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Cover: IRRI principal scientist S. S. Virmani inspects the hybrid rice varieties in the field.

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MINI REVIEW

Breeding to enhance yield potential of rice at IRRI: the ideotype approach

P.S. Virk, G.S. Khush, and S. Peng

Rice is the staple food for the largest number of people on Earth. According to one estimate, global rice production must reach 800 million t from the present 585 million t in 2003 to meet the demand in 2025. Because irrigated rice contributes more than 75% of the total rice production, enhancing its yield potential would be key to meeting the global rice requirement for an additional 215 million t. Therefore, the average yield of irrigated rice varieties must increase in tropical rice lands from 5 to 8.5 t ha^{-1} (Peng et al 1999). To achieve the target yield level, rice varieties with a yield advantage of about 20% over widely grown varieties under tropical conditions must be developed. Alternatively, we must increase the area under rice, but there is little scope for expanding irrigated rice area. In fact, the cultivated rice area is decreasing as a result of urbanization and industrialization.

Yield potential is defined as the yield of a variety when grown in environments to which it is most adapted, with nutrients and water nonlimiting and pests and diseases and other stresses effectively controlled (Evans 1993). During the 1960s, the yield potential of the irrigated rice crop increased from 6 to 10 t ha^{-1} in the tropics. This was accomplished at IRRI primarily by reducing plant height through the incorporation of a recessive gene, *sd1*, for short stature from Chinese variety Dee-geo-woo-gen. In 1962, IRRI plant breeders made a cross that resulted in the development and release of IR8 in 1966, the first semidwarf variety in the tropics. IR8 represented a new plant architecture—short stature, high tillering, sturdy stems, and dark green and erect leaves (Jennings 1964). The plant type represented by IR8 and succeeding varieties was extremely effective in increasing the productivity of irrigated rice lands (Khush 1995). The yield potential of IR8 was about 9.5 t ha^{-1} during the dry season in the tropics when it was released in 1966. However, it now yields about 7.5–8.0 t ha^{-1} under the best management (Peng et al 1999). Several subsequent IR varieties have outyielded IR8 by 15–20%. Moreover, several of them have shorter growth duration and their per day productivity is even higher.

Plant breeders and physiologists at IRRI in the late 1980s postulated that the plant type of these varieties may limit further improvement in yield potential. They produce a large number of unproductive tillers and have excessive leaf area that may cause mutual shading and a reduction in canopy photosynthesis and sink size, especially when grown under direct-seeded conditions (Dingkuhn et al 1991). Most of these varieties have high tillering capacity and small panicles. The large number of unproductive tillers, which limit sink size and contribute to lodging susceptibility, was identified as the major constraint to yield improvement in these varieties. Furthermore, simulation models predicted that a 25% increase in yield potential was possible by modifying the following traits of the semidwarf plant type (Dingkuhn et al 1991): (1) enhanced leaf growth in combination with reduced tillering during early vegetative growth, (2) reduced leaf growth along with sustained high foliar N concentration during the reproductive stage and late vegetative growth, (3) a steeper slope of vertical N concentration gradient in the leaf canopy with more N present in the top, (4) expanded storage capacity of the stems, and (5) improved reproductive sink capacity along with an extended grain-filling period.

These factors prompted IRRI scientists to propose modifications to the high-yielding indica plant type in the late 1980s in order to increase the yield potential. The proposed new plant type (NPT) has low tillering capacity (3–4 tillers when direct seeded, 8–10 tillers when transplanted); few unproductive tillers; 200–250 grains per panicle; a plant height of 90–100 cm; thick and sturdy stems; leaves that are thick, dark green, and erect; a vigorous root system; 100–130-d growth duration; and increased harvest index (Peng et al 1994, Khush 1995). This ideotype became the "new plant type" highlighted in IRRI's strategic plan (IRRI 1989). The goal was to develop an NPT with yield potential 20–25% higher than that of existing semidwarf varieties of rice in the tropical environment during the dry season.

However, at the time, the ideotype approach to plant breeding was not considered novel. In fact, it was proposed by Donald (1968), who defined "crop ideotype" as an idealized plant type with a specific combination of characteristics favorable for photosynthesis, growth, and grain production based on knowledge of plant and crop physiology and morphology. He anticipated that it would be more efficient to define a plant type that was theoretically efficient and then breed for this ideotype (Hamblin 1993).

Meanwhile, IRRI has also been looking at hybrid rice breeding to increase the yield potential of rice in the tropics. (However, this topic is beyond the scope of this paper and will be reviewed in another paper.)

Rationale for identifying yield-enhancing traits in the new plant type

Yield is a function of total dry matter and harvest index (grain to straw ratio). Therefore, yield can be increased by enhancing the total dry matter or harvest index or both. Modern, high-yielding, semidwarf varieties produce about 18–19 t of biomass ha^{-1} and their harvest index is around 0.45–0.50. Cultivars producing 22 t of biomass and with a harvest index of 0.55 should produce about 12 t of grain per hectare. The harvest index can be increased by increasing the sink size. For example, we can raise the number of grains per panicle. On the other hand, we need to develop plants with sturdier stems so that nutrients can be applied at higher rates to enhance total biomass.

The choice of traits to breed for an ideal plant type for the irrigated lowland came from several different perspectives. Further details on reduced tillering, large panicles, grain density, grain-filling percentage, leaf characteristics, growth duration, root system, and disease and insect resistance have been discussed elsewhere (Peng et al 1994, Khush 1995, Khush and Peng 1996).

Germplasm for new plant type

Breeding work for the development of NPT started as early as 1989 (Khush 1995). Bulu varieties or javanicas from Indonesia have low tillering, large panicles, and sturdy stems. This germplasm is now referred to as the tropical japonicas (Khush 1995). (For clarity, we shall refer to this NPT as NPT-TJ.)

Around 2,000 bulu varieties were assessed in the field during 1989 and donors for developing NPT-TJ were identified. A few examples of donors used in the preliminary breeding were Gendjah Wangkal (for the low-tillering trait), Ketan Gubat (for large panicles), Senhkeu (for thick stems), and Shen Nung 89-366 (for short stature) (Peng et al 1994). In addition to bulus from Indonesia, many tropical japonica donors were identified in germplasm from Malaysia, Thailand, Myanmar, Laos, Vietnam, and the Philippines (Virk and Khush 2003).

Breeding for new plant type

Hybridization was undertaken in 1990. Since most of the bulu varieties were tall, these were crossed with a semidwarf breeding line, Sheng Nung 89-366, obtained from Shenyang Agricultural University, China. The selected donors were crossed and breeding lines with the proposed ideotype were selected. Since then, more than 2,000 crosses have been made, 100,000 pedigree lines produced, breeding lines with the desired morphological ideotype traits selected, and more than 500 NPT-TJ lines evaluated in observational yield trials. The NPT-TJ lines based on tropical japonica germplasm were developed in less than 5 years. They were grown in a replicated observational trial for the first time in late 1993. As intended, the first batch of NPT-TJ lines had large panicles, few unproductive tillers, thick stems, and large and dark green flag leaves. The grain yield of these lines, however, was not encouraging. We attributed this to low biomass production and poor grain filling. Reduced tillering capacity contributed to low biomass production because the crop growth rate during the vegetative stage of NPT-TJ lines was lower than that of indica varieties (Khush and Peng 1996). Less biomass production was also associated with poor grain filling, but the cause-and-effect relationship has not been established. The poor grain filling of NPT-TJ lines was probably due to the lack of apical dominance within a panicle (Yamagishi et al 1996), the compact arrangement of spikelets on the panicle (Khush and Peng 1996), and a limited number of large vascular bundles for assimilate transport (S. Akita, pers. commun.). The NPT-TJ lines were also susceptible to diseases and insects and had poor grain quality. Fortunately, we traced the unfilled grain problem to certain donor parents such as Songkeu, Djawa Pelet, and Ribon and were able to overcome this problem by including only parents that produce a high percentage of filled grains in subsequent hybridization programs (Virk and Khush 2003). As a result, the yield performance of later NPT-TJ lines was higher than that of previous NPT-TJs and the indica check variety. For example, the best NPT-TJ line outyielded IR72 by 9.5% in an observational field trial conducted at IRRI during the 1998 dry season.

Several NPT-TJ lines were shared with the Yunnan Academy of Agricultural Sciences. From 2000 to 2003, after evaluations under local conditions, Chinese rice breeders released three NPT-TJ varieties, Dianchao 1, Dianchao 3, and Dianchao 2, developed from IR64446-7-10-5 and IR69097-AC2-1, two IRRI NPT-TJ lines. The NPT-TJ lines perform very well in temperate areas where disease pressure is low and consumers prefer sticky and bold grain types.

NPT-TJ lines also serve as an important reservoir of hitherto underused genetic diversity, especially in the tropics, and breeders are starting to use them in their crossing programs. For example, in Indonesia, breeders using IRRI's NPT-TJ line IR66154-521-2-2 as one of the parents released variety Ciapus during 2003. In China and Vietnam, some promising lines originating from crosses with NPT-TJ lines are being evaluated in farmers' fields.

Further improvement of the new plant type

Further fine-tuning was necessary as the NPT showed traits that could still be improved. An increase in tillering capacity of the NPT-TJ lines was envisaged to increase biomass production. Moreover, most of the NPT-TJ lines lacked resistance to tropical diseases and insects as the parents used for developing these lines were susceptible. For example, there were no donors for resistance to brown planthopper and tungro virus in tropical japonica germplasm. Farmers and consumers in tropical rice-growing countries prefer varieties with long and slender grains and intermediate amylose content.

As the fine-tuning process continued, in 1995, modern high-yielding indica varieties/elite lines were included in the hybridization program. With this, the development of improved NPT lines began. Since these lines are derivatives from crosses between indica and japonica germplasm, we shall call them NPT-IJs. This was necessary, as explained above, to increase biomass, incorporate genes for resistance to tropical diseases and insects, and change grain appearance and quality, and thereby ensure wider acceptability among farmers and consumers in Asia.

More than 400 NPT-IJ lines have been evaluated in observational yield trials. During 2001, several NPT-IJ lines outyielded the best indica check variety by up to 30% in breeders' replicated yield trials (Khush et al 2001). Encouraged by the superior performance of the NPT-IJs, we subjected them to more rigorous yield testing during 2002 and 2003. In the 2002 dry and wet seasons, several NPT-IJ lines significantly outyielded check variety IR72 (see table). The NPT-IJ lines approached the 10 t ha^{-1} yield barrier. However, IR72158-16-3-3-1 and IR72967-12-2-3 might not have expressed their yield potential fully since their harvest index was below 50% and grain filling was not greater than 80% (Peng et al 2004). In the 2003 dry season, NPT-IJ line IR72967-12-2-3 was the top yielder. It produced 10.16 t ha^{-1}, which was significantly higher than indica check variety yield.

It is obvious that yield improvement was achieved with the NPT-IJ lines. The yield increase was attributed to increased panicle number per m^2, improved grain-filling percentage, larger panicles with a large number of spikelets, more biomass, and higher harvest index. These lines with crop growth duration of 115–125 d belong to the early to medium-maturing group and will have a minimum effect on the intensification of cropping systems in the tropics.

To achieve a 10% increase in yield potential of irrigated lowland rice in the tropics, the following are the target traits: 330 panicles per m^2, 150 spikelets per panicle, >80% grain filling, 25 mg grain weight (oven-dry), 22 t ha^{-1} aboveground total biomass (at 14% moisture content), and 50% harvest index (Peng and Khush 2003). Among these traits, the key is a panicle size of 150 spikelets per panicle. During 2004, we have initiated a breeding program to examine these issues. A crop management strategy has to be developed to fully express the yield potential of NPT-IJ lines with large panicles. As breeding efforts continue, it is expected that more elite NPT-IJ lines with improved yield potential, disease and insect resistance, and grain quality will be developed.

It is important to note, however, that the NPT project has succeeded quite dramatically from another perspective. Before this project, the japonica genepool was essentially excluded from irrigated breeding programs in the tropics. In fact, crosses between the two subspecies had very limited success. Notable exceptions are Tongil rice in Korea and Mahsuri in the rainfed lowland tropics. At present, we have NPT-IJ lines derived from single or three-way crosses between the japonica NPT-TJs and the elite indica HYV genepool. It appears that this new "mixed" genepool can generate improvements in secondary traits such as lodging resistance and nutritional quality.

Related to this is the potential to exploit this new genetic variation in heterosis of F_1 hybrids. The current hybrids grown in the tropics are nearly all derived from the indica-indica hybrids developed at IRRI. However, recent results in China have shown immense potential for intersubspecific heterosis. The ability of the NPT-TJ and NPT-IJ lines to produce such hybrids for the tropics is being

Grain yield and some yield components of new plant type lines grown at IRRI in the 2002 dry and wet seasons.

Genotype	Grain yield (t ha^{-1})	Biomass production (g m^{-2})	Harvest index (%)	Panicles (no. m^{-2})	Spikelets (no. panicle^{-1})	Grain filling (%)	1,000-grain weight(g)
Dry season							
IR72 (check)	7.8	1,696	44.1	450	83.4	85.5	23.3
IR71700-247-1-1-2	9.8	1,661	55.6	470	120.7	84.3	19.3
IR72158-16-3-3-1	9.7	1,876	46.6	328	145.7	70.1	26.1
IR72967-12-2-3	9.6	1,893	44.5	343	133.5	67.1	27.5
IR72158-16-3-3	9.4	1,944	46.2	338	144.0	70.8	26.1
IR68552-100-1-2-2[a]	6.3	1,833	33.3	294	109.3	76.7	24.8
LSD (0.05)	0	143	3.0	31	8.8	5.0	0.4
Wet season							
IR72 (check)	5.4	1,364	38.7	404	81.5	71.1	22.6
IR71700-247-1-1-2	6.5	1,336	42.7	407	106.2	70.0	18.9
IR72164-348-6-2-2-2	6.4	1,487	39.6	303	122.4	75.2	21.1
IR73711-130-1-3-1	5.7	1,311	36.4	282	115.3	64.7	22.7
IR73459-120-2-2-3	5.61	1,529	34.6	280	108.2	68.0	25.7
IR68552-100-1-2-2[a]	2.9	1,489	36.0	273	133.3	60.1	24.3
LSD (0.05)	0.61	119	3.8	25	9.2	8.2	0.3

[a]NPT-TJ line; the rest are NPT-IJ lines.

explored at IRRI. Also, NPT-IJs offer higher maintainer frequency and hybrid rice breeding programs are expected to benefit from the use of these lines (Virk and Khush 2003).

Conclusions

IRRI's NPT-TJ lines are based on tropical japonica germplasm. Three varieties originating from this germplasm have been released for general cultivation to farmers in Yunnan, China. They yield around 13 t ha^{-1}, 1 t more than local cultivars. These varieties perform well in temperate areas where disease pressure is low and preference is for sticky, bold-grain types. However, farmers and consumers in tropical rice-growing countries prefer varieties with long and slender grains. To further improve the NPT (in terms of ability to withstand disease and insect pressure in tropical environments) and ensure wider acceptability, NPT-TJ lines were crossed with elite indica lines. Great progress has been made in this respect and several promising high-yielding NPT-IJ lines with long and slender grains have become available and are being shared with various national breeding programs. NPT-IJ lines with improved yield potential, disease and insect resistance, and grain quality continue to be an integral component of our breeding strategy. Furthermore, by incorporating genes from this underused source of genetic variation in potential varieties released to farmers in the tropics, we shall ultimately enhance the genetic variability deployed in the majority of rice lands. We strongly believe that seeking and incorporating genetic diversity for potentially yield-enhancing traits is a good investment in the present as well as in future breeding efforts. Ideotype breeding seems to be a good approach for enhancing the yield potential of rice. Finally, selection of individual traits for ideotype breeding and exploiting the genetic variability require a team effort— physiologists and agronomists give their inputs, while breeders do the gene juggling in the field.

Exploitation of hybrid vigor through hybrid rice breeding is another approach for increasing the yield potential of rice in the tropics. Evidence supports the merits of transferring yield-enhancing loci from exotic germplasm and wild species and efforts are under way to increase the yield potential of tropical rice. Biotechnological approaches such as the development of C_4 rice are likewise being investigated.

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Development and use of hybrid rice technology to increase rice productivity in the tropics

S.S. Virmani and Ish Kumar

Tropical rice-growing countries need an increased supply of rice because of their increasing populations and decreasing land and water resources. Hybrid rice technology offers an opportunity to increase rice yields and thereby ensure a steady supply. After the successful development and use of hybrid rice in China, IRRI took the lead in developing the technology for tropical rice-growing countries. Appropriate parental lines and hybrids involving cytoplasmic male sterility and thermosensitive genic male sterility systems have been developed and shared freely with public and private institutions in collaborating countries. Grown on about 1 million ha in 2003, several hybrids from the public and private sectors have been released and commercialized in India, the Philippines, Vietnam, Bangladesh, and Indonesia. Farmers are harvesting 1–1.5 t ha^{-1} higher yield from these hybrids. Rice hybrids are expanding faster in areas of moderate stress possibly because of the homeostasis effect. Earliness and higher per day productivity of hybrids have made them attractive for farmers interested in crop diversification to increase their income. Grain quality and resistance of hybrids to biotic stresses depend on parental lines. Hybrid rice breeders are thus developing new improved hybrids by breeding/selecting appropriate parental lines. Hybrid seed production technology is being improved and seed yields are progressively being increased at the seed growers' level. Many seed growers get hybrid seed yield ranging from 1 to 3.5 t ha^{-1}, which is very economical. The commitment of public- and private-sector agencies for breeding, seed production, and marketing has increased recently. Almost 60 seed companies in the public, private, and nongovernmental organization sectors are now producing and marketing hybrid rice seed.

Additional yield of hybrids resulted in greater profitability to farmers and greater chances of achieving food security. In 2003 alone, when hybrids showed, on average, at least 1 t ha^{-1} higher yield, adoption of the technology resulted in an additional 1 million t of rice grains worth about $120 million. The seed production activity alone (about 20,000 t) for this 1 million ha area resulted in the creation of additional jobs, worth 1 million extra person-days (at 50 extra persons ha^{-1}) and a vibrant hybrid rice seed industry. Major constraints to the expeditious adoption of hybrid rice technology are identified and future opportunities are discussed.

Rice has a special significance in Asia, where about 90% of the rice is produced and consumed as a staple food. Considering the increasing demand because of population increase on the one hand and decreasing land and water resources available for rice cultivation on the other, it is critical to develop and use rice technologies that will result in higher yields. Experience in China (Lin and Yuan 1980, Ma and Yuan 2003) and outside China, in IRRI (Virmani et al 1982, Virmani 2003), India (Mishra et al 2003), Vietnam (Hoan and Nghia 2003), the Philippines (Redoña et al 2003), Bangladesh (Julfiquar and Virmani 2003), and several other countries clearly indicates that hybrid rice technology offers a viable option to meet this challenge. Hybrid rice varieties have clearly shown a 1–1.5 t ha^{-1} yield advantage over semidwarf inbred high-yielding varieties (HYVs) in farmers' fields in China and other countries.

The term "hybrid" is used to refer to the first filial generation of a cross between two genetically diverse parents. The commercial hybrid refers to a superior F_1, which not only outperforms the better parent but also shows significant (at least 1 t ha^{-1}) yield superiority over the best high-yielding inbred variety of similar duration and possesses acceptable grain quality. Hybrid rice research in China began in 1964 and the first cytoplasmic male sterile (CMS) line was developed in 1972 from a male sterile plant found in a wild rice population in 1970 (Yuan 1977). Subsequently, the first commercial rice hybrid was developed in China in 1976 (Lin and Yuan 1980). It gave about 20% higher yield than that of commercial high-yielding varieties of similar duration. Since the release of this first hybrid, the area under rice hybrids has increased consistently in China (Fig. 1). Hybrid rice research at IRRI started when some leading hybrids from China (Shan You 6, Wei You 6, and Shen You 2) were introduced in 1978 and evaluated in 1979. However, none of these hybrids outyielded the local high-yielding check varieties, such as IR36 and IR42, primarily on account of their nonadaptability to tropical conditions and their susceptibility to tropical diseases and pests. The hybrids derived from Chinese CMS lines and IRRI restorer lines did show significantly higher yield (Virmani et al 1982) than IR36 and IR42, but commercialization of such hybrids was not possible due to the nonadaptability of the female parents to tropical conditions. IRRI spearheaded efforts to develop hybrid rice technology for the tropics in collaboration with interested national programs. Progress made in the development and use of hybrid rice technology in the tropics until 2001 has been reviewed from time to time (IRRI 1988; Virmani 1994, 1996, 2003). This paper highlights these achievements.

Development of parental lines

Breeding CMS lines adapted to the tropics began in 1980, using the CMS source (WA) from China. A commercially usable CMS line needs to have complete and stable male sterility, adaptability to tropical rice-growing conditions, and good outcrossing potential to effect an economically viable hybrid seed production. From the first set of CMS lines developed from 1983 to 1987, IR58025A has been used more extensively to develop public and private commercial rice hybrids in national agricultural research and extension systems (NARES). However, millers and consumers in countries such as India and Bangladesh have complained that hybrids derived from this CMS line

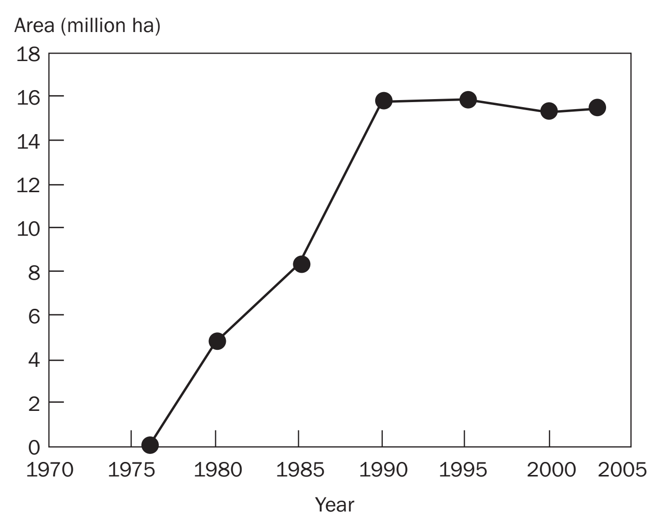

Fig. 1. Area planted to rice hybrids in China.

have low head rice recovery, are sticky, and are aromatic. Therefore, new CMS lines possessing less chalkiness, intermediate amylose content, and less (or no) aroma were developed recently at IRRI (Table 1). These lines also have cytoplasmic diversity to overcome the risk of potential genetic vulnerability of hybrid rice to disease/insect susceptibility associated with WA cytoplasm. Fortunately, no specific disease- or insect-related problem has been associated with WA cytoplasm (Faiz 2000), although 75% of the hybrid rice area in China and 100% of that outside China are planted to hybrids possessing such cytoplasm. Despite this situation, new cytoplasm inducing male sterility in rice has been identified (Li and Zhu 1988; Virmani 1994; Pradhan et al 1990a,b; Dalmacio et al 1995, 1996; Li and Yuan 1999) and cytoplasmically diverse CMS lines have been developed at IRRI, in China, and in other countries. At IRRI, we have also developed alloplasmic CMS lines possessing different CMS sources in the genetic background of maintainer lines IR58025B, IR62829B, and IR68879B. These lines maintain the sterility of Dissi, IR62829B mutant, and Gambiaca cytoplasm. More recently developed CMS lines (Table 2) possess higher outcrossing and better grain quality.

The frequency of restorers among elite indica, tropical japonica, temperate japonica, and basmati types has been found to be variable (Table 3). While there is no dearth of restorers among indica rice cultivars for most CMS systems, no restorers have been found for CMS lines possessing *Oryza perennis* and *O. glumaepatula* cytoplasm identified at IRRI (Dalmacio et al 1995, 1996). Restorer frequency is also low among elite japonica as well as basmati lines in which restorer gene(s) get transferred through conscious or unconscious breeding efforts for the purpose. In this context, indica/japonica intermediate lines possessing new plant type traits would be more useful.

During the past two decades, another type of male sterility that is sensitive to the environment and is induced by the interaction of environmental factors with nuclear genes has also been used to develop rice hybrids (Virmani and Ilyas-Ahmed 2001). The daylength-controlled male sterility is called photoperiod-sensitive genic male sterility (PGMS) and the temperature-controlled male sterility is called thermosensitive genic male sterility (TGMS). In the tropics, TGMS is more practical to use since daylength differences are small (Virmani and Ilyas-Ahmed 2001). Though many TGMS lines were developed in China, only a few were usable—only those having a low critical sterility point (CSP). The TGMS lines with a high CSP (higher than 24 °C [mean] or 20–28 °C [max-min temp]) were not reported to be safe for seed production because variation in temperature during the seed production period can result in fertility in the male sterile line, thus causing a mixture in the F_1 seed. Most of the hybrids released in China are primarily on TGMS line Pei-ai-64S. This line has a low CSP at 23.5 °C and a photoperiod of 13 h, and thus is most usable. At IRRI, six TGMS-bred lines—IR68301S, IR73727-23S, IR73834S, IR75589-31S, IR75589-41-13-17-15-3S, and IR75589-41-13-17-15-22S—have been found to

Table 1. Some improved CMS lines developed at IRRI[a].

