
Problem soil and poor-quality water	–0.7708

Genotypes with high mean yield, regression values nearing unity (b_i), and the lowest deviation from regression (S^2d_i) under multiple environments are considered the most suitable, stable, and adaptable for growing in problem soils (Mishra et al 2004). Stability parameters showed that varieties TRY2, IR64, ADT36, ASD16, TR2000-3, and ADT45 were found more adaptable and stable across all three environments (Table 3). Some other varieties (TKM11, IR72, TKM9, and CSR11), though adaptable to sodic soils, had low mean yield. Therefore, they could be effectively used only for hybridization programs (pyramiding a sodicity tolerance gene). On the other hand, ASD18, ADT42, and IR50 were more suited to favorable environments since the values of regression coefficient b_i were significantly higher than 1.

Table 3. Stability parameters of short-duration rice varieties.[a]

Variety	Parentage	Mean grain yield (t ha^{-1})	b_i	S^2d_i
ASD20	IR18348/IR25863/IR58	4.23	2.12**	2.56**
ASD18	ADT31/IR50	4.07	1.68**	–0.43
ADT37	BG280-1-2/PTB33	3.77	2.25**	1.07**
MDU5	*O. glaberrima*/Pokkali	3.48	0.48	10.43**
TRY2	IET6238/IR36	4.97	0.93	0.05
ASD16	ADT31/Co 39	4.68	0.80	0.96
ADT43	IR50/Improved White Ponni	4.53	1.24	–13.03**
TKM11	C22/BJ1	2.52	0.54	0.673
IR72	TN(1)/Chiangung 242	4.08	0.97	1.58
ADT42	AD9246/ADT29	4.38	1.57**	0.78
ADT41	Dwarf mutant of Basmati 370	3.25	1.40**	–2.936**
IR64	IR5657-33-2-1/IR2061-465-1-5-3	4.88	1.09	0.236
TKM9	TKM7/IR8	4.07	1.05	–0.406
TKM10	Co 31/C22	2.32	0.41**	–6.94**
IR50	IR2153-14/IR28/IR36	4.52	1.60**	0.008
CO 47	IR50/Co 43	4.65	1.14	–13.86**
ADT36	Triveni/IR20	4.33	0.66	–0.001
CSR10	M40-431-24-114/Jaya	3.03	0.17	–9.067**
CSR11	M40-431-24-114/Basmati 370	3.35	0.11	0.020
CSR23	IR64//IR4630-22-2-5-1-3/IR9764-45-2-2	4.77	0.47	–14.30**
CSR13	CSR1/Basmati 370//CSR5	4.28	0.57	–12.34**
TR2000-3	IR51471-2B-2-1-1	4.83	0.71	0.009
TR2000-8	IR55210-3R-8-1-2	4.77	0.78	–14.29**
ADT45	IR50/Co 37	4.83	1.26	0.061
Grand mean		4.11		
SE		0.51		

[a]** = significant at the 1% level.

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