Line	Cytoplasm type	Days to maturity	Grain type	Amylose content	Aroma
IR58025A	WA	120	Long slender	Low	Strong
IR68897A	WA	114	Long slender	Int	Strong
IR73328A	Mut. IR62829B	115	Medium	Int	Mod
IR75596A	Dissi	114	Medium	Int	Strong
IR70369A	WA	121	Med bold	Int	Slight
IR70959A	WA	126	Med bold	Low	Strong
IR73318	Mutant	113	Medium	Low	Nil
IR75601	Gambiaca	114	Medium	Int	Strong
IR75603	Gambiaca	113	Medium	Low	Strong
IR75608	Kalinga	111	Medium	Low	Strong
IR80555	WA	119	Short	High	None
IR80556	WA	115	Medium	High	None
IR80557	WA	121	Medium	Int	None

[a]Med= medium, Int=intermediate, Mod=moderate.

Table 2. Comparison of outcrossing rate of some old and new CMS lines.

CMS line	Cyto-source	Outcrossing score observed in CMS nursery[a]				
		2004 DS	2003 DS	2002 WS	2002 DS	2001WS
Old CMS lines						
IR58025A	WA	3	3	3	5	3
IR68888A	WA	3	5	5	5-7	5
IR68897A	WA	3-5	5	5	3-5	3-5
New CMS Lines						
IR78369A	ARC	1-3	3	3	3	3-5
IR79126A	ARC	1-3	3	3-5	3	3-5
IR79128A	WA	3	3	5	1-3	1-3
IR79156A	WA	1	1-3	3	1	1
IR80151A	WA	1-3	1-3	3-5	1-3	1-3

[a]1=very good, 3=good, 5=fair, 7=poor, 9=very poor.

Table 3. Frequency % of restorers and maintainers among elite indica, tropical japonica NPT and basmati types.

Type	Restorers	Maintainers
Indica	40	5
Tropical Japonica	-0	70
I/TJ derivatives (NPT)	40	15
Basmati	5	30

have a low CSP and are being used to develop two-line hybrids for tropical conditions. Additional TGMS lines possessing good phenotypic acceptability, high outcrossing, and good grain quality are being developed. Efforts are also under way to develop TGMS lines in other tropical countries—India (DRITG-1 to 4 and TS 29; UPRI 95-140 and UPRI 167); Vietnam (VTGMS 6S, VTGMS 7S, VTGMS 8S, and VTGMS 11S), and the Philippines. Vietnam has recently commercialized a two-line hybrid (TH 3-3) that is reported to have high yield and good grain quality (Hoan 2004, pers. commun.).

Yield advantage and production efficiency of rice hybrids

With the development of parental lines (CMS, maintainer, and restorer) and their derived hybrids at IRRI and their free sharing with public and private institutions working in national programs, several public- and private-sector hybrids have been developed and released in various countries (Table 4). Data gathered in India (Mishra et al 2003), the Philippines (Redoña et al 2003), Bangladesh (Julfiquar and Virmani 2003), Indonesia (Suwarno et al 2003), Sri Lanka (Abeysekera et al 2003), Vietnam (Hoan and Nghia 2003), Myanmar (Nwe et al 2003), and Colombia (Muñoz et al 1998) showed a 15–20% yield advantage of rice hybrids over inbred HYVs. This yield advantage was even higher (20–30%) because of homeostatic effects. Hybrids also showed higher per day productivity than inbred HYVs (Table 5). The earlyduration hybrids found their niche in areas where an additional crop of potato was planted after rice by farmers in Punjab, Haryana, and western Uttar Pradesh to increase their profitability. Peng et al (2003) observed higher N-use efficiency in the hybrid IR68284H than with check variety IR72 (Fig. 2). Earlier studies (IRRI 1993) had shown a significantly higher response of hybrid IR64616H to late-season N application than IR72. More recent studies at IRRI (Virk and Virmani unpubl.) also indicated higher water-use efficiency of some hybrid rice and inbred rice. These results clearly show increased production efficiency of rice hybrids compared with inbred rice and illustrate how hybrid rice technology becomes relevant in the current competitive global economic scenario.

Adaptability of rice hybrids to certain stress environments

Rice hybrids are known to have high vegetative vigor and a stronger root system. These features enabled them to show better seedling tolerance for low temperature (Kaw and Khush 1985), salt tolerance (Akbar and Yabuno 1975, Senadhira and Virmani 1987), flood tolerance (Singh 1983), and ratooning ability (Chauhan et al 1983). Rice hybrids were also found to be adaptable in the aerobic rice ecosystem (George et al 2002). Collaborative trials in Egypt showed stronger heterosis in hybrids in saline soils than in normal soils (Fig. 3). Rice farmers of Maharashtra, Uttar Pradesh, Bihar, Jharkand, and Chhatisgarh states in India, where rice is cultivated mostly in rainfed lowlands with supplemental irrigation and where it is exposed to moderate water and drought stress, witnessed the fast expansion of hybrid rice technology in 4 years' time.

Table 4. IRRI and locally bred rice hybrids released for commercial cultivation in tropical countries.

Hybrid	Country of release	Year of release
APRH-2	India	1994
MGR-1	India	1994
KRH-1	India	1994
Magat	Philippines	1994
CNRH-3	India	1995
DRRH-1	India	1995
KRH-2	India	1995
Pant Sankar Dhan	India	1995
PHB-71	India	1997
Mestizo	Philippines	1998
ADTRH-1	India	1998
COHR-2	India	1998
Narendra Sankar Dhan-2	India	1998
Sahyadri	India	1998
Panay	Philippines	1999
HYT-57	Vietnam	1999
IR69690H	Bangladesh	2001
Pusa RH 10	India	2001
HRI 120	India	2001
RH 204	India	2001
27PO-2	India	2001
Intani 1	Indonesia	2002
Intani 2	Indonesia	2002
Mestizo 2	Philippines	2002
Mestizo 3	Philippines	2002
Maro	Indonesia	2002
Rokan	Indonesia	2002

Table 5. Productivity of inbreds and hybrids, computed as yield in kg ha^{-1} d^{-1} to maturity, taken from IRRI AYT data, 2002 DS.

Genotype	Maturity (d)	Yield (kg ha^{-1})	Productivity (kg ha^{-1}d^{-1})
PSBRc 28, check	114.0	7038.0	61.7
PSBRc 52, check	115.0	7724.0	67.2
Mestizo, check	124.0	8901.0	71.8
IR79130H	112.0	7613.0	68.0
IR79131H	109.0	7770.0	71.3
IR79174H	114.0	8872.0	77.8
IR79187H	115.0	8407.0	73.1

Grain quality and biotic resistance of rice hybrids

The increased yield of rice hybrids alone does not ensure profitability to farmers if their grain quality is not acceptable and if they fetch a low price in the market. Khush et al (1988) studied this subject intensively and concluded that hybridity per se did not impair grain quality in terms of physical and chemical characteristics as long as both parents possess acceptable grain quality. To develop rice hybrids with acceptable grain quality, hybrid rice breeding programs must give emphasis (if they have not done so in the past) to the critical evaluation of parental lines and hybrids for grain quality before these are released for commercialization. Currently, parental lines and heterotic rice hybrids developed at IRRI are routinely evaluated for grain quality characteristics such as milling percentage, head rice recovery, size, shape, chalkiness, amylose content, gelatinization temperature, gel consistency, and aroma of the grain and compared with check varieties. Some good-quality A, B, R, and TGMS lines and hybrids are listed in Table 5. Since countries have varying preferences in terms of physical, chemical, and cooking quality of rice, hybrid rice breeders need to select their breeding materials carefully. Perez et al (1996) reported that some grain and nutritive quality characteristics of rice hybrid IR64616H and inbred IR72 were affected by the quantity and timing of applied N. There was also an indication of heterosis for iron content in rice grain (G. Gregorio, pers. commun.). Hybrid rice scientists in India have bred a basmati grain rice hybrid (Pusa RH 10) by developing and using basmati CMS and restorer lines (Zaman et al 2003).

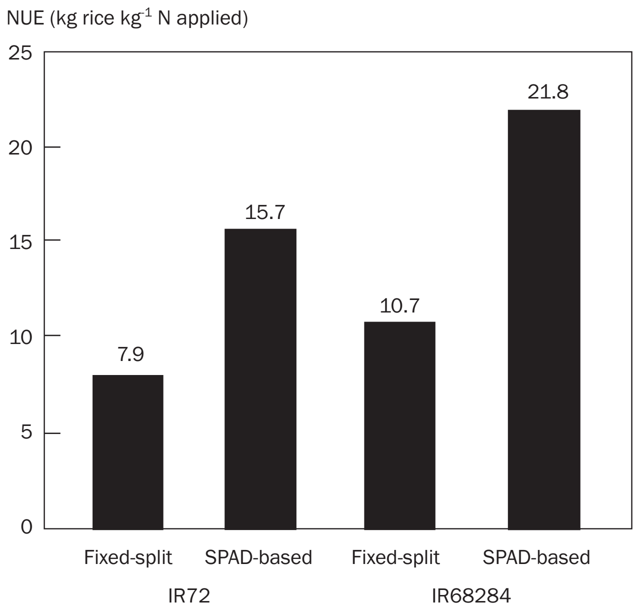

Fig. 2. Nitrogen-use efficiency of IR72 and IR68284H at fixed-split and SPAD-based applications. For IR72, SPAD threshold was 35; 30 kg N ha^{-1} applied at 28 DAT and 45 kg N ha^{-1} at 51 DAT. For IR68284H, SPAD threshold was 34.0; at 23, 44, and 64 DAT, N was applied at 30, 45, and 30 kg ha^{-1}, respectively (Peng et al 2003).

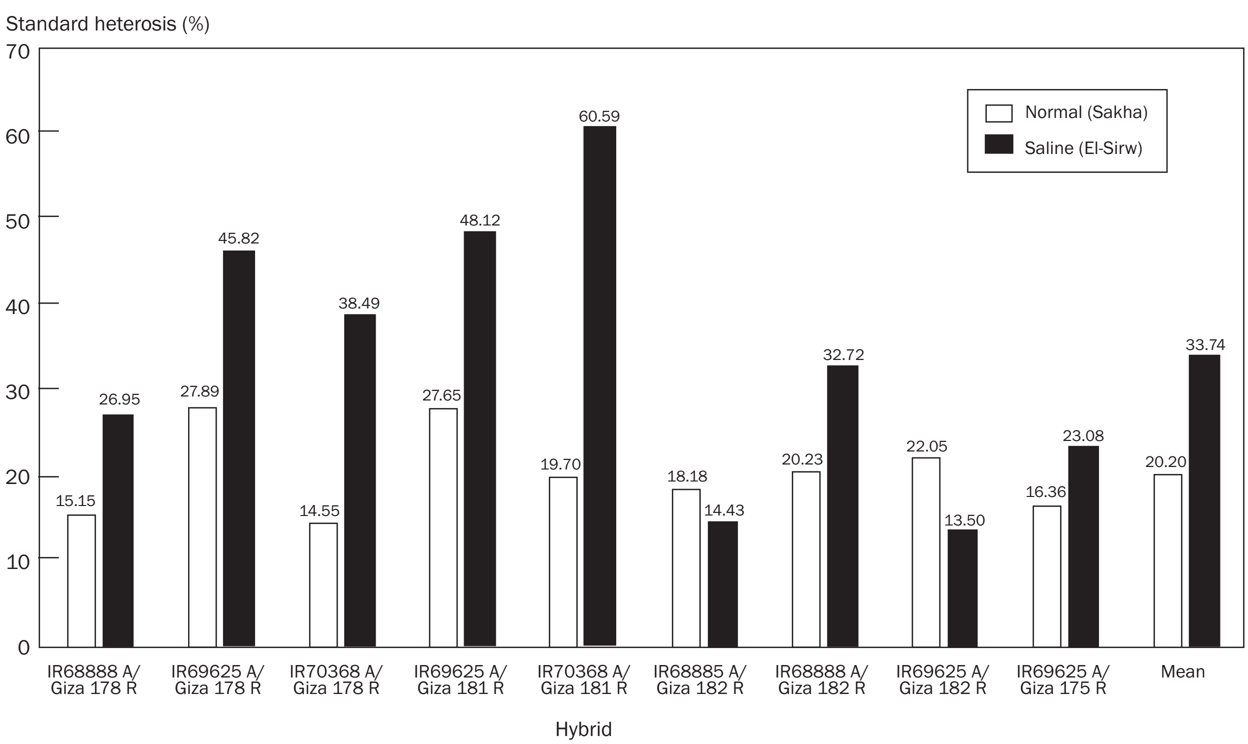

Fig. 3. Standard heterosis of some hybrids in normal and saline soils in Egypt.

Biotic resistance in a rice hybrid is determined by the resistance of its parental lines and whether the latter is controlled by dominant or recessive genes. Hybrid vigor does not make rice hybrids more or less tolerant of biotic stresses than parental lines (Cohen et al 2003). Faiz (2000) reported that the widely used WA CMS system was not associated with susceptibility to blast, bacterial blight, brown planthopper, and whitebacked planthopper. Although there is no imminent danger of genetic vulnerability of hybrid rice derived from the WA CMS system, IRRI is developing new elite CMS lines in diverse CMS systems (Virmani 2003).

Hybrid rice seed production technology

Hybrid rice seed production technology using the CMS system involves two major steps—multiplication of the A line (female parent) and production of hybrid (F_1) seed. Under the environment-sensitive genic male sterility (EGMS) system, the first step is simplified because an EGMS line can be multiplied through selfing by growing it within an appropriate temperature or daylength regime.

Plant characteristics that are helpful in increasing outcrossing in rice include taller height of pollen parent vis-à-vis seed parent, small and horizontal flag leaves, high number of panicles per square meter, higher number of spikelets per panicle, good panicle exsertion, and synchronization of flowering of seed and pollen parents. The floral traits (large, exserted stigma in seed parent and long anthers, filaments, and high pollen number in pollen parent) are useful for outcrossing. The flowering behavior traits (number of days of blooming, time of blooming, duration of blooming, duration of floret opening, and angle of floret opening) also influence outcrossing rate. The environmental factors that affect outcrossing in rice include temperature, relative humidity, light intensity, and wind velocity. In China, conditions favorable for good outcrossing in rice have been identified: daily temperature of 24–28 °C, relative humidity of 70–80%, diurnal differences in temperature of 8–10 °C, and sunny days with a breeze (Xu and Li 1988). Field conditions considered suitable are fertile soil, a dependable irrigation and drainage system, and minimum risk of disease and insect infestation.

Seed yield obtained from a male sterile line used in a hybrid seed production plot is a function of a) yielding ability of the male sterile line (extrapolated from the yielding ability of its maintainer line), b) proportion of male sterile line to pollen parent, and c) outcrossing rate of the male sterile line. Improvement in any of these components can help increase hybrid rice seed yield.

Extensive research in China, IRRI, and other countries has identified specific guidelines and practices for hybrid rice seed production, which are packaged in manuals (Yuan 1985, Virmani and Sharma 1993) and research papers (Mao 1988). Using these practices, hybrid seed yields from 0.7 to 4.0 t ha^{-1} (average 1.5 t ha^{-1}) have been obtained in the tropics. In the 2003 dry season, several seed companies in India obtained seed yields of 2–3 t ha^{-1} in Karim Nagar District in Andhra Pradesh.

Economic viability

The availability of good-quality seed at a reasonable price is crucial to the large-scale adoption of hybrid technology in any crop. Studies conducted in China (He et al 1984, 1987a,b, 1988) confirmed the yield advantage of hybrid rice over inbreds by at least 1 t ha^{-1}. The increased yield overcompensated for the extra investment in seed and chemical inputs, although yield was subsidized. The increased yield of rice hybrids increased profitability at the household level and achieved food security at the national level. An economic evaluation showed that hybrid rice seed production in China (He et al 1987b, 1988) was profitable if hybrid rice seed yields were 1.5 and 2.0 t ha^{-1}. In the initial years (1976-86) of adopting hybrid rice technology, seed yields were rather low (375 kg to 1 t ha^{-1}). The Chinese government subsidized seed production and subsequently improved seed yield significantly to 1.5 t ha^{-1} (in the late 1980s) and 2.7 t ha^{-1} (in the 1990s) (Mao et al 1998). This led to considerable expansion of the hybrid rice area (up to 17 million ha) by the mid-nineties. During the past few years, though, it has come down to 15 million ha on account of the increased economic liberalization policies of the Chinese government encouraging rice farmers to diversify their cropping and farming systems to increase their household income (there was an overall reduction in rice area by 4 million ha). In addition, the improved economic condition of the people has increased the demand for high-quality japonica rice, a development that does not make hybrid rice technology conducive to yield improvement.

Economic analyses conducted in India, Vietnam, the Philippines, and Bangladesh have confirmed the hybrids' yield advantage of about 1 t ha^{-1} over inbred check varieties grown by farmers (Janaiah and Hossain 2000). The profitability, however, depended on whether the farmers received a price comparable with that of inbred rice from millers/traders. Some hybrid rice varieties introduced to farmers in certain parts of India fetched a 5–10% lower price, which resulted in profitability lower than that of inbred HYVs. In the Philippines, however, hybrid Mestizo had a 5–10% higher price than check variety IR64, making this technology more profitable (Francisco et al 2001, Redoña et al 2003). For a sustained expansion of the technology, it is crucial that the grain quality of hybrid rice be at least comparable with (if not better than) that of check varieties.

The economics of hybrid seed production has also been studied in India (Janaiah and Hossain 2000) and the Philippines (Gaspar et al 2001). Results indicate that, with an average procurement price of \$1.00 kg^{-1} and an average seed yield of 1.25 t ha^{-1}, hybrid rice seed production was 65% more profitable than inbred rice cultivation. In the Philippines, where hybrid rice seed yields were low (600 kg ha^{-1}), seed growers could make a profit only if the seed procurement price was high (\$2.25 kg^{-1}). To bring the seed procurement price to a reasonable level, seed yield in the Philippines is being increased further; in 2004, many seed growers got more than 1 t ha^{-1} (the highest was 1.8 t ha^{-1}). Seed companies in these countries sell hybrid rice seed to farmers at \$2.00–2.50 kg^{-1}. The large margin (e.g., in India) was needed to keep the private seed companies in business, considering the existing thin and dispersed market for hybrid rice seeds. As the technology picks up, economies of scale and increased seed yield would reduce the cost of production and thereby allow seed companies to sell hybrid seed at a lower price to farmers. The growing competition in the seed business would also let seed companies reduce the selling price of hybrid rice seed over time.

The production of hybrid rice seed is labor-intensive but it is viable enough to attract private or NGO-based seed companies. Seed production can be organized in countries where labor is available at a reasonable price and hybrid rice seed demand is created among farmers. Almost 60 seed companies in the public, private, and NGO sectors are working in Asia to produce and market hybrid rice seeds. These companies have a forum—the Special Interest Group on Hybrid Rice, which meets under the auspices of the Asia Pacific Seed Association (APSA)—through which they discuss issues related to commercialization of the technology.

Major constraints

Major constraints to the expeditious and large-scale adoption of hybrid rice technology outside China have been identified:

- Poor grain quality of some hybrids compared with premium-quality rice varieties.
- Inconsistent performance of the first set of released hybrids because of inappropriate deployment and inadequate agronomic management.
- Inconsistent seed yields and high cost of hybrid seeds.
- Lack of action plans to cover the targeted areas in a country.
- Inadequate coordination between public and private sectors in disseminating the technology.

These constraints are being addressed by the agencies responsible for research, seed production, extension, and/or policymaking in the NARES in collaboration with IRRI, FAO, and APSA. With concerted efforts, the pace of adoption of the technology outside China can be enhanced significantly in the next 3–5 years. Reports from India that hybrid rice area this year would be about 50% more than last year (280,000 ha) confirm this.

Future opportunities

The high yield of hybrids is being combined with acceptable grain quality through appropriate breeding and selection of parental lines. Opportunities exist for enhancing the level of heterosis through crosses between indica and NPT lines derived from tropical japonica/indica and the use of selected heterotic groups and gene blocks (Virk et al 2003). Better agronomic approaches and nutrient and pest management strategies are being developed to maximize yield expression and attain consistently higher yields from hybrids. The continuously increasing seed yields in China (Mao et al 1998) and other countries indicate the possibility of reducing the cost of hybrid seed. Genetic improvements are being made to increase the outcrossing rate of new seed and pollen parents. Hybrid rice breeding efficiency can be increased by using the TGMS system and nuclear male sterility-facilitated recurrent selection procedures to breed parental lines. Also, molecular marker-aided selection can help in identifying fertility restorers and TGMS lines more effectively.

Early vegetative vigor and the better developed root system of hybrid rice make it adaptable to salinity-prone and low-temperature-prone irrigated areas (during the boro season). The strong root system enables hybrid rice to improve its water-use efficiency. Prospects appear good for the adaptation of rice hybrids to certain rainfed lowland and aerobic rice ecosystems. Higher seed yields and lower seed costs can make hybrid rice economically viable for direct-seeded irrigated conditions. Hybrid rice is being commercialized under highly mechanized conditions in the southern United States and Latin America (Andrews 2001).

Dissemination of hybrid rice technology can be improved by establishing effective mechanisms that can link research, seed production, and technology transfer systems. Policymakers can also be sensitized to provide policy support and financial commitment to the development program in selected areas of the country. Five-year action plans for these targeted areas can be developed in consultation with stakeholders. A clear understanding of the respective role of the public and private sector for developing and disseminating the technology should also be reached. IRRI is working in collaboration with FAO, APSA, and China under an Asian Development Bank-funded project for expediting the development and dissemination of hybrid rice technology in nine Asian countries—Bangladesh, India, Indonesia, Myanmar, Korea, Philippines, Sri Lanka, Thailand, and Vietnam. Considerable progress has been made in applied research, training, on-farm demonstration, creating awareness, developing action plans, and identifying policy intervention points to promote the technology. These efforts should help some countries to expand their hybrid rice area and increase their rice varietal yields and production efficiency so they can produce more rice at a cheaper price. The involvement of the seed industry in the dissemination of hybrid rice seed would generate additional rural employment opportunities. Hybrid rice technology can thus make an important contribution to increased food security, production efficiency, environmental protection, and rural job creation.

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Combining ability analysis to identify suitable parents for heterotic rice hybrid breeding

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Hybrid rice offers an opportunity to boost the yield potential of rice. It has a yield advantage of 15–20% over conventional high-yielding varieties (Virmani et al 1993). Hybrid rice research now concentrates on the conversion and identification of stable local cytoplasmic male sterile (CMS) lines and effective restorers from local elite lines through repeated backcrossing. CMS lines developed from IRRI are used to maintain the pace of hybrid rice development. Chances of success are greater if outstanding parents with favorable alleles are chosen, which on crossing would give heterotic hybrids. This study aimed to identify good restorers and CMS lines for heterotic rice breeding.

The CMS lines IR58025A, IR68886A, and IR68897A were crossed with nine elite lines/varieties—Gautam, Dhanlaxmi, Prabhat, Saroj, Pusa 1040, Pusa 1107, PSRM-1-16-48-11, RAU 1411-4, and RAU 1411-10—to generate 27 hybrid combinations in line × tester mating design. The hybrids were evaluated along with parents in a randomized complete block design with three replications at RAU during the 2001 wet season. Thirty-day-old seedlings were transplanted (single rows 2 m long spaced 20 cm apart, 15 cm interplant distance). Days to flowering, plant height, effective tillers hill^{-1}, and grain yield plant^{-1} were noted. Combining ability analysis was carried out following the method of Kemplhorne (1957).

Analysis of variance of combining ability for all four characters revealed significant differences among genotypes, crosses, lines, testers, and line × tester interactions (Table 1). The mean sum of squares due to parents versus crosses also differed significantly, except for yield. The significance of the means of sum of squares due to lines and testers indicated a prevalence of additive variance. However, means of sum of squares due to line × tester were also significant for all four characters, indicating the importance of both additive and nonadditive variance. Several workers reported the predominance of dominant gene action for a majority of the yield traits (Peng and Virmani 1999, Ramalingan et al 1993, Satyanarayana et al 2000), while Vijay Kumar et al (1994) reported the predominance of additive gene action.

An estimation of the general combining ability (GCA) effect of lines and testers revealed that the parents IR68886A, Gautam, Prabhat, and RAU 1411-4 were good combiners for earliness, whereas IR68897A, Dhanlaxmi, Pusa 1107, and Pusa 1040 were better combiners for late flowering, a desirable trait for the lowland ecosystem (Table 2). IR68897A, Dhanlaxmi, and Prabhat were found to be better combiners for dwarfness; PSRM-1-16-48-11, Pusa 1107, and RAU 1411-4 appeared to be better combiners for a good number of productive tillers. Of the male parents, Pusa 1040, PSRM-1-16-48-11, RAU 1411-4, and RAU 1411-10 were identified as better combiners for grain yield and showed superior gene effect.

The usefulness of a particular cross in exploiting heterosis is judged by the specific combining ability (SCA) effect. IR68886A/Pusa 1040 showed the

Table 1. Analysis of variance for combining ability for four characters in rice, 2001 wet season.[a]

Source of variation	df	Days to flowering	Plant height	Effective tillers hill^{-1}	Yield plant^{-1}
Treatment	38	61.08**	523.23**	62.17**	982.64**
Parents	11	67.42**	597.36**	48.72**	1,038.50**
Parents vs crosses	1	61.75**	929.55**	73.29**	1.36
Crosses	26	58.37**	476.24**	67.44**	996.75**
Line	2	28.04**	2,006.58**	31.16**	1,283.97**
Tester	8	44.94**	453.82**	41.77**	732.00**
Line × tester	16	68.87**	296.15**	84.81**	1,093.23**
Error	76	3.99	3.18	1.77	16.60

[a]** = significant at $P = 0.01$.

Table 2. GCA effects of parents for four characters in rice.[a]

Parent	Days to flowering	Plant height	Effective tillers hill^{-1}	Yield plant^{-1}
Line				
IR58025A	–0.04	9.69**	–1.18**	7.72**
IR68897A	1.04**	–6.02**	0.93**	–5.55**
IR68886A	–1.00*	–2.87**	0.25	–2.17**
Tester				
Gautam	–3.92**	0.56	0.64	–9.95**
Dhanlaxmi	3.29**	–9.81**	–0.36	–3.00
Prabhat	–2.15**	–7.90**	–2.14**	–10.17**
Saroj	–0.26	–5.58**	–0.84	–7.50**
Pusa 1107	1.96**	–0.71	2.40**	–5.53**
Pusa 1040	1.40**	1.80**	0.83	12.66**
PSRM-1-16-48-11	0.96*	1.55**	2.45**	9.77**
RAV 1411-4	–1.48**	8.45**	1.27**	5.77**
RAV 1411-10	0.19	11.64**	4.00*	7.94**
SE CD (5%)	1.84	1.65	1.23	3.77

[a]*, ** = significant at P = 0.05 and 0.01, respectively.

Table 3. Yield performance, SCA effect, and heterobeltiosis of 10 rice hybrids, 2001.[a]

Cross	Yield (g pot^{-1})	SCA effect	Heterobeltiosis	Standard heterosis
IR60006A/Pusa 1040	83.66	41.05**	237.33**	111.28**
IR58025A/RAU 1411-10	60.50	12.72**	62.19**	52.78**
IR58025A/PSRM-1-16-48	57.80	18.11**	7.43*	45.96**
IR58025A/Gautam	50.30	20.45**	43.06**	27.02**
IR68897A/RAU 1411-10	49.00	14.50**	31.36**	23.73**
IR68897A/RAV 1411-4	46.16	13.83**	–23.83**	16.57**
IR58025A/PSRM-1-16-48	45.80	–3.77	–14.87**	15.66**
IR58025A/Pusa 1107	44.66	10.37**	27.01**	12.78**
IR68897A/Dhanlaxmi	40.50	16.94**	–4.70	2.28
IR68886A/RAU 1411-4	39.33	–6.27**	35.09	–0.68

[a]*, ** = significant at P = 0.05 and 0.01, respectively.

highest SCA effect (41.05) for yield, followed by the crosses IR58025A/Gautam (20.45), IR68886A/PSRM-1-16-48-11 (18.11), IR68897A/Dhanlaxmi (16.94), IR68897A/RAU 1411-10 (14.50), and IR68897A/RAU 1411-4 (13.83) (Table 3). These crosses were derived from parents having high, average, and low gene effects. The cross IR58025/RAU 1411-10 involved parents with high × high GCA, suggesting an additive × additive type of gene action. Manuel and Palaniswanny (1989) also reported interaction between positive × positive alleles in crosses involving high × high combiners, which can be fixed in subsequent generations if no repulsion phase linkages are involved.

On the other hand, crosses such as IR68886A/PSRM-1-16-648-11, IR68897A/RAU 1411-10, and IR68897A/RAU 1411-4 involve parents with high × low GCA effects, indicating involvement of additive × dominant gene interaction. Peng and Virmani (1999) also reported the possibility of interaction between positive alleles from good combiners and negative alleles from poor combiners in high × low cross combinations. This suggests the exploitation of heterosis in the F_1 generation as its high yield potential would not be fixed in the next generation.

The hybrids IR68886A/Pusa 1040 and IR58025A/RAU 1411-10 have standard heterosis > 50x. Standard heterosis (over Saroj) offers a greater scope for exploiting hybrid vigor.

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Mapping of QTLs for total number of leaves on the main stem of rice

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The total number of leaves (TNL) on the main stem of rice is an important vegetative growth trait. To identify quantitative trait loci (QTLs) conferring TNL, we used one recombinant inbred (RI) line derived from a cross between japonica cultivar Asominori and indica cultivar IR24. Tsunematsu et al (1996) constructed a restriction fragment length polymorphism (RFLP) molecular genetic map covering 127 cM with 375 markers. In this study, a subset of 289 RFLP markers (average interval distance between markers of 4.4 cM) without overlapping for all loci from the original genetic map (Tsunematsu et al 1996) was used to map QTLs for TNL.

In this experiment, seeds of 71 RI lines along with their parents, Asominori (P1) and IR24 (P2), were sown on 7 Jun 2001 and 10 Apr 2002, respectively. After 25 (2001) and 30 d (2002), seedlings were transplanted into rice fields of the Experiment Farm, Miyazaki University, Japan, at a single seedling hill^{-1} and 10 × 15 cm spacing. Other management practices followed conventional methods. The leaf number on the same main stem of two plants in each plot was recorded every 5 d until the emergence of the flag leaf. Average values were used for statistical analyses. In both years, all experiments were conducted in a randomized complete design with two replications.

The QTL analyses for TNL were performed by the Windows QTL Cartographer computer program, software version 2 (Wang et al 2003), through both single-marker and composite interval mapping (CIM) analyses. In single-marker analysis, when F values exceeded a value necessary for a probability value less than 0.005, the QTLs were considered significant. In CIM analysis, a locus with LOD > 3.0 was declared a putative QTL. In this study, only the QTLs detected by both methods were listed. In addition, the additive effects and percentage of variation explained by an individual QTL were also estimated.

Continuous variations and transgressive segragation (Fig. 1) were observed in the RI population, indicating that TNL was quantitatively inherited. A total of six QTLs for TNL were identified and mapped to chromosomes 3, 5, 6, 8, 9, and 12 (see table, Fig. 2) and were tentatively named *q*TNL-3, *q*TNL-

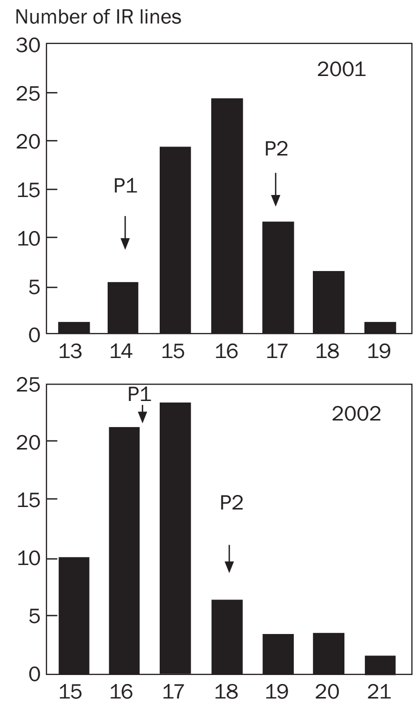

Fig. 1. The distribution of total number of leaves (TNL) on the main stem of rice. Black arrows indicate values of Asominori (P1) and IR24 (P2).

Table 1. QTLs associated with total number of leaves (TNL) in the main stem of rice.

Name[a] of QTL	Chromosome	Interval marker[b]	Probability[c]	Peak LOD value	Additive effect[d]	Variation[e] (%)
2001						
qTNL-3	3	C563-*XNpb184*	0.001	3.1	–0.33	8.2
qTNL-5	5	*R2232-Y1060L*	0.002	4.4	–0.41	13.3
qTNL-6	6	*R1985B*-C674	0.000	5.2	0.48	15.7
*q*TNL-9	9	*C796C*-R2638	0.000	5.2	–0.54	13.8
qTNL-12	12	*XNpb148*-XNpb258	0.003	3.2	–0.35	11.0
2000						
qTNL-3	3	C563-*XNpb184*	0.003	3.8	–0.43	12.6
qTNL-5	5	R2232-*Y1060L*	0.004	3.2	–0.31	9.6
qTNL-6	6	*R1985B*-C574	0.000	5.6	0.52	13.8
*q*TNL-8	8	*R902*-R2976	0.000	6.5	0.66	15.5
qTNL-12	12	*XNpb148*-XNpb258	0.003	4.8	–0.45	5.6

[a]**Bold letters** indicate QTLs detected in both years. [b]*Italic* letters indicate the nearest markers linked to putative QTL. [c]Indicates probability values and that the putative QTL is unlinked to the nearest marker by single-marker analysis method. [d]Positive values of additive effects indicate that Asominori alleles are in the direction of increasing traits. [e]Percentage of explained phenotypic variation.

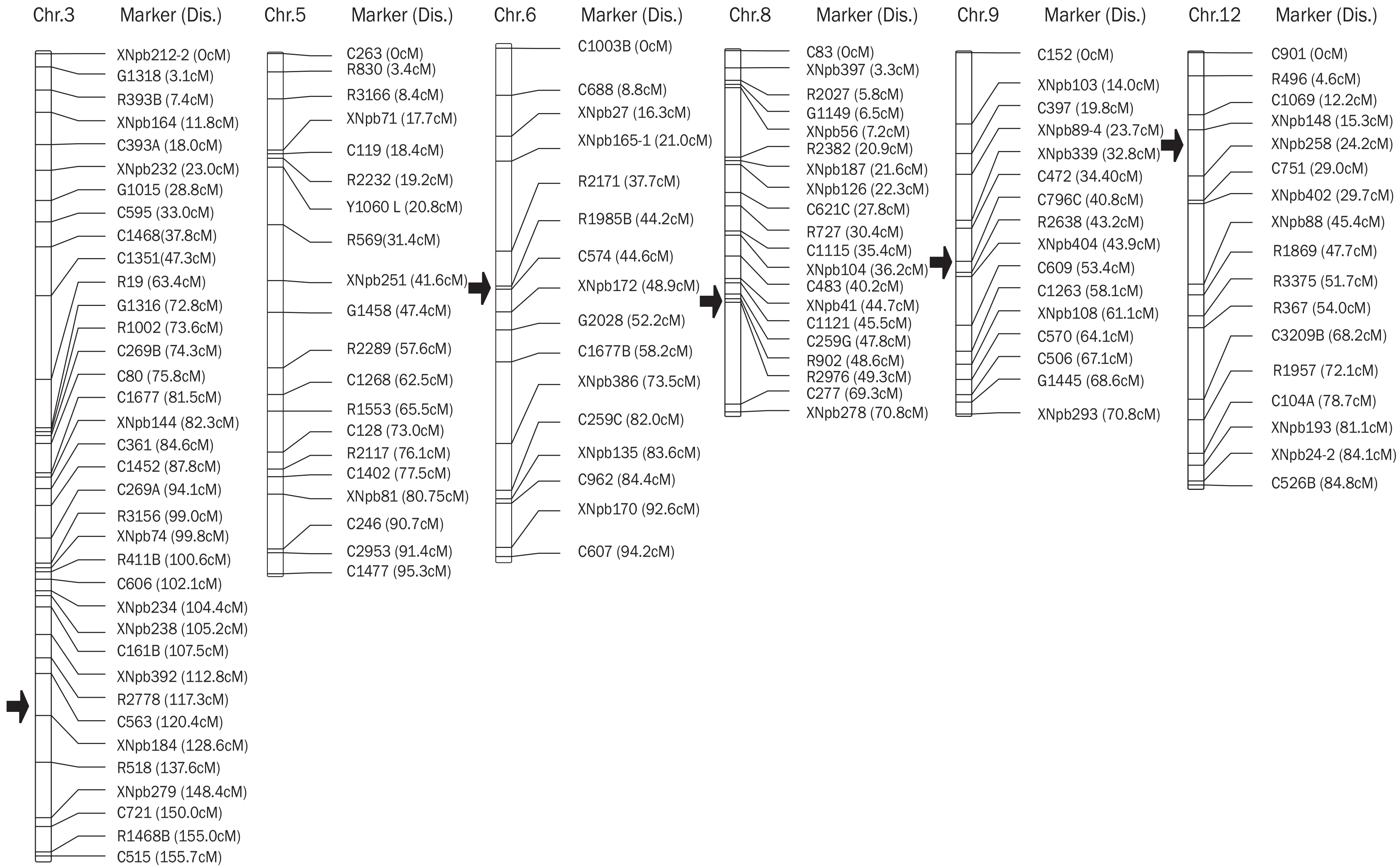

Fig. 2. Chromosomal locations of QTLs for TNL on the main stem in an RI population derived from Asominori/IR24. Black arrows indicate location of peak LOD for the QTL detected.

5, *q*TNL-6, *q*TNL-8, *q*TNL-9, and *q*TNL-12. Four QTLs, except *q*TNL-8 and *q*TNL-9, were commonly detected in both years. Individually, *q*TNL-3 was detected near XNpb184 (chromosome 3), explaining 8.2–12.6% of total phenotypic variation. *Q*TNL-5, located near Y1060L (chromosome 5), explained 9.6–13.3% of total phenotypic variation. *Q*TNL-6, located between R1271 and R1985B (chromosome 6), accounted for 13.8–15.7% of total phenotypic variation. *Q*TNL-12, located between XNpb148 and XNpb258 (chromosome 12), explained 5.5–11.0% of total phenotypic variation. The remaining two QTLs, *q*TNL-8 (chromosome 8) and *q*TNL-9 (chromosome 9), were detected in only 1 year and explained 15.5% and 13.8% of the total variation, respectively. In addition, four QTL (*q*TNL-3, *q*TNL-5, *q*TNL-9, and *q*TNL-12) alleles from IR24 and two QTL (*q*TNL-6 and *q*TNL-8) alleles from Asominori contributed to the increase in TNL. These findings confirm transgressive segregation and continuous variation in RI populations. In comparing the genomic positions of these QTLs for TNL (this study) with QTLs for days to heading in the same population (Yoshimura et al 1998), four QTLs (*q*TNL-3, *q*TNL-5, *q*TNL-6, and *q*TNL-8) had the same genomic positions. It was understandable that rice with longer days to heading shall have a greater number of leaves. In contrast, two QTLs (*q*TNL-9, *q*TNL-12) may be valuable because they will not influence days to heading in rice.

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International Koshihikari Rice Prize

Call for nomination

The International Koshihikari Rice Prize was established in 1997, the 50th anniversary of the Fukui Agricultural Experiment Station's rice-breeding program. The station's development of the rice variety *Koshihikari*, one of the best varieties in Japan, was an excellent example of the contributions local agricultural experiment stations make to rice production.

The prize recognizes rice researchers and extension specialists working at international, national and local agricultural research stations and universities.

In celebration of the International Year of Rice 2004, the prize will be awarded to the two best candidates. Each Koshihikari laureate will be awarded 500,000 Japanese yen during an award ceremony scheduled for 4 November 2004 in Tokyo, Japan. As part of the ceremony, the laureates are asked to make a presentation about their achievements in rice research and extension.

The nomination deadline is 31 August 2004. For more information and access to the online nomination form, go to www.irri.org/docs/koshihikari.pdf. All inquiries about nominations and procedures should be directed to the secretariat by email to ta1938@hotmail.com.

Rajendra Mahsuri 1, a potentially high-yielding rice variety for medium and shallow lowland ecosystems of Bihar, India

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Rajendra Mahsuri 1 (designated RAU83-500) is developed from the cross BR51-46/Mahsuri. This variety was released by RAU for commercial cultivation in 2003.

Rajendra Mahsuri 1 is a semidwarf variety (100–110 cm) that matures in 140–145 d. It can be grown in medium land to shallow lowland (up to 30-cm water depth) ecosystems. It has medium slender grain with white kernels and good milling and cooking quality. This nonlodging variety has shown field resistance to brown planthoppers and leaffolders and moderate resistance to sheath blight and bacterial leaf blight.

In yield trials and on-farm trials using farmers' plots, Rajendra Mahsuri 1 showed yield consistency and wide adaptability. Under medium land conditions, it gave an average yield of 5.0 t ha^{-1} compared with checks Sita (4.2 t ha^{-1}) and Kanak (4.4 t ha^{-1}). It also performed well under shallow lowland conditions, yielding an average of 4.9 t ha^{-1} compared with Radha's 4.0 t ha^{-1} and Satyam's 4.1 t ha^{-1} (Table 1). Rajendra Mahsuri 1 was also tested in shuttle breeding trials at 10 sites of eastern India: under normal planting with 30-d-old seedlings and delayed planting with 60-d-old seedlings under rainfed lowland conditions. Rajendra Mahsuri 1 ranked second under normal planting and fourth under delayed planting conditions (Table 2).

Table 1. Performance of Rajendra Mahsuri 1 (RAU83-500) in medium land and shallow lowland ecosystems at four sites in Bihar, India, 2000-02.

Entry	Av grain yield (t ha^{-1})				Mean	Increase over check varieties (%)
	Patna	Bikramganj	Pusa	Sabour		
Medium-land ecosystem						
RAU83-500	5.8	6.6	3.6	4.1	5.0	
Sita (check)	4.2	5.5	2.9	3.2	4.0	25.0
Kanak (check)	4.5	6.1	3.4	3.6	4.4	13.6
Shallow-land ecosystem						
RAU83-500	5.8	5.0	4.2	4.7	4.9	
Radha (check)	4.7	4.8	3.8	2.7	4.0	22.5
Satyam (check)	4.9	4.7	3.9	2.9	4.1	19.5

Table 2. Performance of Rajendra Mahsuri 1 (RAU83-500) in shuttle breeding trials under the ICAR and IRRI Collaborative Project, 2002 wet season.[a]

Designation	Grain yield (t ha^{-1})										Mean	Increase over check varieties (%)
	Bhabanipatna (Orissa)	Chinsurah (West Bengal)	Cuttack	Gerua (Assam)	Masodha (Uttar Pradesh)	Motto (Orissa)	North Lakhimpur (Assam)	Patna	Pusa	Titabar (Assam)		
Normal planting (30-d-old seedlings)												
RAU83-500	–	2.6 (10)	5.0 (5)	5.3 (7)	6.3 (3)	4.5 (4)	3.5 (1)	4.8 (1)	3.2	3.3	4.3 (2)	
Sabita (check)	–	2.7 (9)	4.8 (8)	4.0	3.1	4.1 (9)	2.5 (7)	3.8 (7)	4.6	3.0	3.6	19.4
Mahsuri (check)	–	2.4	3.7	4.1	5.3	4.2 (8)	2.0	3.5 (9)	4.7 (3)	3.1	3.7	16.3
CD at 5%	–	0.3	0.9	0.8	0.4	0.2	0.8	1.4	0.5	0.6		
CV (%)	–	4.8	12.2	11.7	5.3	2.1	19.9	23.9	9.3	9.5		
Delayed planting (60-d-old seedlings)												
RAU83-500	2.2 (7)	2.1 (10)	3.1	4.1	4.5 (7)	4.4 (3)	2.0 (6)	3.7 (6)	1.6	2.0	3.0 (4)	
Sabita (check)	2.0	2.5 (6)	3.1 (10)	2.2	3.0	3.9 (9)	2.8 (2)	3.5 (9)	2.3(4)	1.5	2.7	11.1
Mahsuri (check)	2.0	1.7	3.1 (9)	1.6	3.1	3.7	0.9	3.5	2.5(1)	1.5	2.3	30.4
CD at 5%	0.2	0.3	0.8	0.6	0.3	0.3	0.6	1.2	0.5	0.4		
CV (%)	5.9	5.1	16.5	12.0	5.8	3.8	23.4	22.0	19.5	10.6		

[a]Numbers in parentheses represent rank.

Pant Sankar Dhan 1 established a new high yield record in farmers' fields in northern India

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Rice production and productivity in India's favorable irrigated ecosystem have remained almost stagnant for a long time. Among the available options to overcome this problem, exploitation of yield heterosis through hybrid breeding is considered the most potent one. Scientists at the GBPUAT succeeded in meeting the expectations of northern Indian farmers by developing and commercializing the first hybrid, Pant Sankar Dhan 1, in the public sector.

The hybrid was released by the State Varietal Release Committee in 1997 for cultivation under irrigated transplanted conditions in the entire state of Uttar Pradesh, including the plains of the present Uttaranchal State. This hybrid was obtained from the cross UPRI 95-17A/UPRI 92-133(R) using the three-line approach of the cytoplasmic genic male sterility system for seed production. It is semidwarf and has dark green foliage, erect leaves, and a strong stem. Its short duration (115 d) makes the hybrid ideal for multiple-cropping systems, especially the predominant rice-wheat system in the entire Indo-Gangetic plains of the country.

Results of front-line demonstrations (FLDs) conducted in farmers' fields during 1999-2001 showed an average yield of 6.7 t ha^{-1} (range was 6.5–7.2 t ha^{-1}) (see table). It had an overall superiority of 43.6% over the best local variety and an absolute advantage of 2.04 t ha^{-1}. The maximum yield of the hybrid recorded in FLDs during specific years was 8.0 t ha^{-1} in Udham Singh Nagar and Meerut districts in 1999, 9.0 t ha^{-1} in Muzaffarnagar in 2000, and 11.7 t ha^{-1} in Nainital in 2001. To achieve higher yield, Pant Sankar Dhan 1 should be grown in good fertile soil with better manage-ment practices, particularly at the early stage of crop growth. The crop should also be protected from diseases/pests and harvesting should be done on time.

Pant Sankar Dhan 1 can compete very well with other good-quality rice varieties such as Pusa Basmati 1 grown in western Uttar Pradesh and the Uttaranchal plains. The yield recorded by the hybrid was almost three times that of Pusa Basmati (4.1 t ha^{-1}). Because of its very attractive, long, slender, translucent grains and good cooking quality, it has become popular with farmers. It is expected that large-scale promotion of this hybrid in the region would help solve the problem of reduced profitability. The governments of Uttaranchal and

Performance of Pant Sankar Dhan 1 in front-line demonstrations in western Uttar Pradesh and Uttaranchal, 1999-2001.

State	Year	Grain yield (t ha^{-1})			Percent superiority	Max recorded yield of hybrid (t ha^{-1})	
		Pant Sankar Dhan 1	Local checks	Yield gain over check			
Uttar Pradesh	1999	6.9 (5)[a]	3.5 (5)	3.4	96.0	8.0	(Meerut)
	2000	6.6 (25)	4.9 (25)	1.7	54.7	9.0	(Muzaffarnagar)
	2001[b]	–	–	–	–		
State	Mean	6.6	4.6	2.0	45.8		
Uttaranchal	1999	6.7 (5)	4.9 (5)	1.8	37.5	8.0	(Udham Singh Nagar)
	2000	5.2 (2)	4.3 (2)	0.9	21.2	5.5	(Udham Singh Nagar)
	2001	7.1 (11)	4.5 (11)	2.6	35.6	11.7	(Nainital)
State	Mean	6.8	4.4	2.4	53.7		
Overall mean (both states)		6.7	4.6	2.1	43.6		

[a]Numbers in parentheses indicate number of demonstrations (1.0 ha each). [b]In 2001, no front-line demonstration was conducted in Uttar Pradesh as Uttaranchal, a new state in which Pantnagar University is situated, was carved out from Uttar Pradesh.

Uttar Pradesh have made an ambitious plan to implement prenatal line multiplication and hybrid seed production. Recognizing the yield potential of Pant Sankar Dhan 1, Syngenta India Ltd., a bioscience multinational corporation, has signed a memorandum of understanding with GBPUAT for hybrid seed production and marketing of this public-bred hybrid.

TRY(R)2: a short-duration, salt-tolerant rice variety

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Out of 11 million ha of salt-affected cultivable land in India, 0.42 million ha are found in Tamil Nadu. Most of the salt-affected areas of this state are ill-drained wetlands and rice is cultivated extensively on these lands. Though two medium-duration (130–135 d) high-yielding salt-tolerant varieties (TRY1 and CO 43) are popular in these areas, they are ideal for cultivation during the wet season (Sep-Jan). Farmers have been growing other improved varieties during the dry season (Jan-Apr and Jun-Sep), when more pronounced symptoms of salinity stress are common, leading to substantial yield losses.

After two decades of research, the first short-duration salt-tolerant rice variety—Trichy (Rice) 2 abbreviated as TRY(R)2—was released for cultivation in 2002. TRY(R)2 is a cross derivative of IET6238/IR36 and was an entry in the 1991 Saline and Alkaline Tolerance Varietal Trials. The culture SSRC91216 has been evaluated in comparative yield trials at ACRI farms along with other improved short-duration varieties such as ADT36 (Triveni/IR20) and ASD16 (ADT31/CO 39) since 1991. The variety was further tested in salt-affected farmers' fields in 108 villages (see table). Farmers' holdings were selected in all the rice-growing districts of Tamil Nadu and, within the districts, fields with problem soils were chosen as the test sites. The trials were conducted on 400-m^2 plots without replication. The results showed that TRY(R)2 with an average productivity of 5.4 t ha^{-1} and a 1,000-grain weight of 22.84 g is capable of producing yields that are 19.7% and 11.9% higher than those of checks ADT36 and ASD16, respectively.

This new salt-tolerant variety has a plant height of 95–100 cm and matures in 115–120 d only. It responds to a high level of N fertilizers and is tolerant of blast under field conditions. Short duration and high yield coupled with salt tolerance make TRY(R)2 a highly suitable variety for cultivation in the saline soils of Tamil Nadu during the summer season.

Grain yield (t ha^{-1}) of TRY(R)2 in multienvironment on-station and on-farm trials.

Trial	At site	TRY(R)2	ADT36[b]	ASD16[b]
On-station trials(10 y)	9.6–10.1	4.6	3.5	3.7
On-station METs[a] (4 sites)	–	3.8	3.1	3.4
On-farm METs, 1996-97 (19 sites)	8.3–9.7	4.9	4.2	4.4
On-farm METs, 1997-98 (16 sites)	8.2–9.3	6.0	5.1	5.3
On-farm METs, 1998-99 (31 sites)	7.9–9.2	5.9	4.7	5.2
On-farm METs, 1999-2000 (42 sites)	8.0–9.5	5.3	4.5	4.8
Overall		5.4	4.5	4.8

[a]METs = multienvironment trials. [b]Check variety.

TXD85 and Line 88: new high-yielding varieties with acceptable grain quality in Tanzania

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Rice farmers in Tanzania prefer varieties with good grain quality. They like nonsticky cooked rice with strong aroma. Initial rice breeding efforts that started in 1965 did not focus on cultivars possessing grain quality preferred by farmers and local consumers. Consequently, farmers' adoption of varieties released up to 1985, such as Katrin and Selemwa, has been low largely because of their unacceptable grain quality.

In 1983, the then newly established Dakawa Research Center in Morogoro initiated a hybridization-breeding project that aimed to develop improved rice cultivars with desirable grain quality. From 1983 to 1986, we made crosses between Supa, the most preferred local cultivar, and some introduced lines from IRRI and North Korea. Among the first crosses, a promising progeny, TXD40-85-35-2-3 (Line 85), was identified in 1984 from cross No. 40 (Supa/KM67). The male parent KM67 is an early maturing cultivar from North Korea.

From 1987 to 1999, the new variety, designated TXD85, was evaluated in on-station and multilocation yield trials across the country. With a good yield range of 4.7–8.1 t ha^{-1} in on-station replicated trials, TXD85 produced 36% higher yield than did the parent Supa in 1987-88. The 1991-92 yields were 4.0% higher than that of check Katrin (Table 1).

In multilocation on-farm yield trials, TXD85 was superior to Supa by 44% (Table 2). TXD85 is semidwarf (88.6 cm) and has good tillering capacity (10.5 tillers plant^{-1}) and medium growth duration (95 d to 50% flowering) (Table 3). Because of its semitall plant stature, farmers can comfortably harvest it using the straw-cutting method with sickles. In addition, because of its similarly large and long grain size (31.7 g) and good milling recovery, farmers blend the milled TXD85 with variety Supa to enhance the aroma of the former.

However, TXD85 is susceptible to rice yellow mottle virus (RYMV). Kernels of promising lines derived from cross No. 40 (TXD40) had white belly. In an attempt to improve this deficiency in some promising TXD40-derived lines, we backcrossed TXD40-85-35 with

Table 1. Yield performance of (t ha^{-1})TXD85 and Supa in different trials, Dakawa, 1987-99.

Year	Trials/entries (no.)	Range	Yield (t ha^{-1})	
			TXD85	Supa (check)
1987	PYT-10	4.5–7.6	7.6	4.5
1988	PYT-10	4.8–6.2	6.1	4.8
1988	UYT-Late-8	3.6–8.5	8.1	5.9
Mean			7.2	5.3 (35.8%)
1991	AYT-16	5.3–7.6	5.3	5.3 Katrin
1992	AYT-13	3.4–6.1	4.7	4.3 Katrin
Mean			5.0	4.8 (4%)
			TXD 88	*Check IR8*
1989	PVT-12	7.6–9.0	8.0	7.2
1989	UVT-6	6.5–8.1	8.1	6.5
1990/Dry[a]	RYT-6	4.8–7.5	6.0	5.8
Mean			7.4	6.5 (14%)
1991	RYT-6	5.3–6.2	6.2	5.3 Katrin
1991/Dry[a]	AYT-16	5.3–7.6	7.3	5.4 Katrin
1992	AYT-6	3.4–6.2	6.2	5.1 Katrin
1992/Dry[a]	AYT-13	4.1–6.8	5.9	4.8 Katrin
Mean			6.4	5.2 (23%)

[a]Under irrigation.

Table 2. Yield performance (t ha^{-1}) of TXD85 and Line 88 in on-farm trials.

Year	Location	Trial/entries (no.)	Range	TXD 85	Line 88	Supa[a]
1998	Mbarali	MLYT-12	4.4–7.5	6.4	6.2	5.5
1998 Dry	Madibira[b]	MLYT-20	4.9–8.6	7.1	4.9	4.9
1999	Mombo	MLYT-7	3.4–6.4	6.3	4.3	3.4
Mean				6.6	5.1	4.6 (43.5/10.9%)

[a]Values in parentheses are yield advantages of test entries over the check. [b]Under irrigation.

either Supa or Subarmati. From backcross No. 88 involving TXD40-85-35 and Subarimati, a promising progeny, TXD88-1-B-1-2, was identified (Kanyeka, unpub. data). The progeny was tested in on- and off-station yield trials from 1988 to 2002. It exhibited high yield potential in preliminary trials and was further evaluated in advanced trials (Table 2). In on-station trials conducted from 1989 to 1990 at Dakawa, Line 88 (as it was commonly called) yielded from 4.8 to 8.1 t ha^{-1} (mean yield 7.4 t ha^{-1}), which was 14% higher than the yield of check variety IR8. It also produced 23% higher yield than check Katrin in 1991-92 (Table 1). Line 88 is photoperiod-insensitive and yielded 5.9–7.3 t ha^{-1} in the dry season when Supa could not flower at all (data not shown). Similar to TXD85, Line 88 is also semitall (92.6 cm) with heavy grains (33.4 g). It matures 3 wk earlier than Supa (Table 3).

In on-farm trials, farmers ranked Line 88 (officially released as such in 2002) as either highly acceptable or acceptable across three villages of Kilombero and Ulanga districts. The line is also very susceptible to RYMV.

Table 3. Farmers' ranking of Line 88 and comparison of TXD85 and Line 88 with Supa.[a]

Characteristic	Farmers' ranking of Line 88 in Kilombero villages			Comparison of lines for other traits			
	Ichonde	Mangu'la	Mbasa	TXD85	Line 88	Supa	DAK83
Plant stature and height (cm)	HA	HA	HA	70.5	92.6	130	92.9
Tillering capacity $hill^{-1}$	HA	A	HA	10.5	10.6	6.9	8.9
Days to 50% flowering and flowering uniformity	A	A	A	95	95	128	88
Grain size % and weight $1{,}000^{-1}$ (g)	A	A	A	31.7	33.4	32.9	26.9
Yield and yield ha^{-1}	HA	HA	HA	6.5	6.2	4.5	4.9
Milling quality	HA	HA	A	–	–	–	–
Cooking quality	HA	HA	A	–	–	–	–
Aroma	A	A	A				
Reaction to RYMV disease	–	–	–	MS	HS	S	HS

[a]HA = highly acceptable, A = acceptable, MS = moderately susceptible, HS = highly susceptible, S = susceptible.

TXD306—a high-yielding and medium-maturing aromatic rice for the rainfed lowland and irrigated ecosystems in Tanzania

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Most of the earlier released rice varieties in Tanzania were high-yielding but deficient in acceptable grain traits, especially eating and cooking quality. In most cases, they were given low market values by both farmers and consumers. In the early 1980s, a breeding program was established to address this problem. The major focus of the Supa Improvement Program (SIP) was to develop new varieties by incorporating grain quality components from a widely adopted local variety, Supa, while incorporating other traits that farmers prefer most under rainfed lowland and irrigated ecosystems.

TXD306 was derived from a double cross between Supa/Pyongyang and Subarimati, then backcrossed to Supa (Supa/Pyongyang8//Subarimati)/Supa). Preliminary selection was made from the F_6 generation on the basis of grain yield and plant height during the 1993 wet season. The variety was again selected in the 1993-94 dry-season strong aromatic yield trials. The variety was assessed for rice yellow mottle virus and blast resistance. TXD306 was found to be moderately susceptible to both diseases. The variety was advanced into on-station trials, where it proved superior to the local check (Table 1). To determine farmers' variety preferences, the candidate variety was tested at four different villages under farmer management practices from 1999-2000 to 2001-02.

Subsequent to these evaluations, the variety was recommended for farmer production by the National Seed Release Committee in December

2002. TXD306 is a photoperiod-insensitive, high-yielding, high-tillering, medium-maturing, relatively aromatic variety with good grain and milling qualities, and higher 1,000-grain weight (28.0 g). It responds well to fertilizer application. Being semidwarf and having sturdy stems, it resists lodging. It yields 4.5–5.0 t ha^{-1} in rainfed lowland and up to 5.5 t ha^{-1} in irrigated ecosystems. Under farmers' conditions, TXD306 yields 3.7–4.3 t ha^{-1} (Table 2).

Table 1. On-station performance of TXD306 for three seasons at Dakawa station under irrigated conditions, Morogoro, Tanzania.

Variety	Grain yield (t ha^{-1}) per season		
	1992-93 WS	1993-94 WS	1993-94 DS
TXD306	4.2	4.3	3.7
Supa (local check)	3.7	3.8	–
CV (%)	7.9	11.3	10.1

Table 2. On-farm mean yield performance of TXD306 at four villages in Tanzania.

Variety	Grain yield (t ha^{-1}) per location				Mean grain yield (t ha^{-1})
	Malinyi	Mngeta	Zombo	Bahi	
TXD306	4.8	4.8[a]	4.1[a]	3.3	4.3
Supa (local check)	4.4	3.6	3.2	3.4	3.7
CV (%)	22.8	24.5	16.6	27.3	

[a]Significantly higher than the check at 5% level.

Sahyadri, a popular rice hybrid for western India

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A popular variety, Karjat Rice Hybrid 1 (KJTRH 1), was identified at the Regional Agricultural Research Station, Karjat District, Raigad, in Maharashtra State, India. Obtained from a cross between CMS line IR58025A and BR827-35-3- 1-1-1 R, this hybrid was released for commercial cultivation as Sahyadri in Maharashtra in 1998. Later, the Central Varietal Release Committee approved its commercial cultivation in western India (covering Maharashtra, Goa, and Gujarat states) in 2000. Sayhadri has 125–130-d duration, is medium-tall (115–120 cm), is nonlodging and nonshattering, and has high yield potential (6.0–7.5 t ha^{-1}). It has long slender grain type, good milling quality (69.3% rice recovery), and 51.5% head rice recovery. It has good cooking quality, slight stickiness, slight aroma, 1.63 elongation ratio, and 26.2% amylose (Table 1). The kernels are suitable for parched, beaten, and puffed rice preparations.

Sahyadri was tested in farmers' fields throughout Maharashtra from 1996 to 1998. It had an excellent performance (6.9 t ha^{-1} grain yield) with an average 49.3% increase in yield over check variety Jaya. It showed better yield stability under varying agroclimatic conditions in the state and an increase in productivity. The hybrid consistently showed high yield potential in 943 large-scale demonstrations in Maharashtra, Goa, and Gujarat in the last 6 years, with an average yield of 6.4 t ha^{-1} and 41.1% increase over the check variety (Table 2).

Sahyadri performed well in multilocation trials conducted all over India. It was tested at 64 locations along with 13 other hybrids during the 1999 kharif. It ranked fifth in yield (5.2 t ha^{-1}) and had a 8.6% increase in yield over the best national check, Jaya (4.8 t ha^{-1}) (Table 3). It ranked first in yield (average of 6.3 t ha^{-1} over 15 locations) during the rabi-summer 1999-2000 season. The increased yield was 1.11 t ha^{-1} higher than that of the best national check, Sasyasree (5.2 t ha^{-1}). Over 46 locations in 14 states of India during the 2000 kharif, Sahyadri ranked third in average yield (5.1 t ha^{-1}). A yield advantage of 0.5 t ha^{-1} over Jaya (4.6 t ha^{-1}) was noted in these trials. This confirmed Sahyadri's wider adaptability in various agroecological conditions of the country.

Sahyadri is the first rice hybrid under large-scale cultivation in Maharashtra. Farmers, policymakers, administrators, officers of the State Agricultural Development Department, and scientists were convinced of its high yield potential (7–13 t ha^{-1}). Seed growers have successfully produced 2.0–2.5 t ha^{-1} of hybrid rice seed. Farmers were satisfied with the yield perfonnance of Sahyadri and demand for the seed increased every year. The area under hybrid rice cultivation increased to 15,000 ha during 2002 in Maharashtra. The target is to bring 15,000 ha of area under hybrid rice in the state in the coming 5 years. In view of Sahyadri's high yield potential, wider adaptability, higher straw yield, and acceptable grain quality, the new hybrid became most popular in western India. It is also grown in West Bengal, Uttaranchal, and Uttar Pradesh states.

Table 1. Morphological and quality features of Sahyadri.

Character	Detail
Duration (d)	125–130
Plant height (cm)	115–120
Yield (t ha^{-1})	6–7.5 (potential 15 t ha^{-1})
Tillers (no.)	20–30
Grains $panicle^{-1}$ (no.)	180–200
Length of panicle (cm)	22
1,000-grain weight (g)	28
Milling (%)	69.3
Head rice recovery (%)	51.5
Kernel length (mm)	7.18
Kernel breadth (mm)	2.39
Length-breadth ratio	3.004
Grain type	Long slender
Alkali value	6.6
Water uptake (mL)	160
Volume expansion ratio	4.6
Kernel length after cooking (mm)	11
Elongation ratio	1.63
Amylose content (%)	26.2
Grain chalkiness	Occasionally present

Table 2. Yield performance of Sahyadri and Jaya in different trials and demonstrations conducted in Maharashtra, Goa, and Gujarat, 1996-2002.

Trial/location/season/year	Trials/ demonstrations (no.)	Av yield (t ha^{-1})		Percent increase over check
		Sahyadri	Jaya	
Maharashtra				
Multilocation trials (1996 kharif)	5	5.6	4.4	26.5
Multilocation trials (1997 kharif)	9	4.5	3.7	23.7
Large-scale demonstrations (1997 kharif)	22	8.4	5.9	43.3
Observational yield trials (1996 rabi)	7	7.0	4.3	63.4
Observational yield trials (1997 rabi)	20	6.3	4.7	35.3
Observational yield trials (1997 kharif)	181	6.4	4.9	31.7
IHRT–2 (1997 kharif)	12	6.8	6.4	6.4
Front-line demonstrations (1998 kharif)	22	8.4	5.7	43.4
Front-line demonstrations (1998-99 rabi)	19	6.7	5.0	34.9
Front-line demonstrations (1999 kharif)	33	5.6	4.4	27.1
Front-line demonstrations (1999-2000 rabi)	50	5.1	3.7	38.3
Front-line demonstrations (2000 kharif)	48	5.2	3.9	31.9
Front-line demonstrations (2000-01 rabi)	19	5.8	3.4	45.6
Front-line demonstrations (2001 kharif)	170	6.2	3.9	58.1
Front-line demonstrations (2001-02 rabi)	77	7.4	4.3	72.1
Front-line demonstrations (2002 kharif)	205	6.9	4.2	65.1
Front-line demonstrations (2002-03 rabi)	20	7.2	5.2	37.0
Gujarat				
Front-line demonstrations (2001 kharif)	10	5.7	3.9	44.6
Gujarat				
Front-line demonstrations (2002 kharif)	14	7.0	4.6	52.4
Grand mean	943	6.4	4.6	41.1

Table 3. Yield performance of Sahyadri in multilocation trials throughout India.

Season, year	Locations (no.)	Yield (t ha^{-1})		Percent increase over check
		Sahyadri	Best check[a]	
Kharif, 1999	64	5.2	4.8	8.6
Rabi, 1999-2000	15	6.3	5.2	21.3
Kharif, 2000	46	5.1	4.6	10.8

[a]Best checks were Jaya (kharif, 1999-2000) and Sasyasree (rabi, 1999-2000).

Diversity and relative abundance of Orthoptera in an irrigated rice ecosystem in Madurai, India

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The diversity and relative abundance of Orthoptera in an irrigated rice ecosystem were studied in three field trials during 2000 kharif and rabi and 2001 kharif in the wetlands of ACRI, Madurai, Tamil Nadu, India (altitude about 147 m). Temperatures vary from 24.4 to 36.5 °C. The study area receives water from the Vaigai Dam. Annual rainfall was 893 in 2000 and 954 mm in 2001, mostly coming from the northeast monsoon that occurs from July to November. The treatments involved protected (weeded) and unprotected (unweeded; 10 weeds m^{-2}) rice ecosystems. Sampling was done at weekly intervals; seven to nine samplings in each season were taken. The diversity of species within a habitat was calculated by a diversity (Whittaker 1972). The Jaccard index was used to calculate similarities among the taxa found in the protected and unprotected rice ecosystems (Jaccard 1908). The values of the Jaccard coefficient index (Cj) ranged from 0 (no similarity—species absent in both weeded and unweeded ecosystems) to 1 (perfect similarity—species present in both weeded and unweeded ecosystems). Data were plotted as a percentage of similarity. Cj is computed using

$$Cj = j / (a + b - j)$$

where j is the number of taxa occurring in both samples, A (weeded plot) and B (unweeded plot), a is the number of taxa in sample A, and b is the number of taxa in sample B.

The present study revealed the occurrence of 21 species of grasshoppers and 4 species of crickets in the rice ecosystem (Table 1). Among grasshoppers, 13, 13, and 9 taxa were present in the protected plots) and 20, 20, and 19 taxa in the unprotected plots, respectively, during the

Table 1. Diversity and relative abundance of Orthoptera in a rice ecosystem.

Species/family	2000 kharif		2000 rabi		2001 kharif	
	Protected	Unprotected	Protected	Unprotected	Protected	Unprotected
Acrididae						
Acrida exaltata exaltata (Walk.)	2	4	3	2	–	8
Gastrimargus africanus Sauss.	–	2	–	2	1	6
Hieroglyphus banian Fab.	–	–	–	–	8	2
Oxya nitidula Walk.	22	15	28	25	16	12
O. fuscovittata (Marsch.)	9	12	18	20	7	14
Chrotogonus oxypterus Blanch.	–	2	–	3	–	–
C. brachypterus Bal.	–	2	–	2	–	–
Acrotylus humbertianus Sauss.	–	1	–	1	–	4
Ailopus thalassinus tamulus Fab.	1	1	–	1	–	2
Sphingonotus savigni Sauss.	–	4	–	3	–	4
Diablocatantopus pinguis (Stål.)	1	1	1	1	–	3
Catantopus ferrugineus Walk.	1	1	1	2	–	4
Euprepocnemis alacris alacris Serv.	1	2	1	1	–	2
Cyrtocanthacris tartarica (Lin.)	1	5	2	12	2	8
Anacridium flavescens (Fab.)	–	2	–	2	–	3
Pyrgomorphidae						
Atractomorpha crenulata (Fab.)	2	6	2	8	2	4
Tettigonidae						
Sphaneroptera gracilis Bur.	4	2	6	3	2	6
Euconocephalus incertus (Walk.)	–	6	2	8	–	5
Conocephalus maculates (Le Guillou)	8	12	16	11	10	8
C. chinensis (Redtenb.)	3	5	5	8	4	10
Holochlora albida Brun.	1	3	2	5	–	2
Total number of taxa	13	20	13	20	9	19
Gryllidae						
Metioche vittaticollis (Stål.)	8	5	6	4	10	6
Telogryllus sp.	3	6	2	7	2	8
Modigryllus sp.	2	4	1	4	2	2
Gryllodes sigillatus (Walk.)	4	5	3	2	4	5

*Values in the column are total number of individuals collected in each season.

2000 kharif and rabi and 2001 kharif. All four species of crickets were recorded in both ecosystems. Among the short-horned grasshoppers, two species—*Oxya nittidula* (Walk.) and *O. fuscovittata* (Marsch.)—were the most dominant taxa in both ecosystems. *Hieroglyphus banian* Fab. was recorded during the 2001 kharif only.

The other taxa of short-horned grasshoppers—*Acrida exaltata exaltata* (Walk.), *Gastrimargus africanus* Sauss., *Chrotogonus oxypterus* Blanch., *C. brachypterus* Bal., *Acrotylus humbertianus* Sauss., *Diabloca-tantopus pinguis* (Stål.), *Catantopus ferrugenius* Bol., *Euprepocnemis alacris alacris* Serv., *Cyrtacanthacris tartarica* (Lin.), *Anacriduim flavescens* (Fab.) (Acrididae), and *Atractomorpha crenulata* (Fab.) (Pyrgomorphidae)—were rare. Of the long-horned grasshoppers (Tettigoniidae), *Spheneroptera gracilis* Bur., *Conocephalus maculatus* (Le Guill.), *C. chinensis* (Redtenb.), and *Holochlora albida* Brun. were the most common species, with *C. maculatus* being the dominant taxon in all three seasons in both weeded and unweeded ecosystems. *Euconocephalus incertus* (Walk.) was the rare species. Four species of crickets—*Metioche vitatticollis* (Stål.), *Telogryllus* sp., *Modygryllus* sp., and *Gryllodes sigillatus* (Walk.)—were common. *M. vitatticollis* was the most dominant and most abundant. Eighteen species of weeds were recorded in the unweeded plots. Among the weeds, *Echinochloa colonum* (L.) Link., *E. crus- galli* (L.) Beauv., *Cyperus rotundus* L., *C. difformis* L., *C. iria* L., *Fimbristylis miliaceae* (L.), *Marselia quadrifoliata* Presl., and *Convolvulus arvensis* L. were dominant.

The diversity index showed perfect similarity (1.00, 0.90, 1.00, 0.88) at the initial and maturity stages of crop growth (Table 2). This indicates that the common species (*O. nitidula* and *O. fuscovittata*) had more individuals than the rare species. This supports the findings of Capinera and Sechrist (1982). But Hurd et al (1971) contend that the abundance of one species has little effect on other species in a stable ecosystem. A greater diversity of short-horned grasshoppers was recorded in the fourth, fifth, sixth, and seventh week of sampling in the three seasons. This confirms the host-plant geographical distribution hypothesis, which states that widely spread plant species (weed species) have a richer regional pool of insects and, consequently, richer insect species (Ricklets 1987, Cornell and Lawton 1992). Long-horned grasshoppers and crickets exhibited higher diversity in the fourth- and fifth-week samplings. This may be attributed to availability of more weed plant species, alternate resources, and favorable climates in unweeded plots (Sheltan and Edwards 1983). *Holochlora albida* was a tourist grasshopper in the rice ecosystem. Tourist insects are nonpredatory taxa with no known functional association with rice, except for shelter, sun basking, and sexual display (Moran and Southwood 1982).

This study shows that, 10 d after transplanting, the diversity of Orthoptera was less in both protected and unprotected ecosystems. During the flowering stage, diversity and relative abundance of grasshoppers were greater in unprotected plots. Oligophagous grasshoppers were more abundant in protected plots than in unprotected plots. The polyphagous taxa of grasshoppers occurred only in unprotected plots (rice + weed plants). Species richness and evenness were greater in unprotected plots. Rare species with fewer individuals always occurred during the successional

Table 2. Taxonomic similarity of orthopterans found in protected and unprotected rice ecosystems.[a]

Crop stage	Short-horned grasshopper			Long-horned grasshopper			Crickets		
	2000 kharif	2000 rabi	2001 kharif	2000 kharif	2000 rabi	2001 kharif	2000 kharif	2000 rabi	2001 kharif
Tillering	0.70	0.80	0.88	1.00	1.00	1.00	0.66	1.00	0.00
	0.71	0.75	0.80	1.00	0.75	1.00	0.50	0.66	0.00
	0.70	0.60	0.60	0.90	0.66	0.90	0.50	0.66	1.00
Flowering	0.33	0.50	0.56	0.50	0.55	0.45	0.50	0.33	1.00
	0.40	0.50	0.42	0.55	0.50	0.46	0.50	0.66	0.50
	0.45	0.42	0.55	0.55	0.66	0.75	0.00	0.66	0.00
Maturity	0.36	0.40	0.86	0.75	0.70	1.00	0.00	0.66	0.00
	0.63	0.57	–	0.80	0.75	–	0.00	0.50	–
	0.92	0.80	–	0.90	1.00	–	0.00	0.00	–

[a]Values are indices.

age of the crop in unprotected plots. During tillering and maturity, grasshoppers showed greater similarity (less diversity).

The diversity of grasshoppers was less during tillering and at maturity and greater during flowering in unprotected plots because of the numerous species of grasses present (resource concentration hypothesis). The diversity and relative abundance of grasshoppers were determined by species and growth stage of grasses in unprotected plots.

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Pseudomonas strain GRP_3 induces systemic resistance to sheath blight in rice

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Fluorescent pseudomonads (FLPs) are a dominant group in the rhizosphere, exerting plant growth-promoting action through various mechanisms that involve siderophores, release of hydrocyanic gas, production of indole acetic acid, secretion of antibiotics, and inducing systemic resistance (Duffy and Defago 1999, Rao et al 1999). These properties make plant growth-promoting rhizobacteria (PGPR) very useful for disease and crop productivity management. Several workers have successfully demonstrated the induction of systemic resistance (ISR) by FLPs and this presents an attractive alternative for biocontrol of diseases beyond root- and soil-borne pathogens. FLP isolate GRP_3 is a well-established PGPR, which shows promise in controlling several phytopathogens. In this report, data are presented to confirm ISR to sheath blight fungal pathogen *Rhizoctonia solani* brought about by this isolate in rice.

The FLP isolate GRP_3, originating from soybean, was maintained in King's B agar medium. Its efficacy for ISR was checked using rice cultivar Pusa Basmati. There were four treatments: tricyclazole fungicide spray at 1 g L^{-1}, seed bacterization by GRP_3 (10^8 cfu mL^{-1}), root dipping (10^8 cfu mL^{-1} at both times), and the untreated control. Rice seedlings were inoculated 37 d after sowing with 7-d-old *R. solani* sclerotia (grown on PDA). Sheath blight severity was monitored after 7 d of pathogen infestation by calculating the disease index. The greenhouse experiment (temperature 35 ± 2 °C; relative humidity 90% ± 2%) was conducted with six replicates (10 plants per replicate) in each treatment. The effect of GRP_3 treatment on plant resistance was monitored by estimating peroxidase and total soluble phenol content (Lagrimini and Rothstein 1987, Meena et al 2000). Peroxidase usually appears in response to stress imposed on the plant. Peroxidase also plays an important role in the lignification of the cell wall, which ultimately provides a physical barrier to the plant. This was correlated with the estimation of phenols in the leaves of rice plants.

Disease resistance evaluated in the greenhouse trials showed promising results on the basis of disease index. Seed bacterization followed by root dipping (dual treatment) resulted in only 46% infection with lesion length reduced (5.0 mm). The relative infection in nonbacterized control plants was 93%, with a lesion length of 32 mm. The disease index indicated that mycelial growth and sclerotial germination of *R. solani* were inhibited by GRP_3. The dual treatment reduced disease incidence in rice to a significantly greater degree than did other single treatments. This disease inhibition showed density-dependent signaling and induction of defense signaling.

Hydrogen peroxide generated after pathogen infection and wounding is highly toxic to the cell and it must be eliminated promptly to prevent metabolic death. The interaction of peroxidases and phenolics results in cell-wall thickening, which is also a mode of creating a physical hindrance to the fungal pathogen. Compared with the control (0.15 U g^{-1} leaf tissue), peroxidase activity was higher (1.40 U g^{-1} leaf tissue) in plants exposed to the dual treatment and seed-bacterized plants (1.35 U g^{-1}). The level of phenol in the dual treatment was higher (1.55 mg g^{-1} leaf tissue) than in the untreated control (1.22 mg g^{-1} leaf tissue). Suppression of the disease is related to the enhancement of signaling compounds or secondary messengers such as H_2O_2. It would appear that, in the dual treatment, the decline in effective molecules is followed by a burst, with the second exposure of the antagonist a consequence of reactivation of the signaling cascade. Tricyclazole (Beam), a systemic fungicide used mainly in rice disease control, was used as a positive control for determining the extent of ISR. The Beam treatment resulted in less *R. solani* infection in the respective treatment, but once the disease was established, a significant lesion appeared. At the 5% level, the treatments with GRP_3 and Beam showed a higher level of disease inhibition and induction of resistance against *R. solani* (Table 1).

Correlation analysis suggested that the increased expression of peroxidase and phenol synthesis was governed by the GRP_3 treatment ($R^2 = 0.71$). According to Hammerschmidt and Kuc (1982), phenolics (including lignin precursors) are directly toxic to the pathogens. Also, in the presence of peroxidase, these molecules polymerize, resulting in the thickening of cell walls, which are difficult to penetrate and degrade.

Experimental results showed the efficacy of *Pseudomonas* strain GRP_3 in inhibiting *R. solani*, thereby minimizing disease spread. Analysis of peroxidase and its relevance to phenolics provides an alternative plant-signaling approach besides the usual signaling system involved in the induction of a plant defense system. Further studies on the purification and characterization of the active signal molecules are under way.

Table 1. Disease index of *Rhizoctonia solani* infection in rice (Pusa basmati) after treatment with fluorescent pseudomonad strain GRP_3.

Treatment	Disease index[a]	
	Infected plants (%)	Lesion length (mm)
Control	93.5	32.0
Fungicide[b] (Beam) treatment	36.8	26.7
Seed bacterization	60.0	10.7
Seed bacterization + root dipping	46.6	5.0
Root dipping[c]	73.3	8.3

[a]Av of 30 plants. [b]1 g L^{-1} spray after transplanting. [c]At transplanting.

Table 2. Peroxidase expression and total soluble phenol synthesis in response to GRP_3 treatment.

Treatment	Peroxidase activity (U g^{-1} fresh-weight leaf tissue)	Total soluble phenols (mg g^{-1} fresh-weight leaf tissue)
Control	0.51 ± 0.001	1.223 ± 0.0289 b
Fungicide[a] (Beam) treatment	1.06 ± 0.003	1.343 ± 0.0178 b
Seed bacterization	1.35 ± 0.007 a	1.421 ± 0.0289 b
Seed bacterization + root dipping	1.40 ± 0.013 a	1.566 ± 0.0089
Root dipping[b]	0.86 ± 0.06	1.150 ± 0.0013 b

[a]1 g L^{-1} spray after transplanting. Av of 30 plants. [b]At transplanting. Values followed by the same letter are not significant (LSD = 0.05).

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Pattern recognition on sample characteristics of invertebrates in an irrigated rice field

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As a basis of ecological equilibrium and sustainable production in rice fields, invertebrate biodiversity and conservation have been given close attention in recent years. Sampling individuals to attain greater biodiversity variation in a manageable number of samples and making these samples more representative are the objectives of rice invertebrate sampling. However, techniques such as estimation of species richness, population genetics, and others could not provide adequate knowledge on specific taxa on the basis of invertebrate characteristics and sampling strategy. In this study, sampling sets of invertebrate species investigated in the IRRI rice field at different periods (mar18, apr15, oct08, and sep17, each with 60 samples; sampling sites spaced 2 m apart and sampled using a RiceVac apparatus and a 0.16-m^2 bucket enclosure) were lumped into higher taxonomic groups and functional groups using biodiversity software LUMP. Karhunen-Loève transformation (Bian and Zhang 2000) was used to analyze the sample characteristics of invertebrate taxa and sample variation. The aim was to design a sampling strategy of maximizing biodiversity variation in a manageable number of samples (Jin and Lu 2003) to achieve a greater understanding of rice invertebrate characteristics and the effects of extraction of sample information.

The Karhunen-Loève transformation is calculated as follows: assume that a sample has m characteristics and sample $\boldsymbol{x}$, where $\boldsymbol{x} = (x_1, x_2, \dots, x_m)^{\mathrm{T}}$, can be expanded with a complete orthogonal system $\boldsymbol{u}_j$, $j = 1,2,\dots,m$, : $\boldsymbol{x} = \sum_{j=l}^{m} c_j \boldsymbol{u}_j$. If the first p terms are used to estimate $\boldsymbol{x}$, its estimate will be $\boldsymbol{x}' = \sum_{j=l}^{p} c_j \boldsymbol{u}_j$, and the corresponding mean square deviation is $\xi = \mathrm{E}[(\boldsymbol{x} - \boldsymbol{x}')^{\mathrm{T}}(\boldsymbol{x} - \boldsymbol{x}')] = \mathrm{E}[\sum_{j=p+1}^{m} c^2_j]$. After that, $c_j = \boldsymbol{u}^{\mathrm{T}}_j \boldsymbol{x}$, $\xi = \sum_{j=p+1}^{m} \boldsymbol{u}^{\mathrm{T}}_j \boldsymbol{\Phi} \boldsymbol{u}_j$, where generated matrix $\boldsymbol{\Phi} = \mathrm{E}[\boldsymbol{x}\,\boldsymbol{x}^{\mathrm{T}}]$. If the training samples were not classified in advance, let $\boldsymbol{\Phi} = \mathrm{E}[(\boldsymbol{x}-\boldsymbol{\mu})(\boldsymbol{x}-\boldsymbol{\mu})^{\mathrm{T}}]$, where $\boldsymbol{\mu}$ is the vector of population mean of all training samples. Using Lagrange's method of multipliers and maximizing ξ, the following formulas are obtained: $(\boldsymbol{\Phi} - \lambda_j I')\boldsymbol{u}_j = 0$, $j = p+1, p+2, \dots, m$. Let $p = 0$ and assume that $\lambda_1 \geq \lambda_2 \geq \dots \lambda_m$. Choose the first p eigen values that meet the condition $\sum_{j=p+1}^{m} \lambda_j / \sum_{j=p+1}^{m} \lambda_i \geq \alpha$, where α is the percentage of information remaining from the transformation and $1 > \alpha > 0$. After that, calculate $\xi = \sum_{j=p+1}^{m} \lambda_j$. The first p eigenvectors corresponding to the p eigenvalues, $\boldsymbol{u}_j$, $j = 1,2,\dots,p$, can be used to construct an orthogonal coordinate system, which is just the p-dimensional Karhunen-Loève coordinate system in m characteristic space. The vector of expansion coefficients of sample $\boldsymbol{x}$ in the Karhunen-Loève coordinate system is the Karhunen-Loève transformation of $\boldsymbol{x}$.

If training samples were classified in advance, $\boldsymbol{x} \in C_i$, $i = 1,2,\dots,q$. The priori probability of class i is P_i and the mean vector of the class is μ_i, $i = 1,2,\dots,q$. Calculating for $\boldsymbol{\Phi}$,

$$\boldsymbol{\Phi} = \sum_{i=l}^{q} P_i\,\mathrm{E}[(\boldsymbol{x}-\mu_i)(\boldsymbol{x}-\mu_i)^{\mathrm{T}}]$$

Let $J(x_j) = (\boldsymbol{u}^{\mathrm{T}}_j S \boldsymbol{u}_j)/\lambda_j$, where $\boldsymbol{x}_j = \boldsymbol{u}^{\mathrm{T}}_j \boldsymbol{x}$ is the characteristic after transformation was made, and $S = \sum_{i=l}^{q} P_i(\boldsymbol{\mu}_i - \boldsymbol{\mu})(\boldsymbol{\mu}_i - \boldsymbol{\mu})^{\mathrm{T}}$, where $\boldsymbol{\mu}$ is the vector of the population mean of all training samples. Assume that $J(x_1) \geq J(x_2) \geq \dots \geq J(x_m)$ and choose the first p eigenvectors that correspond to the p eigenvalues, $\boldsymbol{u}_j$, $j = 1,2,\dots,p$. In this procedure, we assume that $P_i = n_i/n$, where n is the total number of training samples and n_i is the number of training samples belonging to class i.

For the sample $\boldsymbol{x}$ to be recognized, calculate its relative deviation $||\boldsymbol{x}-\boldsymbol{x}'||/||\boldsymbol{x}'||$, if $||\boldsymbol{x}-\boldsymbol{x}'||/||\boldsymbol{x}'|| < T$, where T is the permitted relative deviation. The sample is considered to be either homo-geneous to the set of training samples or hetero-geneous to the sample set.

Results with single (60 samples) and incorporated sampling sets (4 * 60 samples) showed significant invertebrate orders presenting sample variations in the rice field—these were Hemiptera, Mesogastropoda, and Symphypleona. In the early seasons, Hemiptera was the most important order, but Mesogastropoda was dominant in the late seasons.

The significant functional groups were plant feeders, mixed herbivores, neustonic (water surface) swimmers (semiaquatic), shredders, chewers of coarse particulate matter, and terrestrial crawlers, walkers, jumpers, or hunters. Dominant rice pests such as external plant feeders and mixed herbivores and their natural enemies such as neustonic (water surface) swimmers (semiaquatic), and terrestrial crawlers, walkers, jumpers, or hunters were all categorized under these functional groups. There were similarities in characteristic taxa between Mar18 and Oct08 and between Apr15 and Sep17.

Results of Karhunen-Loève transformation on invertebrate order-based sampling sets indicated that recognizing samples in the same set of training samples by Karhunen-Loève transformation produces the best performance. For example, the ratio of mean relative deviation recognizing training samples to mean relative deviation recognizing samples to be recognized were 0.2815/0.2344, 0.2813/0.2344, 0.4691/0.3669, and 0.2246/0.1548 for Mar18, Apr15, Oct08, and Sep17, respectively. The performance of recognizing samples to be recognized is better than that of recognizing training samples. The mean relative deviation to recognize 240 training samples in the incorporated sampling set was 0.3798, which was generally in the scope of the mean relative deviation of a single sampling set (60 samples).

Overall, recognition performance with respect to samples of Sep17, taking Mar18, Apr15, and Oct08 as a set of training samples, was the best. The recognition performance of Sep17 to Mar18 and Apr15 was good. There were no significant seasonal differences in sample recognition. Generally, the recognition performance of the Karhunen-Loève transformation to invertebrate order-based sampling sets was better in view of the theoretical interval of relative deviation $(0, \infty)$.

As in recognition of invertebrate order-based samples, recognizing functional group-based samples in the same set of training samples by Karhunen-Loève transformation produced the best performance. The mean relative deviation of recognition of 240 training samples in the incorporated functional group-based sampling set was 0.2736, the same magnitude as that of mean relative deviation of a single sampling set (60 samples).

Recognition of Mar18 and Apr15 to themselves gave the worst performance. Recognition of Apr15 and Oct08 to Sep17 had better performance and Sep17 gave the best recognition performance to Mar18. These recognition performances did not indicate significant seasonal trends. These results were different from those of the Shaanon-Wiener tests but similar to the randomization tests (Zhang and Schoenly 2001). In general, recognizing functional group-based samples did not result in a performance better than that indicated by recognition of invertebrate order-based samples.

Karhunen-Loève transformation should be used to achieve information on sample variations (Bian and Zhang 2000). Taxa, be they invertebrate orders or functional groups, with little sample variation will not remain as significant characteristics in the transformation. As a result, some taxa with importance in integrated pest management (IPM) or those with larger abundance will not be significant characteristics used to recognize samples. Diptera, Coleoptera, and Araneae are dominant invertebrates in IPM, but they do not typically represent sample variations. On the other hand, there was no significant difference between Apr15 and Sep17 with respect to invertebrate orders and functional groups and between Mar18 and Oct08 with respect to functional groups in the Shaanon-Wiener diversity tests. However, similar conclusions cannot be drawn in the sample analyses of the Karhunen-Loève transformations. This points to the substantial difference between biodiversity analysis (such as analysis of biodiversity index and species richness estimation) and sample analysis (such as Karhunen-Loève transformation). We may use the Karhunen-Loève transformation to determine significant taxa resulting in sample variation to design a sampling strategy to maximize biodiversity variation in a manageable number of samples as emphasized by population genetics and genetic biodiversity theories (Jin and Lu 2003). Methods involving biodiversity index, species richness estimation, and population genetics are not efficient enough to answer these specific questions.

Overall, the significant invertebrate orders that resulted in sample variations in the irrigated rice field were Hemiptera, Mesogastropoda, and Symphypleona. In the early seasons, Hemiptera was the most important order; in the later seasons, it was Mesogastropoda. The significant functional groups that resulted in sample variations were external plant feeders, mixed herbivores, neustonic (water surface) swimmers (semiaquatic), shredders, chewers of coarse particulate matter, and terrestrial crawlers, walkers, jumpers, or hunters.

The Karhunen-Loève transformation can be used to reduce the dimensionality of characteristic space of invertebrate biodiversity without loss of significant information carried by the samples. It is effective in compressing data and saving storage space in situations with large numbers of sampling data.

The eigenvectors resulting from Karhunen-Loève transformation are "characteristic samples" of training samples that can be used to analyze the characteristic taxa of invertebrate biodiversity. We may use the Karhunen-Loève transformation to recognize samples and design a sampling strategy that will maximize biodiversity variation in a manageable number of samples.

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Nonparametric richness estimators of hierarchical arthropod taxa in irrigated rice fields

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The biodiversity of functional groups or higher taxonomic groups determines the overall appearance (and consequently biomass production) of agroecosystems (Schoenly and Zhang 1999) and forest ecosystems (Tilman et al 1997). Species-based richness is best estimated with the estimator Bootstrap (Zhang and Schoenly 1999). However, achieving the most possible richness of hierarchical arthropod taxa also contributes toward a greater understanding of arthropod biodiversity in the rice field. In this study, sampling sets of arthropod species were investigated in the IRRI rice field in different periods (i.e., 18 Mar, 15 Apr, 8 Oct, and 17 Sep), each with 60 samples. Sampling sites were spaced 2 m apart and were sampled using a RiceVac apparatus and a 0.16-m^2 bucket enclosure. The sampling sets were lumped into higher taxonomic groups and functional groups using biodiversity software LUMP. Seven nonparametric estimators were compared using software EXTSPP1 and EXTSPP2 (Schoenly and Zhang 1999; see LUMP, EXTSPP1, and EXTSPP2 at www.irri.org/Biodiversity Software/index.html). These estimators were represented as Chao 1 and Chao 2; Jackknife 1 and Jackknife 2 (i.e., first-order jackknife and second-order jackknife); Bootstrap; and Chao 3 and Chao 4. The objective of this study is to determine what estimator gives the best estimate of the richness of hierarchical arthropod taxa in an irrigated rice field. Three bias indices—total bias (MD), absolute bias (MSD), and relative bias (MSPD)—were used to evaluate the performance of seven nonparametric estimators (Zhang and Schoenly 1999):

$MD = \sum_{i=l}^{n}(S_i - S)/n$; $MSD = \sum_{i=l}^{n}(|S_i - S|)/n$; $MSPD = \sum_{i=l}^{n}(|S_i - S|/S)/n*$ 100% where S_i denotes the estimated richness in the ith randomization and S is the observed taxonomic richness for all samples in the sampling set. MD, MSD, and MSPD take the average overall randomizations (n).

The lumping analyses showed 66, 71, 75, and 75 arthropod families in sampling sets mar18, apr15, oct08, and sep17, respectively. Results from running EXPSPP1 and EXTSPP2 (nonparametric, 5,000 times of randomization, sampling bias for $s1^*$ and $s2^*$ was 0.05) indicated that, in almost all communities, Bootstrap estimates on family richness yielded the least absolute bias and relative bias. Seven estimators overestimated family richness, except Chao 1, which gave underestimates in some communities. Overall, Jackknife 2 produced the largest positive MD in all communities. Chao 3 and Chao 4 were the most accurate estimators in terms of MD, except for sep17.

Most of the estimators gave increasing estimates of family richness as sample size increased, except for Chao 3 and Chao 4, which yielded a slightly higher estimate when sample size was 2. Estimates of Chao 1, Chao 2, and Jackknife 2 decreased when sample size was larger than 32–38, 28–40, and 38–53 samples, respectively, in the mar18 set. The corresponding intervals for the apr15 set were 35–46, 28–38, and 35–47 samples. Jackknife 1 estimates decreased when sample size was larger than 50–57 (apr15). Chao 4 reversed its estimates when sample size was more than 45–58. Bootstrap yielded steady and the least biased estimates of family richness.

The sample sizes found to achieve unbiased estimates of family richness are 18±4, 18±3, 23±1, 15±1, 23±3, and 19±3 samples for Chao 1, Chao 2, Jackknife 1, Jackknife 2, Chao 3, and Chao 4, respectively.

Sampling sets mar18, apr15, oct08, and sep17 harbored 17, 16, 18, and 18 arthropod orders, respectively. Chao 1, Chao 3, and Chao 4 understimated the richness of arthropod orders with a negative MD. Jackknife 1 yielded the least positive estimates in apr15 and sep17. However, Jackknife 2 yielded the least positive MD only in mar18 and oct08. Bootstrap yielded the largest positive MD but produced the least MSD and MSPD in all communities.

Colwell and Coddington (1994) set a 95% level of confidence; the samples required to achieve 95% of confidence for the mar18, apr15, and oct08 sets were 32, 13, and 47, respectively.

Most estimators yielded increasing estimates of order richness as sample size increased. However, estimates of Chao 3 and Chao 4 were higher with a sample size of two. Chao 3 and Chao 4 showed changes when sample size was larger than 39–46 or 38–46 samples (mar18) and 38–42 or 36–42 samples (oct08). In the oct08 set, the same changes were seen with sample sizes 33–39, 33–38, 31–36, and 23–26 for Chao 1, Chao 2, Jackknife 1, and Jackknife 2. Jackknife 1 and Jackknife 2 produced changes with 26–36 and 21–25 samples in mar18. Bootstrap yielded the least biased but slightly fluctuating estimates of order richness.

The sample sizes needed to achieve unbiased estimates of order richness were 23±8, 21±5, 19±8, 13±7, 33±10, and 30±11 for Chao 1, Chao 2, Jackknife 1, Jackknife 2, Chao 3, and Chao 4, respectively.

The observed richness of functional groups for mar18, apr15, oct08, and sep17 was 21, 20, 22, and 21, respectively. Chao 1, Chao 3, and Chao 4 understimated richness of arthropod functional groups with a negative total bias. Chao 2 yielded unsteady values of MD. In most communities, Jackknife 1 yielded the least positive MD, making it the most accurate estimator for total bias. Jackknife 2 and Bootstrap produced a larger positive MD. However, Bootstrap estimates yielded the least MSD and MSPD among estimates of functional groups in all communities. The number of samples required to achieve a 95% level of confidence in the estimation for mar18 was 51.

All estimators yielded increasing estimates of richness of functional groups as sample size increased, except for Chao 3 and Chao 4, whose sample size was less than 3 in all communities. Bootstrap yielded the least biased but most fluctuating estimates of richness of functional groups.

The sample sizes needed to achieve unbiased estimates of richness of functional groups were 34±4, 30±4, 23±4, 16±3, 36±2, and 33±3 for Chao 1, Chao 2, Jackknife 1, Jackknife 2, Chao 3, and Chao 4, respectively.

In different rice-growing seasons, the estimated richness of families ranged from 71 to 103; orders, 16–19; and functional groups, 17–27.

Bootstrap steadily yielded the least MDS and MSPD in all sample sizes, and thus has the least relative error in richness estimations of arthropod taxa in irrigated rice fields. With respect to species and families, Bootstrap, Chao 3, and Chao 4 gave the most precise estimates. Jackknife 1 generally yielded the least positive MD, but it was the least precise estimator.

The sample sizes to achieve unbiased estimates of hierarchical arthropod taxa (except for Bootstrap) were between 15 and 35, with differences among estimators and hierarchical levels of arthropod taxa. Generally, these sample sizes to achieve unbiased richness estimates of functional groups were the largest and second largest for unbiased estimates of order richness. These were similar to unbiased estimates of richness of species and families. Of these estimators, Jackknife 2 required the smallest sample size, which needed only 13–15 samples to achieve unbiased estimates of hierarchical taxa. These values were basically steady for Jackknife 1 (20–23 samples) and Jackknife 2.

Overall, Bootstrap is suggested as the best estimator of hierarchical arthropod taxa in irrigated rice fields. An alternative way is using any of the estimators with their unbiased sample sizes. As estimator performance is a function of the distribution of species in the system under study, and a full evaluation of all these estimators must be done using real data sets that reflect a diverse range of organisms and habitats (Colwell and Coddington 1994).

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Lumping and correlation analyses of arthropod taxa in tropical irrigated rice fields

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As a natural equilibrium mechanism for the occurrence of crop pests, biodiversity is one of the most important regulation forces for safe, nonpolluted, and sustainable production of crops. Recent studies showed that the biodiversity of functional groups or higher taxonomical groups could dominate the development and sustainable production of agroecosystems (Schoenly and Zhang 1999) and forest ecosystems (Tilman et al 1997). In this study, the sampling sets of rice arthropod species that were investigated on the IRRI farm at four time intervals (i.e., 18 Mar, 15 Apr, 8 Oct, and 17 Sep 1996, each with n = 60 samples, represented as mar18, apr15, oct08, and sep17, respectively) were lumped using biodiversity software LUMP and linear correlations between arthropod taxa were analyzed. Utility software LUMP is a data management tool that aggregates abundance by sample data according to predefined taxa in a database (Schoenly and Zhang 1999; www.irri.org/Biodiversity Software/index.html). Abundance of families, orders, functional groups, and habitat zones by samples can be obtained by using LUMP. The objective of this study is to determine the dominant arthropod taxa and correlations with statistical significance between these taxa and, thereafter, to understand the profile of arthropod biodiversity as a natural equilibrium mechanism in tropical irrigated rice fields.

Lumping analyses indicated 21 functional groups in the sampling set mar18. For the apr15, oct08, and sep17 sets, 20, 22, and 21 functional groups were recorded, respectively. In mar18, the dominant functional groups were neustonic (water surface) swimmer (semiaquatic) (29.2%); external plant feeder (18.5%); shredder, chewer of coarse particulate matter (17.9%); tourist (nonpredatory species with no known functional role other than as prey in ecosystem) (7.9%); etc. The dominant functional groups in apr15 were lumped as external plant feeder (38.2%); terrestrial crawler, walker, jumper, or hunter (20.5%); and neustonic (water surface) swimmer (semiaquatic) (18.7%); etc. In oct08, external plant feeder (26.3%); terrestrial crawler, walker, jumper, or hunter (17.6%); neustonic (water surface) swimmer (semiaquatic) (14.9%); and shredder, chewer of coarse particulate matter (13.7%), etc., were the dominant functional groups. The dominant functional groups of sep17 were lumped as external plant feeder (46.8%); neustonic (water surface) swimmer (semiaquatic) (13.9%); terrestrial crawler, walker, jumper, or hunter (10.2%); and shredder, chewer of coarse particulate matter (10.2%), etc. Overall, the dominant functional groups of arthropods were external plant feeder; terrestrial crawler, walker, jumper, or hunter; neustonic (water surface) swimmer (semiaquatic); and shredder, chewer of coarse particulate matter (see Scheonly and Zhang 1999 for the definition of functional groups).

In the mar18 sampling set, there were strong correlations between the tourist species and neustonic (water surface) swimmer (semiaquatic) ($r = 0.551$, $P = 0.0001$). For apr15, strong correlations existed between the following pairs of functional groups: external plant feeder and terrestrial crawler, walker, jumper, or hunter ($r = 0.739$); external plant feeder and neustonic (water surface) swimmer (semiaquatic) ($r = 0.541$, $P = 0.0001$); external plant feeder and collector (gatherer, deposit feeder)($r = 0.561$, $P = 0.0001$); external plant feeder and shredder, chewer of coarse particulate matter ($r = 0.589$, $P = 0.0001$); terrestrial crawler, walker, jumper, or hunter and collector (gatherer, deposit feeder)($r = 0.582$, $P = 0.0001$); terrestrial crawler, walker, jumper, or hunter and shredder, chewer of coarse particulate matter ($r = 0.626$, $P = 0.0001$); and terrestrial flyer and collector (gatherer, deposit feeder) ($r = 0.530$, $P = 0.0001$). In the oct08 sampling set, the number of terrestrial crawler, walker, jumper, or hunter showed significant correlations ($P = 0.0001$) with external plant feeder ($r = 0.541$) and terrestrial blood sucker ($r = 0.539$); the neustonic (water surface) swimmer (semiaquatic) was significantly correlated to terrestrial crawler, walker, jumper, or hunter ($r = 0.575$) and shredder, chewer of coarse particulate matter ($r = 0.619$). A strong correlation between planktonic (water column) swimmer and diver and predator and parasitoid was found in sep17 ($r = 0.817$, $P = 0.0001$).

The lumping analyses revealed that there are four, four, six, and five habitat zones colonized by arthropods in sampling sets mar18, apr15, oct08, and sep17, respectively. A large amount of arthropod individuals colonized on plant canopy (41.32%, 73.14%, 62.55%, and 71.42% for mar18, apr15, oct08, and sep17, respectively) and water surface (45.74%, 19.19%, 27.13%, and 23.79% for the sampling sets mentioned). In other habitat zones, such as water column, bottom dwelling, dryland, wetland, host tissue, and combination of two or more of the above (other than wetland and host tissue), the harbored number of arthropod individuals was only 12.94%, 7.67%, 19.32%, and 4.79%, respectively, for the above sampling sets. Strong positive correlations were noted between plant canopy and water surface for sampling sets mar18 and apr15 ($P = 0.0001$).

A total of 17, 16, 18, and 18 arthropod orders were found in the sampling set mar18, apr15, oct08, and sep17, respectively. The dominant arthropod orders in mar18 were Hemiptera (49.5%), Symphypleona (15.7%), Diptera (12.4%), and Cyproida (6.2%). In sampling set apr15, the dominant arthropod orders were lumped as Hemiptera (63.9%), Araneae (8.1%), and Coleoptera (7.7%). For oct 08, Hemiptera (41.9%), Diptera (12.0%), Mesogastropoda (9.2%), Coleoptera (8.7%), and Symphypleona (7.8%) were the dominant arthropod orders. Dominant orders of sep17 were lumped as Hemiptera (59.6%), Diptera (10.0%), Symphypleona (9.3%), and Coleoptera (9.3%). Overall, Hemiptera, Diptera, and Coleoptera were the dominant arthropod orders in the biodiversity consortium.

For the mar18 set, there were strong correlations between Diptera and Hemiptera ($r = 0.542$, $P = 0.0001$), and between Hymenoptera and Acari ($r = 0.555$, $P = 0.0001$). In sampling set apr15, Coleoptera showed strong correlations ($P = 0.0001$) with

Diptera (r = 0.656), Hemiptera (r = 0.727), and Araneae (r = 0.652); Hemiptera was strongly correlated with Acari (r = 0.558), Diptera (r = 0.571), and Araneae (r = 0.574); Acari was significantly correlated with Coleoptera (r = 0.539) and Araneae (r = 0.548). Strong correlations were also found between Lepidoptera and Arthropleona (r = 0.568). For oct06, there were strong linear correlations (P = 0.0001) between Isoptera and Thysanoptera (r = 0.720), and between Strepsiptera and Dermaptera (r = 0.695). In addition, strong correlations (P = 0.0001) were found between Ephemeroptera and Cyproida (r = 0.598), and between Neuroptera and Mesogastropoda (r = 0.984).

Most of the functional groups were found in different seasons. Of the 20–22 functional groups found, the external plant feeder; neustonic (water surface) swimmer (semiaquatic); terrestrial crawler, walker, jumper, or hunter; and shredder, chewer of coarse particulate matter were the dominant functional groups in every season. Strong positive correlations (P = 0.0001) frequently occurred between external plant feeder and terrestrial crawler, walker, jumper, or hunter; and between neustonic (water surface) swimmer (semiaquatic) and some other functional groups. It was important to find that, in this arthropod biodiversity consortium, the predators such as neustonic (water surface) swimmer (semiaquatic) and terrestrial crawler, walker, jumper, or hunter constituted the dominant natural enemies, and that parasitoids/parasites have little influence on this system of biodiversity. The reason for this pest-natural enemy profile is not yet clear.

In the wet season, there were strong positive correlations in the occurrences of rice arthropods on plant canopy and water surface because the arthropods on the plant canopy always drop to the water surface, thereby providing food for the arthropods on the water surface.

The dominant arthropod orders in the different seasons were Hemiptera, Diptera, and Coleoptera. They harbor some dominant insect pests and natural enemies. The strong correlations between Coleoptera, Diptera, and Hemiptera reflected the natural functionality of biodiversity played in pest-natural enemy interactions. Lepidoptera, an important insect order, did not play a significant role in this biodiversity consortium.

Almost all of the strong correlations were found to be positive correlations; the negative correlations between arthropod taxa were found to be not statistically significant. This indicates that no perfect equilibrium mechanism exists in arthropod biodiversity and that arthropod biodiversity may be supplemented with external forces in order to maximize the benefits of IPM. Further investigations should validate this conclusion.

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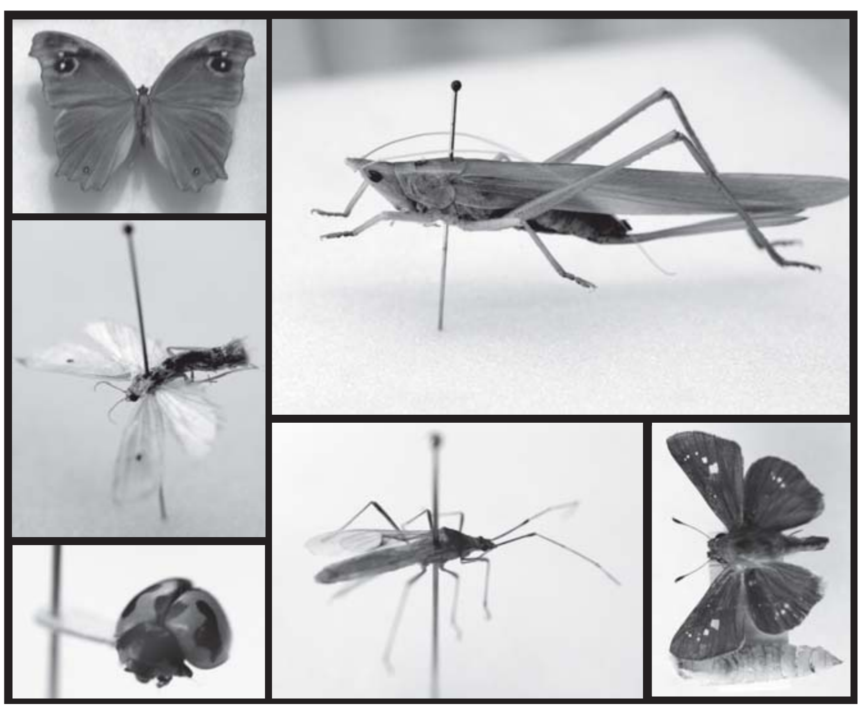

Rodents and other small mammals in Banaue and Hungduan Rice Terraces, Philippines

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The rice terraces of Banaue and Hungduan, Ifugao Province, Philippines, are a unique agricultural system in the Southeast Asian context. The terraces typically scale the lower and middle slopes of an extremely rugged landscape in which valley floors lie at 900 m and local peaks rise abruptly to heights of 1050 m. The landscape presents a complex mosaic of habitats including significant areas of primary and secondary montane forest (see figure).

Farmers in both areas rank rodents as first of the three most important preharvest pests of rice (Catudan et al 2003, Joshi et al 2000). Rodents also damage a range of other crops in cultivated and noncultivated habitats and are regarded as significant pests in rice storage facilities and domestic households.

Our objectives were to determine (1) the habitat distribution of major rodent pest species and (2) whether these habitats are used by rodent species that might be a special conservation concern. The latter is important because Luzon Island supports 22 native rodent species, 18 of which are endemic (Heaney et al 1998). In addition, we were interested in establishing baseline data that will help assess changes in rodent status in this unique ecosystem.

Small mammals were surveyed in both Banaue and Hungduan municipalities from November 2002 to November 2003. To assess activity in the rice terrace habitat, we used multi-capture live traps (47 cm × 26 cm × 26 cm) combined with plastic barrier fences erected around early planted rice crops (transplanted 2 wk ahead of the main crop) that served as attractants for rodents. Each rectangular unit measured 10 m × 5 m. The barriers were strategically installed adjacent to the forest, farm houses, and river banks. In addition, using fly glue traps, snap traps, and opportunistic digging and hunting, animals were collected from various nonrice habitats such as terrace walls and orchards. Specimens for taxonomic identification were preserved in 10% formalin and samples for DNA analysis were fixed in 90% ethanol.

Six species were captured. The house rat, *Rattus rattus*, was captured in both municipalities and in all habitats, including the forest. The majority were captured in traps set in the terraces and in the community-trap barrier system (C-TBS) set up around the rice crop. The local variety of this widespread pest species is sometimes called *R. rattus mindanensis* (or *R. tanezumi* [Heaney et al 1998]). It was introduced in the Philippines from mainland Southeast Asia during prehistoric times. It is the principal rodent pest in most, if not all, of the major rice-growing areas of the Philippines.

The Pacific rat, *Rattus exulans*, was captured infrequently and only in the rice terraces. Also introduced in the Philippines, probably during prehistoric times, this species is found in "agricultural areas throughout the country at all elevations" and is "often present in disturbed forest, but usually rare in primary forest" (Heaney et al 1998). In areas of primary forests with few native rodents, it can also be common. In many parts of Southeast Asia, *R. exulans* is a significant house pest; in Banaue and Hungduan, the house mouse occupies this niche.

Mus musculus, the house mouse, was captured in large numbers at Banaue and Hungduan but only in and around houses. This species was probably introduced in the Philippines during the early historic period. Philippine populations of *M. musculus* are usually referred to as the subspecies *castaneus*, but this requires confirmation with DNA analysis. House mice are responsible for major losses in stored food throughout Asia, especially in stored cereals such as wheat and rice.

Rattus everetti, the common Philippine forest rat, is larger than *R. rattus* and it has a distinctive white tip on the tail. Heaney et al (1998) described this species as "common in primary forest, uncommon in secondary forest, and usually absent in agricultural areas." We trapped four individuals in September 2003 in a forest habitat at Baang, Hungduan, and one individual at Poblacion, Banaue. Nothing is known about the ecology of this species but, from the structure of its skull and teeth, it is probably a generalist herbivore—one that feeds on leaves, fruits, and seeds of a wide range of plants and maybe invertebrates.

The Luzon striped shrew rat, *Chrotomys mindorensis*, was trapped in the rice terraces at Banaue. Three species of this distinctive genus were found in Luzon and all are regarded as endangered or vulnerable (Rickart and Heaney 1991). Heaney et al (1998) noted that *C. mindorensis* occurs in "primary and secondary forest and occasionally in adjacent agricultural areas." Our capture of *C. mindorensis* in the rice terraces suggests that either this species is very common in the adjacent forest or it makes regular trips to the terraces. We consider the latter hypothesis to be more plausible, and further suggest that this species may enter the fields in search of invertebrate prey such as crustaceans and snails. We held two adult *C. mindorensis* in captivity for a period of 2 mo and they consumed golden apple snails (*Pomacea canaliculata* [Lamarck]). This species almost certainly has a beneficial impact on the agricultural system by helping control invertebrate pests.

Banaue and Hungduan municipalities are in Ifugao Province, which is in Luzon Island of the Philippines.

Through its digging activities in the forest, it likely plays an important role in the bioturbation of the forest soils.

We captured small numbers of the Indian house shrew, *Suncus murinus*, another historic or late prehistoric introduction in the Philippines. Heaney et al (1998) reported this species from "urban and agricultural areas, often in disturbed forest, occasionally in primary forest." We caught house shrews in both localities, in areas very close to the houses. It probably eats a combination of food scraps and invertebrates. It was much less abundant than the house mouse.

An important finding is the absence of the ricefield rat, *Rattus argentiventer*, in the region. This species is recorded in Laguna and Mindoro provinces of Luzon and in Cebu, Mindanao, and Negros islands. When present in an area, it is usually abundant. We are confident that this species has not yet infested the rice terrace systems of Ifugao. *R. argentiventer* is the major rodent pest in rice-growing systems of mainland Southeast Asia and the Indonesian archipelago.

In summary, the unique environment of Banaue and Hungduan supports a mixed small mammal community of introduced pest and native nonpest species. The two nonpest native rodents probably rely on the forest habitat for maintenance of local populations. However, both species probably visit the rice terraces on an occasional to regular basis. *R. everetti*, as a probable dietary generalist, might cause some damage to rice and other field crops. *C. mindorensis*, on the other hand, is primarily carnivorous and may well help control agricultural pests such as

P. canaliculata. That these native species make occasional to regular visits to the rice terraces highlights the importance of developing an integrated rodent management program that can effectively manage the rodent pest species and, at the same time, conserve the nondestructive (or even beneficial) native rodents and other small mammals.

More intensive trapping in the forest habitats at Banaue and Hungduan is required to document the full diversity of native rodents and other small mammals in the region. Previous collection records in surrounding areas of Luzon point to at least 10 other rodent species, including some listed by the International Union for the Conservation of Nature and Natural Resources as vulnerable (e.g., *Crateromys schadenbergi*). Documenting the diversity of local rodents and other mammals in the Ifugao rice terraces remains an important objective of our study.

Another important observation is that introduced rodent species are not yet pervasive in forest habitats. Indeed, of the four introduced small mammals collected in the region, only *R. rattus* was trapped within the forest habitat. In other parts of the country, two other introduced species, *R. exulans* and *S. murinus*, were common in disturbed primary or secondary forests. This difference is probably due to the persistence in the Banaue and Hungduan forest remnants of a relatively diverse and abundant native mammal fauna, the native species effectively "holding back" the competitively inferior invaders. This is a good indication that the rice terrace environment, despite its long history of human intervention, remains healthy. Any future developments can be compared with this important benchmark. In the future, we will look at the life history patterns of key pest and nonpest rodent species to understand more fully their population dynamics and interactions with other species.

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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 bio-available 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).

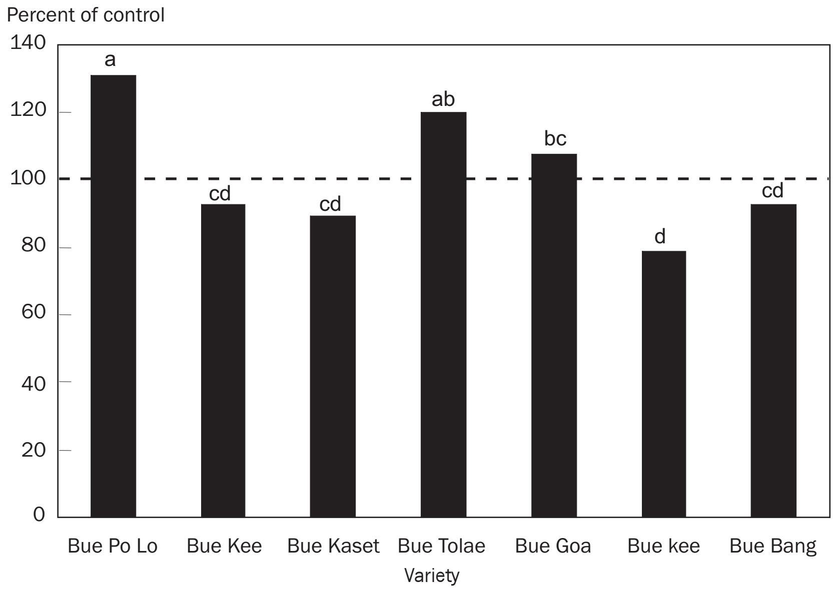
Grain Fe concentration of hand-pounded rice from Tee Cha was found to be highly variable (see table). The hand-pounded varieties with grain Fe concentration >10 mg g^{-1} were Bue Po Lo, Bue Kee (B), Bue Tolae, and Bue Kee (F). Bue Po Lo, Bue Kee (B), and Bue Kee (F) had a higher grain Fe concentration 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.

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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 $\pm$ 1 cm) in the first week of July each year at 20 $\times$ 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.

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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).

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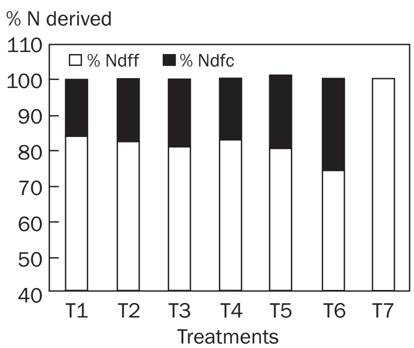

Nitrogen contribution by immobilized cyanobacteria to rice seedlings (cultivar ADT36) grown under hydroponic conditions.

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.

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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

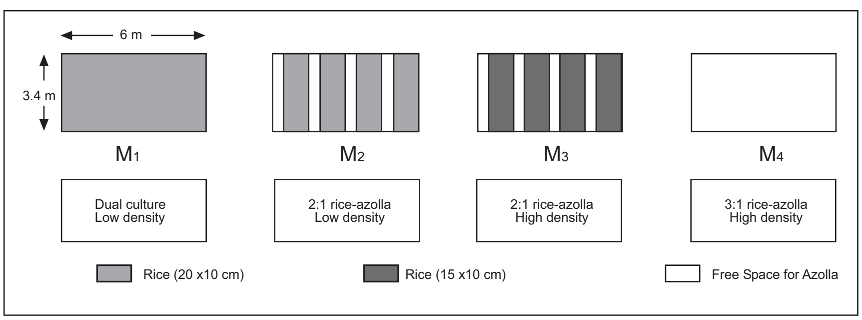
[a]Significance at 5% (*) and 1% (**) levels; ns – not significant.

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.



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	

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, nonreplicated 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.

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.

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.

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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.

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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 $\pm$ 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).

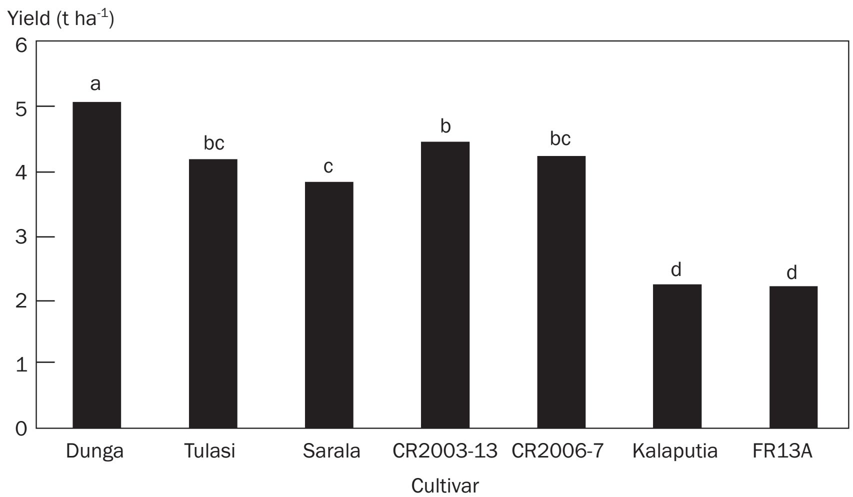
To compare the yields of the selected submergence-tolerant cultivars under normal conditions, another experiment was conducted under favorable rainfed lowland conditions with seven photoperiod-sensitive rice cultivars, plus three checks. Check cultivar Durga outyielded the other cultivars (see figure). 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

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.

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.

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.

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.

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

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Chlorophyll fluorescence parameters as indicators of submergence tolerance in rice

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Complete submergence of lowland rice occurs during flash floods in wide areas of Southeast Asia, resulting in partial to near-complete crop damage and, hence, poor grain yield. Submerged plants have to adjust to conditions of low oxygen tension and poor light intensity to survive. Mortality has been partially attributed to the damage caused to the photosynthetic apparatus by the poor light intensity and low oxygen (Sarkar et al 2001). Photosystem II (PS II) is well known for its sensitivity to abiotic stresses and hence is a good choice to study response and adaptation to stress by plants (Strasser and Tsimilli-Michael 2001). Recently, the use of different fluorescence parameters to monitor responses to abiotic stresses has been reviewed (Sayed 2003). The present study describes an indirect method to distinguish between tolerant and susceptible rice cultivars based on their chlorophyll (Chl) fluorescence transients.

Three rice (*Oryza sativa* L.) cultivars differing in their responses to submergence—FR13A (tolerant), IR42 (susceptible), and Sabita (submergence-avoiding type)—were submerged in floodwater as described earlier (Sarkar et al 2001). The experiment was conducted twice with three replications at CRRI. The Chl 'a' fluorescence transients of nine individual leaves were measured in each treatment. The data represented an average of 18 measurements of each parameter.

Chlorophyll fluorescence was measured using a plant efficiency analyzer (Handy PEA, Hansatech Instruments Ltd., Norfolk, UK). The chlorophyll fluorescence transients were induced by a red light of 3,000 µE m^{-2} s^{-1} and recorded from 10 µs up to 1 s. All measurements were done on fully dark-adapted attached leaves. From the first O-J-I-P transients, several bioenergetic parameters were derived according to the equations of the J-I-P test using BIOLYSER program (R.M. Rodriguez, Bioenergetic Laboratory, University of Geneva; available at www.unige.ch/sciences/biologie/bioen). Chlorophyll 'a' fluorescence at 20 µs, 2 ms, and 30 ms, and the time required to achieve maximum fluorescence are termed as the O, J, I, and P step, respectively. The J-I-P test refers to the analysis of structural integrity of chloroplasts and function based on fluorescence emission data (Strasser and Strasser 1995).

The floodwater characteristics revealed little variation in pH, whereas temperature varied from 25.2 to 31.4 ºC during the study period. Light intensity at 60-cm water depth varied from 39.2% to 44.9% of the control, though there was a clear diurnal variation in oxygen concentrations from 2.32 to 3.45 mg L^{-1} at 0630 h to 5.15 to 7.48 mg L^{-1} at 1730 h.

Chlorophyll concentration decreased under submergence (Fig. 1), the magnitude of the reduction being more prominent and sharper in submergence-avoiding-type cultivar Sabita, particularly after 6 d, compared with the other two cultivars. Susceptible cultivar IR42 maintained higher chlorophyll content than tolerant cultivar FR13A up to 8 d after submergence. Significant differences were noticed between susceptible and tolerant cultivars only after 10 d of submergence.

Fv/Fm, a parameter commonly known as maximum quantum yield of primary photochemistry or maximal relative electron transport rate (ETR) of PS II (Waldhoff et al 2002), decreased under submergence, more notably in IR42 and Sabita, but with no significant change in FR13A (Fig. 2A). The other parameters such as area (designates the pool size of the electron acceptors Q_A on the reducing side of PS II), PI(abs) (related to productivity of photosynthetic metabolites), and driving force (associated with photosynthetic capacity of the observed system) started declining after 4 d of submergence, especially in susceptible cultivars (Fig. 2B, C, and D). The PI(abs) increased for the first 2 d in the susceptible and submergence-avoiding cultivars, followed by a sharp decline, whereas tolerant FR13A showed a decline in PI after the first 4 d and at a

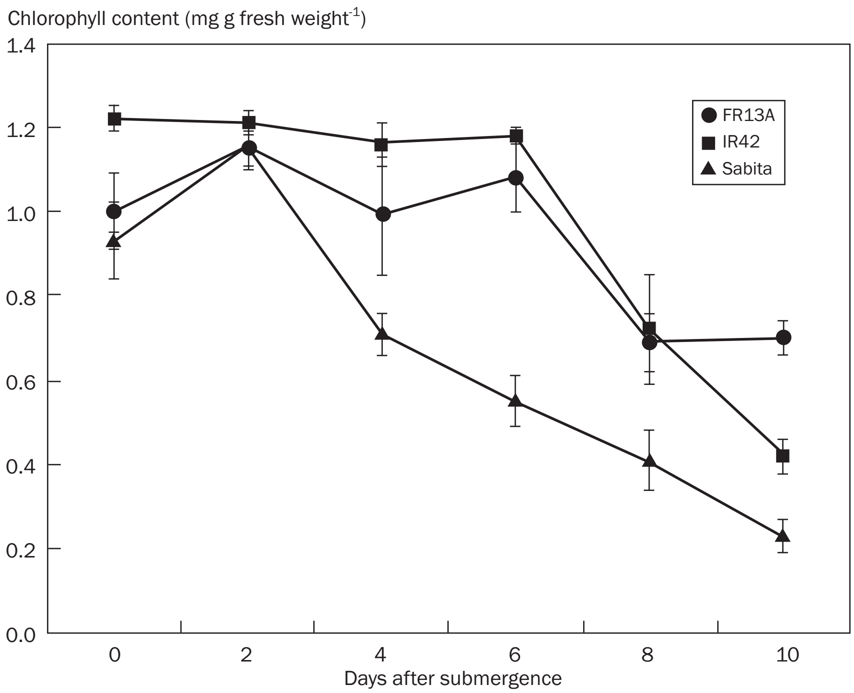

Fig. 1. Changes in chlorophyll content during submergence. Vertical bar represents mean ± standard deviation.

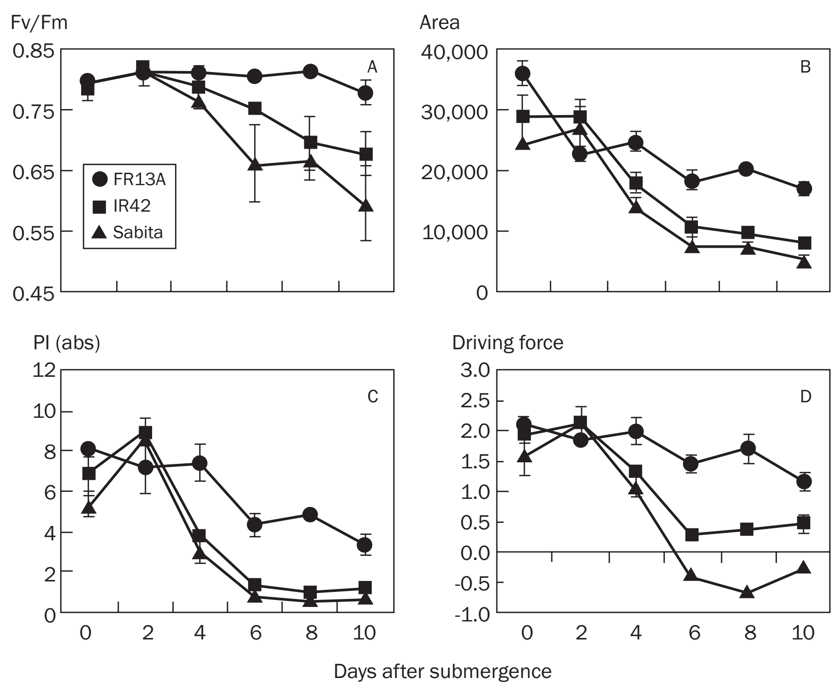

Fig. 2. Changes in some chlorophyll fluorescence parameters under submergence. Fv/Fm, where Fv = variable fluorescence [minimum fluorescence at 20 µs (Fo) minus the maximum fluorescence (Fm)]; area (the region above the fluorescence curve between Fo and Fm); PI(abs) = performance index (absorption). Unit of each parameter is arbitrary. Vertical bar represents mean ± standard deviation.

substantially lower rate than that observed in the susceptible lines.

There was no mortality even in the susceptible cultivar after 6 d of submergence (data not shown). After 10 d of submergence, survival was 100% in FR13A, whereas it was below 15% in IR42 and Sabita. A comparison between chlorophyll content and chlorophyll fluorescence parameters suggests that chlorophyll fluorescence is more sensitive to submergence. By measuring chlorophyll fluorescence, different parameters could be obtained, which could clearly differentiate between susceptible and tolerant cultivars as early as 4–6 d of submergence, when even the susceptible cultivar showed no mortality. The technique was suitable for attached leaves as well as the dark-adapted detached leaves, which gave similar results. We applied the technique for the first time to study the response of different rice cultivars to submergence. The chlorophyll fluorescence-based screening technique is superior to traditional screening protocols in which mortality is the sole criterion to differentiate between tolerant and susceptible lines. A screening program is under way to apply the method to a large number of rice germplasm accessions available at CRRI, which have been previously screened using the traditional method.

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Pattern of energy use in high-yielding sali rice varieties in Assam, northeast India

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Sali rice, also known as winter rice, is one of the more important types of rice grown in Assam in northeast India. Cultivation begins in June-July and the crop is harvested in November-December. The high-yielding varieties (HYVs) of sali rice cover 55% of the total sali rice area in the state. This study was conducted to find out, operationwise and sourcewise, energy use in sali rice cultivation and assess the cost and return related to energy use of HYVs. The results will be useful in determining the crop's energy requirements.

A three-stage random sampling design used blocks in the first stage of sampling, the village in the second, and farm holdings last. One block was selected in Golaghat District, Assam. From this block, five villages comprising 5% of the villages were selected randomly. Again, from these villages, 15% of the farm households (120 members) were surveyed randomly. The selected farm households were stratified on the basis of heritage: marginal (39) (up to 1.0 ha), small (33) (1.01–2.0 ha), medium (14) (2.01–3.0 ha), and large (16) (more than 3.0 ha).

In this study, total operational energy use is the summation of the quantum of energy contributed by human labor, draft animals, and mechanical power (tractor and power tiller) in performing various field operations. The total operational energy used in cultivation of sali HYVs was 7,651 MJ ha^{-1}, which varied from 6,014 MJ ha^{-1} on marginal farms to 7,565 MJ ha^{-1} on large farms (Table 1). The total operational energy used in the crop was found to increase with an increase in size of farm holdings. Considering all size groupings, the most energy-consuming farm operations were preparatory tillage, threshing and cleaning, harvesting, and transplanting. The average values were 66.7%, 15.2%, 6.5%, and 5.2% of total operational energy, respectively.

The total energy input used in the crop was 10,398 MJ ha^{-1} (Table 2). Energy input was highest on large farms (11,377 MJ ha^{-1}) and lowest on marginal farms (9,456 MJ ha^{-1}). The most important sources of energy were draft animals (4,019 MJ ha^{-1}), farmyard manure and chemical fertilizers (2,898 MJ ha^{-1}), and human labor (1,704 MJ ha^{-1}), contributing 38.7%, 27.9%, and 16.4% of the energy used in the crop, respectively. The large variation in energy sourced from seeds across farms was attributed to larger quantities of seed used to compensate for losses caused by birds, floods, etc. The energy output-input ratio and benefit-cost ratio in sali rice cultivation was 13.52 and 1.82, respectively. (In calculating energy output, both the main product and straw produced were considered.) Net return averaged US$170.11 ha^{-1}; it was highest on small farms ($280.24 ha^{-1}) and lowest on medium-sized farms ($140.21 ha^{-1}). Thus, on the basis of energy use and generation, sali HYV cultivation was found to be profitable.

A huge gap between the quantum of energy input used

Table 1. Energy use (MJ ha⁻¹)[a] in HYV *sali* rice cultivation, by operational and size of farms.

Operation	Marginal	Small	Medium	Large	All farms
Seedbed preparation	300.1 (5.0)	300.2 (4.8)	300.5 (4.8)	300.2 (4.0)	300.2 (4.5)
Preparatory tillage	3,778.0 (62.8)	4,071.3 (64.5)	4,014.6 (64.1)	5,325.7 (70.4)	4,500.0 (66.7)
Sowing	14.7 (0.2)	14.7 (0.2)	14.7 (0.2)	14.7 (0.2)	14.7 (0.2)
Fertilization and manure application	19.6 (1.5)	18.2 (1.5)	19.1 (0.3)	23.1 (0.3)	20.5 (0.3)
Uprooting	91.9 (1.5)	91.9 (1.5)	91.9 (1.5)	95.1 (1.3)	93.2 (1.4)
Transplanting	352.7 (5.9)	352.7 (5.6)	352.8 (5.6)	352.8 (4.7)	352.8 (5.2)
Plant protection	–	8.2 (0.1)	10.0 (0.2)	7.9 (0.1)	6.6 (0.1)
Harvesting	426.2 (7.1)	424.2 (6.7)	427.3 (6.8)	429.1 (5.7)	438.0 (6.5)
Threshing and cleaning	1,030.8 (17.2)	1,029.7 (16.3)	1,031.9 (16.5)	1,016.4 (13.4)	1,024.9 (15.2)
All operations	6,014.0 (100.0)	6,310.9 (100.0)	6,262.8 (100.00)	7564.8 (100.0)	7,650.9 (100.0)

[a]Numbers in parentheses indicate percentage of total operational energy.

Table 2. Energy use (MJ ha⁻¹)[a] in HYV *sali* rice cultivation by source and size of farm.

Item	Marginal	Small	Medium	Large	All
Source					
Seed	880.2 (9.3)	357.4 (3.6)	636.2 (6.6)	767.8 (6.8)	665.5 (6.4)
Farmyard manure	1,044.4 (11.0)	1,058.5 (10.6)	827.3 (8.6)	566.2 (5.0)	831.3 (8.0)
Chemical fertilizer	1,503.5 (15.9)	2,140.1 (21.4)	1,784.5 (18.4)	2,404.4 (21.1)	2,066.4 (19.9)
Plant protection chemical	13.9 (0.2)	117.4 (1.2)	156.8 (1.6)	74.0 (0.7)	82.9 (0.8)
Mechanical power (35-HP tractor and 5-HP diesel pump)	-	492.9 (4.9)	397.2 (4.1)	2,134.1 (18.8)	1028.0 (9.9)
Human	1,720.8 (18.2)	1,701.7 (17.0)	1,714.2 (17.7)	1,665.6 (14.6)	1,704.0 (16.4)
Draft animal	4,293.2 (45.4)	4,118.0 (41.2)	4,152.9 (43.0)	3,764.8 (33.1)	4,019.3 (38.7)
Total energy input use	9,455.9 (100.0)	9,986.1 (100.0)	9,669.0 (100.0)	11,376.6 (100.0)	10,398.0 (100.0)
Energy output (from main product)	52,920.0	66,150.0	55,125.0	63,945.0	61,121.2
Energy output (from byproduct)	67,500.0	90,000.0	70,312.5	81,562.5	79,472.8
Total output produced	120,420.0	156,150.0	125,437.5	145,507.5	140,594.0
Total cost of energy input use ($ ha⁻¹)	173.4	194.6	199.9	238.7	208.3
Gross return ($ ha⁻¹)	326.5	412.9	340.1	394.5	378.4
Net return ($ ha⁻¹)	153.1	218.2	140.2	155.8	170.1
Energy output -input ratio	12.7	11.3	12.9	12.8	13.5
Benefit-cost ratio	1.9	2.1	1.7	1.7	1.8
Recommended energy use	12,616.0	12,912.5	12,955.3	14,163.6	13,161.3
Recommended energy output	165,370.6	165,370.6	165,370.6	165,370.6	165,370.6
Gap in energy use	3,159.6	2,926.3	3,195.0	2,788.6	2,764.3
Gap in energy output	44,950.6	9,220.6	39,933.1	19,863.1	24,776.6

[a]Numbers in parentheses indicate percentage of total operational energy.

and the output realized in relation to the recommended energy input and output for the crop was found (Table 2). These recommended values were calculated following a package of cultural practices recommended by the Department of Agriculture, Government of Assam Agriculture University, Assam, India. The existing gap in energy input and output was 26.59% and 17.62% of that of the recommended energy input and output and was maximum on marginal farms and minimum on small farms. The differences are attributed to differences in the use of chemical fertilizer and farmyard manure energy inputs. This implies that small farms are economically more energy-efficient than the rest.

The study shows more scope for boosting the production of sali rice through a sound, balanced, and rational use of energy inputs in a sustainable and economical way.

Comparing two technologies for quantifying rice plant cover in breeding nurseries

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Selecting more competitive rice (*Oryza sativa*) cultivars may help reduce weed control inputs and increase rice yields (Jordan 1993). Screening many hundreds of breeding lines requires a quick, simple, and accurate method of assessing rice growth at early stages. We found that an important growth variable for predicting productivity under severe competition was early season leaf area index (LAI; m^2 leaf m^{-2} ground) or plant cover (Caton et al 2003). LAI has been similarly identified in several other studies (Gibson et al 2003, Johnson et al 1998). Directly measuring LAI is laborious, however, usually requiring destructive harvests. Indirect methods of estimating LAI, such as measuring light interception with ceptometers (Gibson et al 2001), are difficult to use and may not be sensitive enough. In contrast, plant cover is useful for predicting competitive outcomes (Lotz et al 1994, Ngouajio et al 1999) and may be simpler to estimate than LAI.

Our objective was to compare the new First Growth™ digital canopy camera (Decagon Devices, Inc., 950 NE Nelson Court, Pullman, WA 99163, USA) with a hand-held square grid method of quantifying plant cover in rice nurseries. The camera quantifies percent cover in the field by imaging plots and calculating the proportion of green to total pixels. The hand-held square sampling grid was based on the Daubenmire (1959) square commonly used by vegetation ecologists. It was held above the plot to record the number of grids in which foliage was seen; entries with greater cover would extend into more grids. We compared the two methods in rice nursery plots on the basis of the cover values from each and the time taken for sampling.

The First Growth camera and the square were used to assess the canopy cover of 44 pedigree rice cultivars with three replications per entry, for a total of 132 plots. The nurseries were grown in weed-free conditions using standard management practices in a rainfed lowland environment in the 2002 wet season in Los Baños, Philippines. Each entry was planted in six rows spaced 25 cm apart and 3 m long at a seed rate of 100 kg ha^{-1}.

Plant cover was measured at 14, 21, and 28 d after sowing (DAS) using both the camera and square. All camera images were taken by the same operator at about a 45° angle and a distance of 1.5 m from the center of the plot. The square was a 0.25 by 0.25 m square with string dividers every 0.05 m on each side to create 25 grid units. It was used by the same person throughout the sampling period, held about 0.75 m above the ground, and centered over a rice row chosen at random. We measured the number of grids in which rice foliage was seen.

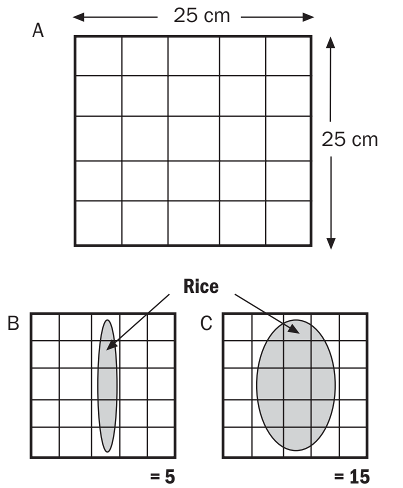
In addition to correlation analysis, we compared the distributions for the data from each method using @RISK (ver. 4.5.2; Palisade Corporation, 31 Decker Road, Newfield, NY 14867, USA). Empirical distributions (histogram functions) were set to the raw data from the square and the camera (n = 132) and 5,000 iterations were run for each function. We used a similar procedure to analyze the distributions of entry means (n = 44) for each method.

Initial correlations between camera and square measurements of 0.34 at 14 DAS and 0.39 at 21 DAS were significant (P < 0.05) but weak, probably because of the small plant sizes. The correlation at 28 DAS was highly significant, though, at 0.83 (P < 0.01).

The distributions of the two data sets were different (see figure). Mean percent cover from the camera was 0.18 (see table) and 90% of the values were between 0.05 and 0.32. The mean number of grids was 6.4, with 90% of the values between 3 and 10. Grid data were more centrally grouped, perhaps indicating that the camera had greater sensitivity. From 21 to 28 DAS, the range increased more (doubled) for the grid data than for the camera data (see table). The distributions of the entry means for both data sets were much more similar than the raw data (not shown). Both were skewed to the right.

Comparison of plant cover estimates by grid (number of grids) or camera (percent cover) in rice nursery plots, with means, 95% confidence intervals (CI), standard deviations (SD), and range of values (min-max).

DAS	Number of grids			Percent cover		
	14	21	28	14	21	28
Mean	4.67	4.92	6.39	0.012	0.092	0.180
CI	4.52–4.82	4.75–5.09	6.04–6.73	0.013–0.0138	0.082–0.102	0.165–0.195
SD	0.87	1.00	1.99	0.0104	0.060	0.085
Range	4.00	7.00	14.00	0.04	0.27	0.42



Distributions of plant cover estimates by (A) camera (percent cover) and (B, C) square grid method (no. of grids; max = 25).

Although the sensitivity of the camera seemed greatest, we think that large differences are probably most important for the planned type of screening. Differences with the square grid of 3 or more units probably best reflected true differences in plant cover between entries.

The camera required about 70 s plot^{-1} but the square grid needed only about 15 s plot^{-1}, a difference of nearly a minute per plot. In addition, under continuous use, the camera readings increased systematically probably because of overheating. To remedy that, the camera was turned off for 30 min or more at a time, further increasing the time taken. Measurements took 2 d with the camera but only about 3 h with the square grid.

The First Growth camera seems promising because it may be sensitive to small cover differences, it captures data digitally, and its use will be familiar to camera users. Nevertheless, the square grid was almost as precise and was much superior in speed and expense. It was also simpler to use, although the metric may be unfamiliar to most users. Most important, use of the square grid will likely facilitate the adoption of screening methods with locally adapted germplasm in national or regional breeding programs.

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Rice yield constraints and production technology: perception of farmers through PRA

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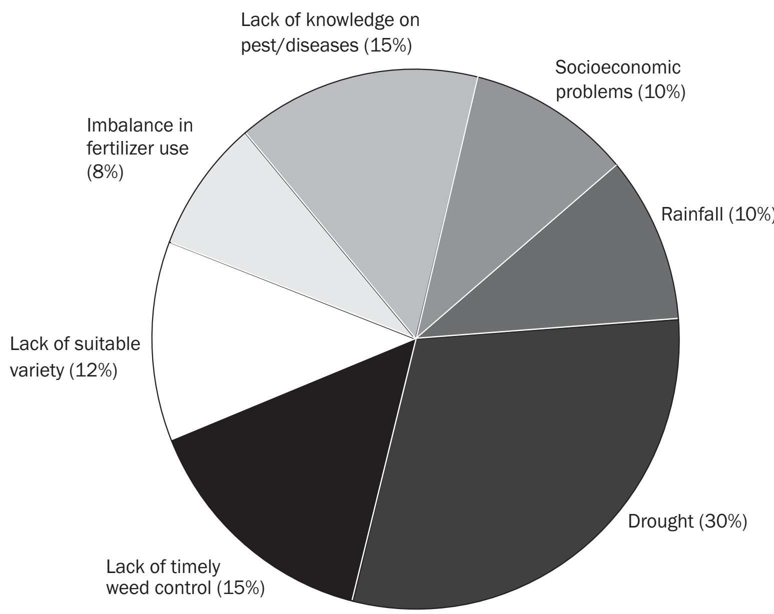
In Durg District of Chhattisgarh, rice is cultivated on about 0.4 million ha, mostly under rainfed conditions. Average productivity is 1.53 t ha^{-1}, slightly higher than that of the state (1.31 t ha^{-1}) but much lower than the national average (1.92 t ha^{-1}). The district receives an average annual rainfall of 1,286 mm, 70% of which occurs from mid-June to mid-September. Yield is limited by erratic distribution of rainfall, a small irrigated area with prolonged *biasi*/transplanting, little attention to timely insect/disease/weed management, imbalance in fertilizer use, and inadequate supply of good-quality seed (Singh 1993).

The experiment involved 200 farmers. The participatory rural appraisal technique was adopted. Eight villages were visited—Thanod, Birejhar, Malood, Pipperchedi, Kodia, Devri, Hasda, and Parastarai—from three blocks (Durg, Dhamdha, and Gunderdehi).

In each village, 25 farmer respondents were asked what production constraints they face. They were also asked to rank rice varieties prevalent in their localities on the basis of desirable characters. The effect of each character on yield was recorded. The reasons cited for low productivity and an average matrix ranking of all villages were included.

The farmers grew rice under rainfed conditions (*biasi* method) inasmuch as irrigation is available for only 17% of the area. The reasons given for the low productivity were drought (30%), lack of timely weed control (15%), lack of suitable varieties (12%), lack of knowledge on insect/disease/weed management (15%), imbalance in fertilizer use (8%), and socioeconomic problems such as animal grazing, poor literacy, etc. (10%) (see figure). Similar findings were reported by Ramasamy (1996) in southern India.

In spite of the availability of high-yielding varieties in the area, farmers still preferred traditional and long-duration rice varieties because of some characteristics



Factors that limit production in Durg.

Farmer-preferred characters and matrix ranking of rice varieties (av of eight villages).

Character	Variety[a]									
	Po	IR36	IR64	Mah	Sw	Mas	Ds	Bds	Ps	Cul
High grain yield	6	7	7	7	9	7	5	6	5	6
High straw yield	5	6	5	8	7	8	10	10	9	6
Pest/disease resistance	7	8	8	7	5	5	9	8	8	6
Good market price	7	8	7	6	7	9	8	8	9	9
Early maturity	8	8	8	6	5	6	6	6	6	6
Tolerance for water stress	3	6	7	3	3	2	7	6	6	6
Good taste	NR	7	6	NR	6	10	8	8	9	6
Good grain quality	7	7	8	6	8	9	NR	8	5	7
Overall grading	43	57	56	43	50	56	53	60	57	52

[a]Po = Poornima, Mah = Mahamaya. Sw = Swarna, Mas = Mashuri Ds = Desi safri, Bds = Bd safri, Ps = Papita safri, Cul = Culture, NR = not recorded. A scale of 2–10 was used: 2 = minimum and 10 = maximum.

that suit their specific needs (Singh et al 2001, Pramanik et al 2001). The 10 varieties commonly grown in Duang were Swarna, Mahsuri, Mahamaya, Papita safri, Culture, Bd safri, Desi safri, IR36, IR64, and Poornima.

Three of these were mid-duration cultivars (Mahamaya, IR36, IR64), six were long-duration cultivars (Swarna, Mahsuri, Desi safri, Bd safri, Papita safri, Culture), and one was a short-duration cultivar (Poornima). The table indicates farmers' ranking of varieties in terms of grain yield performance, straw yield performance, pest and disease resistance, market price, etc. It was apparent that farmers' preference was not based on yield. Hence, the highest grain yielder, Swarna, ranked sixth, whereas the poor yielders, native cultivars Desi safri, Papita safri, and Bd safri, were preferred because of their straw yield, resistance to pests and diseases, good market price, and tolerance for water stress. Early maturity was thought to be a preferred character, but Poornima was ranked lowest. Overall, cultivars were ranked in this descending order: Bd safri, Papita safri, IR36, Mahsuri, IR64, Desi safri, Culture, Swarna, Mahsuri, and Poornima.

In conclusion, more promising rice varieties that will meet farmers' requirements may be introduced in the area. The study showed that good yield potential is not the only main consideration when deciding what varieties to grow. Input-intensive cultivars that put small farmers at a disadvantage are not adopted.

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Economics of weed management in late-planted, minimum-tillage rice in Benue State, Nigeria

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Rice production in Benue State accounts for as much as 40% of the total grown in Nigeria (Avav and Uza 2002). The fertile *fadamas* or floodplains of the Benue River support much of that production. Most farms are small, ranging in area from about 0.5 to 2 ha, and most farmers use recently introduced high-yielding, early maturing rice varieties. However, when planted early, these varieties mature at the peak of the wet season and pose threshing and drying problems. Consequently, the early varieties are not planted earlier than the more traditional late-maturing varieties. This often means more serious problems for farmers from more mature weeds. In response, farmers cut and remove the weeds before cultivation, but this practice greatly increases the cost of rice production. Land preparation expenses could be reduced if rice were planted under minimum tillage. Akobundu (1987) recommended using a preplant broad-spectrum herbicide with quick breakdown effects before planting to clear the vegetation. This study aimed to compare the economics of chemical weed control in late-planted, early maturing lowland rice under minimum and conventional tillage systems.

The experiments were conducted between July 2000 and November 2001 at the Teaching and Research Farm of the University of Agriculture, Makurdi (70° 41′ N, 8° 37′ E, and 98 m above mean sea level), in the southern Guinea Savanna agro-ecological zone of Nigeria. The rice variety used in these experiments was Faro 44 (100–115-d maturity). The herbicides used were Sarosate (glyphosate, 360 g L^{-1}), Propan (propanil, 360 g L^{-1}) and 2,4-D amine (2,4-D, 720 g L^{-}

Table 1. Details of treatments used in weed management experiment, 2000 and 2001 cropping seasons.[a]

Treatment	Minimum tillage		Conventional tillage		
	Glyphosate	2,4-D	Hoe weeding	Propanil	2,4-D
	(kg ha^{-1})		(DAP)	(kg ha^{-1})	
T_1	1.44	1.44	–	–	–
T_2	1.80	1.44	–	–	–
T_3	2.16	1.44	–	–	–
T_4	2.52	1.44	–	–	–
T_5	–	–	1(21)	–	–
T_6	–	–	2 (21 & 42)	–	–
T_7	–	–	–	2.16	–
T_8	–	–	–	–	1.44
T_9	–	–	–	2.16	1.44
T_{10}	–	–	No weeding		

[a]Tillage done after slashing of weeds.

Table 2. Economics of weed management in late-planted rice production under minimum tillage system in Makurdi (mean of 2000 and 2001).

Treatment	Production cost[a] (US\$ ha^{-1})[b]	Grain yield[c] (kg ha^{-1})	Revenue[d] (US\$ ha^{-1})	Profit (US\$ ha^{-1})
T_1	362.46	2038c	812.05	435.11
T_2	384.93	2090c	832.97	448.07
T_3	392.90	2175bc	866.85	473.97
T_4	400.87	2250bc	896.74	495.89
T_5	635.36	2458ab	979.44	344.43
T_6	828.62	2625a	1046.20	217.57
T_7	490.00	1725d	687.50	197.52
T_8	453.77	2100c	836.96	383.21
T_9	501.59	2450ab	976.45	474.88
T_{10}	442.17	1156e	460.72	18.57

[a]Production cost = cost of labor + seed + herbicide + fertilizer. [b]1US$ = ₦138.00, where ₦ is Naira, Nigeria's local currency. [c]Means within a column followed by the same letter(s) do not differ significantly according to Duncan's new multiple range test at P>0.05.'[d]Revenue was based on the 2001 market price of rice at US$0.40 kg^{-1}.

[1]). The land was slashed with the cutlass in mid-July each year before application of treatments (Table 1). The treatments were replicated four times in a randomized complete block design with 6×4-m plots. Glyphosate was applied with a knapsack sprayer in 200 L water ha^{-1}, 14 d after slashing. Conventional tillage was done with the hoe and rice was dry-seeded at 50 kg ha^{-1} by dibbling.

Grain yield (14% moisture content) was measured at harvest. Prevailing labor and market costs of materials were used to obtain the revenue from the grain yield of each treatment. Profit was calculated by subtracting the cost of production (seeds, herbicides, fertilizer, and labor) from the revenue.

The greatest mean grain yield (2,625 kg ha^{-1}, T_6) was obtained from conventional tillage (Table 2). However, the highest net profit of US$495.85 was from minimum tillage (T_4). The high cost of hoe weeding in conventional tillage probably contributed to the lower profit. The grain yield obtained from the additional weeding (T_6) could not pay for the extra weeding cost. Auld et al (1987) maintained that the economics of treating a weed depends not only on the gain in yield of the crop but also on the monetary value of the extra yield and the cost of the weed treatment. Thus, minimum tillage with glyphosate followed by 2,4-D is recommended for weed control in late-planted lowland at Makurdi.

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Rice-duck farming reduces weeding and insecticide requirement and increases grain yield and income of farmers

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Rice is the principal food crop of Bangladesh. About 25 million t of rice are produced on 10 million ha of land (BBS 2001). The present rice production system depends heavily on the use of fertilizers, pesticides, and other inputs. The increased use of agrochemicals and chemical fertilizers has raised concern about environmental pollution. To mitigate this problem, rice-duck farming may be an acceptable solution. Integrated rice-duck farming is known to have numerous benefits for rice farmers.

Experiments began in Sylhet and Barisal in the northeastern and southern part of Bangladesh. The Sylhet region is under the Shurma-Kushira floodplain and Barisal is under the Lower Gangetic floodplain, with rainfall amounting to 4,000–5,000 mm and 2,500–3,000 mm per annum, respectively. The experiments were conducted in farmers' fields during the 2003 T. aus season (late dry season, March-June). Twelve farmers from three villages of Sadar Upazilla, Sylhet, and 10 farmers from three villages of Bakerganj Upazilla, Barisal, were selected. In each farmer's field, 2,800 m^2 of land was used for the trials. The land was divided into two equal plots: one for rice-duck and the other for the farmer's own practice. Moreover, an area of 5 m × 2 m was laid out in a farmer's plot where no insect and weed control measures were followed. In the rice-duck plot, cow dung was applied at 5 t ha^{-1} during land preparation. In the farmer's plot, chemical fertilizers were applied as commonly practiced. A strong levee was made to separate the two plots. In Sylhet, popular variety BR14 was used; in Barisal, Mala (BR2) was grown. In the rice-duck plot, 25-d-old seedlings were transplanted at 25 × 20-cm spacing. Farmers planted their fields on the same day as the rice-duck plot, following their own method with the same variety. Ten days after transplanting, 20-d-old ducklings were released in the rice-duck plot. For the first 3–5 d, ducks were kept in the field for 2–4 h. Later, they were kept in the field from morning to evening. A synthetic thread net was used to surround the rice-duck plot to enclose the ducks in the plot and keep them safe from wild animals. In the farmer's plot, N fertilizer was applied as topdressing, insecticide was sprayed once, and the field was weeded twice. In the rice-duck plot, no weeding, no insecticide, and no chemical fertilizers were used. After removing the ducks from the plot, they were then reared in the pond and natural marshy land. After 4 months, the ducks were either sold or kept for eggs and meat. Each farmer's plot was treated as a replication and data were statistically analyzed using the M-stat program. Data were taken on plant height (at maximum tillering), tiller number $hill^{-1}$ (at PI), weed population (count at 60 DAT), yield-contributing characters, and grain yield. Insect data were collected between 30 and 50 DAT of the crop. Economic analysis was done with the partial budgeting method.

Results showed that the weed population was observed to be significantly lower in the rice-duck plot than in the farmer's plot and control plot in both Sylhet and Barisal (Fig. 1). Control plots had the highest weed population in both locations. Because ducks preferred to eat the tender weeds, their population decreased considerably in the integrated rice-duck plot.

Insect infestation results in Barisal (Table 1) showed that green leafhoppers, brown planthoppers, zigzag leafhoppers, rice bugs, short-horned grasshoppers, long-horned grasshoppers, and rice hispa populations were significantly lower in the rice-duck plot than in the farmer's managed plot. No significant difference in the number of whitebacked planthoppers and stem borers was observed between the rice-duck plot and the farmer's without-duck plots. Ducklings were found catching insects efficiently in the rice-duck plots, thereby reducing the insect population. Similar results were also reported by Choi-Song Yeol et al (1996), Hossain et al (2000), and Furuno (2001). Beneficial insects—carabid beetle, lady bird beetle, damsel fly, spider, and dragon fly—were found in the rice-duck and farmer's practice plots but no significant difference was found between the test plots. Similar results were observed in Sylhet (Table 1). The predominant beneficial insects observed in Sylhet were similar to those seen in Barisal (Table 1).

Higher plant height and higher tiller number were observed in the rice-duck plot

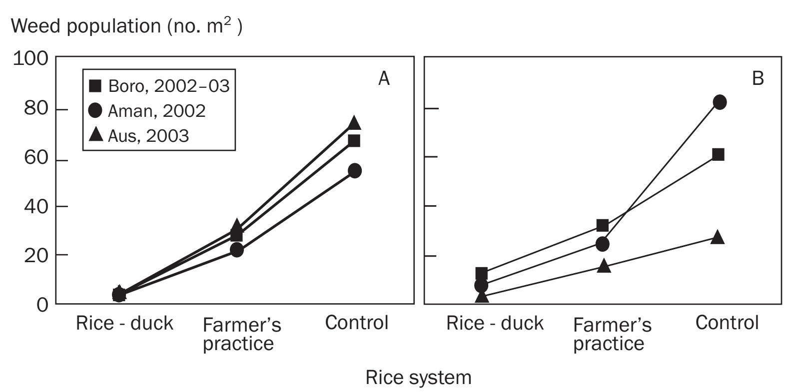

Fig. 1. Effectiveness of ducks in controlling weeds during different rice cultivation seasons, Barisal (A) and Sylhet (B).

compared with the farmer's practice in Barisal (Table 2). The number of panicles hill^{-1} and filled grains panicle^{-1} was significantly higher in the rice-duck plot than in the farmer-managed plot. Significantly higher grain yield (4.0 t ha^{-1}) was produced in the rice-duck plot than in the farmer's plot. Kang-Yang Soon et al (1995) reported that grain yield was 3% higher in plots with ducks than in the sole-rice cultivation system. In Sylhet, similar results were observed (Table 2). Plant height and tiller number were higher in the rice-duck plot. A higher number of panicles and grains panicle^{-1} was also observed in the rice-duck plot. Significantly higher grain yield was produced in the rice-duck plot (4.74 t ha^{-1}) than in the farmer's plot without ducks (3.95 t ha^{-1}).

An economic analysis of the rice-duck practice and farmers' practice showed that 60–70% higher net returns per hectare could be achieved (Taka 10,000–15,000 i.e., US$170–250) with the rice-duck system (Fig. 2). The results reveal that the rice-duck system can reduce insecticide, weeding, and chemical fertilizer costs, increase rice yield, and consequently provide higher economic benefits to farmers while at the same time being environment-friendly.

Table 1. Insect population observed at rice-duck system and farmers' practice at Bakerganj, Barisal, and Sylhet, 2003 T. aus season.[a]

Insect	Total number caught by sweep net (no. 5 sweeps^{-1}wk^{-1})					
	Barisal			Sylhet		
	Rice-duck	Farmers' practice	Difference	Rice-duck	Farmers' practice	Difference
Harmful insects						
Green leafhoppers	2.91	5.15	2.21*	6.21	8.21	2.00ns
Brown plant hoppers	0.17	1.58	1.41**	0.38	0.72	0.34 ns
Whitebacked planthoppers	0.13	0.33	0.20ns	0.15	0.15	-0.00 ns
Zig-zag leafhoppers	0.22	0.72	0.50*	0.50	1.52	1.02 ns
Rice bug	0.25	0.83	0.58*	0.28	0.54	0.26 ns
Short-horned grasshoppers	2.37	4.21	1.84**	8.33	11.17	2.84 ns
Long-horned grasshoppers	0.21	0.75	0.54**	0.21	0.62	0.41 ns
Stem borers	0.12	0.12	-0.00ns	0.71	1.14	0.70 ns
Beneficial insects						
Carabid beetles	1.71	2.25	0.54ns	2.86	2.71	-0.15 ns
Lady bird beetles	1.37	1.29	-0.08ns	11.00	11.30	0.13 ns
Damsel flies	3.29	3.29	-0.00ns	6.14	5.86	-0.28ns
Spiders	0.83	0.96	0.13ns	7.67	7.33	-0.34ns
Dragon flies	0.58	0.96	0.38ns	1.29	2.28	0.99 ns

[a]* Significant at 5% level at *F* test, ** significant at 1% level, ns= not significant.

Table 2. Effects of integrated rice-duck system and farmers' practice on plant characters and grain yield of T. aus rice, 2003, Barisal and Sylhet.[a]

Character	Location and treatment					
	Barisal			Sylhet		
	Rice-duck system	Farmers' practice	Difference	Rice-duck system	Farmers' practice	Difference
Plant height (cm)	133.88	132.42	1.46*	103.80	99.90	3.90*
Tillers (no. hill^{-1})	17.25	12.23	5.02**	17.20	12.23	4.97**
Panicles (no. hill^{-1})	14.36	10.45	3.91**	10.54	8.45	2.09**
Grain (no. panicle^{-1})	126.57	107.71	18.86*	136.57	120.71	15.86*
1,000-grain wt (g)	27.85	26.85	1.00	27.25	26.95	0.30
Grain yield (t ha^{-1})	4.00	3.70	0.30*	3.89	3.32	0.57*

[a]* = significant at 5% level at *F* test, ** = significant at 1% level.

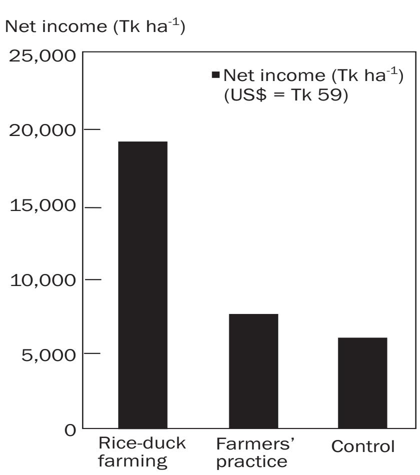

Fig. 2. Net income in different rice systems in Sylhet 2003 aus season.

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Farmers' participatory evaluation of rice varieties and herbicidal technologies in the Godavari Delta

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More than 250,000 ha are under the rice-rice system in the Godavari Delta, the rice bowl of southern India. An increase in productivity can be made possible through a microlevel analysis of the technological gaps regarding varieties and farm technology. Good varieties and excellent herbicidal technologies have been developed for the rice-rice system in the last decade. But only a fraction of the modern weed management practices developed reaches farmers. This study aims to assess these technological gaps and to identify the constraints to the adoption of these practices. In 2000-02, 10 villages were selected in West Godavari District and 20 respondents from each village were taken randomly for the study. The participatory rural appraisal technique was used for the agroecosystem analysis (Conway et al 1987) to compare the performance of four different varieties and evaluate the adoption of herbicidal technology in rice from the farmers' perspective.

A majority of the farmers preferred Samba Masuri and Swarna despite their higher susceptibility to pests and diseases (Table 1). Notwithstanding its low yield, instability, and high risks involved in cultivation, Samba Masuri has spread to other areas because of the premium price it commands and its high profitability. Its high market value is attributed to its superfine, nongelatinous, and oily grain. The cooked grain is silky to touch, slender, very tasty, and suitable for spicy and nonspicy rice preparations. Swarna, on the other hand, is an efficient user of nutrients, versatile, and grown by marginal farmers because it costs less to cultivate. Although yield and yield stability of Vijetha were high, consumers did not like its coarse and not-so-tasty grain.

Farmers' knowledge and adoption of weed control technology were also assessed using the technological gap index developed by Samui et al 2000 (Table 2). On the basis of attitude toward weed management practices in rice, it was found that a majority of the respondents had more than 60% knowledge about summer plowing, suboptimal

Table 1. Farmers' ranking[a] of four rice varieties in coastal Andhra Pradesh.

Characteristic	Vijetha	Samba Masuri	Chaitanya	Swarna
Grain yield	5	4	3	4
Yield stability	4	2	3	3
Risks involved in cultivation	1	4	2	3
Profitability	3	5	3	4
Seed availability	5	3	5	4
Pest and disease incidence	2	5	2	4
Tolerance for weeds	2	1	3	3
Labor use	2	4	2	2
Compatibility with weather	2	2	2	4
Grain shattering	1	2	1	1
Lodging	2	3	2	4
Consumer preference	1	5	2	3
Taste	2	5	2	3
Digestibility	2	5	3	4
Grain size	Coarse	Superfine	Fine	Fine
Straw yield	3	4	4	4
Milling recovery	2	2	4	4
Seed dormancy	5	2	2	2

[a]On a scale of 1–5: 1 = least, 5 = maximum.

plant population, and unskilled labor leading to ineffective weed control. The factors that prevent full adoption were additional costs involved in summer plowing and getting contract labor for transplanting. None of the farmers used manual weeding or herbicide alone. Many adopted integrated weed management practices. Farmers reported the maximum gap (65.4%) with respect to dose and time of herbicide application. There was zero adoption of barnyardgrass control in the rice nursery, though farmers knew about it. The herbicide sales representatives had maximum contact with farmers; agricultural department officers were the least consulted on herbicidal technology. Friends and mass media (radio and TV) were the most often used sources of information on weed management. Farmers preferred broad-spectrum-based chemicals with no toxicity effects on fish (Table 3).

Table 2. Factors that farmers perceive as contributory to effective weed control in rice.

Factor (in order of priority)	Knowledge index (Ki)	Adoption index (Ai)
Improper water management	45	33
Land leveling with power tiller	24	12
Neglect of summer plowing	65	51
Barnyardgrass infestation in nursery	17	0
Poor technical know-how about herbicides	26	9
Dependence on unskilled labor	65	16
Suboptimal plant population	61	28

Table 3. Farmers' preferred characteristics of rice herbicides.

Characteristic	Preference (%)
Broad-spectrum action on weeds	95
Effective control with low dosage	86
Compatibility with fertilizers and insecticides	71
Less phyto-toxicity	62
Persistency of at least 40 DAT	24
Application of broad window of chemicals (15 DAT)	87
No toxicity on adequate biota such as fish and prawns	92

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Impact of farmer field schools on farmers' knowledge: the IPM experience in Sri Lanka

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Two farmer field schools (FFSs) were conducted in the rice-growing district of Matara, Sri Lanka, to disseminate integrated pest management (IPM) technologies. To ensure com-munity participation, two farmer organizations (FOs)—Pahala Vitiyala and Malana—confined to the two villages were selected as implementing organizations (IOs). The FOs selected 25 farmers each for the FFSs (50 out of 150 farmers) and separate FFSs were put up during the yala rice-growing season. Sample size was nearly 34% of the total population.

The FFS is a popular agricultural extension approach that facilitates farmer learning by doing, involving farmers in decision making on the basis of observations and analysis of the microenvironment. FFSs are used to transfer knowledge on IPM. To evaluate the impact on farmers' knowledge, the ballot box test was employed before and after FFSs.

At each location, 20 ballot boxes with cards bearing simple questions and three possible answers to each question were prepared. In most instances, specific specimens were included. The test materials were either fixed on a frame, placed on a stand, or hung on a tree. Farmer participants were then given 20 small cards, indicating their number. This served as the ballot. At the beginning, each participant was requested to stand in front of the ballot box that corresponded to his or her assigned number. Within a minute, the farmer had to answer the question to the best of his/her knowledge. Putting the ballot into the box, he or she had to move to the next spot. This procedure continued until all farmers passed all ballot boxes. Farmers moved from one box to another to answer a question.

Prior to the FFSs, preevaluation was done to estimate the existing knowledge of farmers. At the end of the FFSs, postevaluation was conducted using the same questions and answers displayed in the ballot boxes for the same farmer group. On separate occasions, 18 farmers from Malana and 20 from Pahala Vitiyala participated in this exercise. The results showed that, in the two target groups, existing knowledge ranged from 30% to 70%. However, the mean knowledge score in Malana was 48.5% and that in Pahala Vitiyala was 47.5%. Hence, no significant knowledge variation between the two target groups was observed. A comparison was made on the mean knowledge level during pre- and postevaluation on the basis of ballot box test results. Table 1 demonstrates the results.

Table 1. Differences in mean knowledge levels during pre- and postevaluation stages.

Village	Preevaluation (%)	Postevaluation (%)	Difference in knowledge gain (%)
Pahala Vitiyala	47.5	72.5	27.0
Malana	48.5	71.0	22.5
Total	48.0	71.5	23.5

Table 2. Farmers' knowledge at pre- and postevaluation stages.

Village	Knowledge level (%)			
	Very low	Low	Medium	High
Pahala Vitiyala				
Preevaluation	35	20.0	20.0	25.0
Postevaluation	5.9	38.9	21.7	33.5
Malana				
Preevaluation	22.2	22.2	38.9	16.7
Postevaluation	6.7	22.2	46.6	26.7
Total Sample				
Preevaluation	13.2	22.2	31.6	18.4
Postevaluation	6.2	22.2	45.0	18.8

The pre- and postevaluation results showed that the mean knowledge of the entire target group (total population) has increased from 48% to 71%. This implies a 23.5% increase in knowledge among farmers. Further, the mean knowledge at the two locations, Pahala Vitiyala and Malana, has increased significantly from 47.5% to 72.5% and from 48.5% to 71%, respectively. Farmers in the two target villages were also clustered into four knowledge categories based on their performance. The categorization was done using the farmers' mean knowledge and standard deviation. The results demonstrated that, in both villages, the percentage of farmers in the very-low-knowledge category has significantly decreased at the end of the FFSs (Table 2). In contrast, the percentage of farmers in the low-knowledge category has increased. This implies that many farmers have obtained knowledge on IPM through the FFSs.

This study demonstrates the effectiveness of the FFS as an extension tool to disseminate knowledge pertaining to pest management.

Evaluation of weeding devices for upland rice in the eastern Ghat of Orissa, India

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Phulbani consists of hill ranges that belong to the main line of the eastern Ghat, along with some plains and valleys lying between the hill ranges. Kharif rice is the main crop in this zone. Weeds are a serious problem, reducing the productivity of this crop. Farmers control weeds by hand picking and hoeing, which substantially increases cultivation cost. Weeding by mechanical devices reduces the cost of labor and also saves time. This field trial has been designed to test the efficacy of weeders for use in upland rice.

Eight treatments were tested using a randomized block design with three replications. The experiment was conducted during 1999-2001 at the Dryland Research Farm, OUAT. The field performance and economics of weeder operation were compared. The treatments are T_1—weeding by rake weeder, T_2—weeding by wheel finger weeder, T_3—weeding by rotary peg weeder, T_4—weeding by *gadi* (local weeder), T_5—hand weeding, T_6—weedy check, T_7—use of preemergence herbicide (butachlor), and T_8—weeding by Phulbani dryland weeder. The plots were 6 m × 5.33 m. Variety Zhu 11-26 was seeded at 75 kg ha^{-1}. The fertilizer applied was 60-13.2-24.9 kg NPK ha^{-1}; farmyard manure was applied at 5 t ha^{-1}. Soil drainage conditions were good, soil pH was 5.5, organic C was 0.2%, and available P_2O_5 was 9.2 kg ha^{-1}. The weeder test was made 21 d after sowing. The effective field capacities of the different weeders were determined.

The characteristic features of the weeders tested are shown in Table 1. The Phulbani dryland weeder was developed by the Dryland Agricultural Research Project of OUAT. For the rake weeder and the wheel finger weeder, the pegs were arranged in zigzag. If, for some reason, weeding is delayed, weed overgrowth may block these zigzag pegs.

These weeders, along with the rotary peg weeder, were not suitable when rice seeds were sown at 15-cm spacing. They damaged the tillers during the second weeding. Because of its pointed tips and longer pegs, the Phulbani dryland weeder showed excellent performance in all types of soils with varying soil moisture levels and weed inten-sity. It was also the best soil crust breaker.

The Phulbani dryland weeder registered the highest rice yield (3.9 t ha^{-1}) (OUAT 2000) compared with other weeders (Table 2). The labor involved was least with the Phulbani weeder (57 person-days

Table 1. Characteristic features of the weeders tested.

Weeder	Width (cm)	Cost (Rs)	Blades (no. peg^{-1})	Peg arrangement
Rake weeder	8	46.00	4	Zigzag
Wheel finger weeder	15	428.00	5	Zigzag
Rotary peg weeder	17	398.00	1	–
Gadi (local weeder)	2	30.00	1	–
Phulbani dry land weeder	5	15.00	4	Straight line

Table 2. Field performance of selected weeding devices.

Treatment[a]	Weight of dry weeds at harvest (t ha^{-1})	Grain yield (t ha^{-1})				Effective field capacity (ha d^{-1})				Person-days in weeding (ha^{-1})				Benefit-cost ratio				% increase in yield over hand weeding	Weed control efficiency (%)
		1999	2000	2001	Mean	1999	2000	2001	Mean	1999	2000	2001	Mean	1999	2000	2001	Mean		
T_1	0.75	3.0	3.2	1.4	2.5	0.051	0.069	0.08	0.067	65	75	71	70.3	1.74	1.50	0.71	1.32	12.6	81
T_2	0.55	3.1	3.2	1.1	2.4	0.102	0.075	0.09	0.089	56	75	59	63.3	1.81	1.48	0.56	1.28	12.9	76
T_3	0.50	3.1	3.2	0.9	2.4	0.073	0.072	0.09	0.078	59	73	61	64.3	1.80	1.48	0.50	1.26	17.5	78
T_4	0.85	2.9	3.6	0.9	2.5	0.022	0.009	0.02	0.017	90	189	86	121.7	1.55	1.25	0.43	1.08	15.0	91
T_5	1.32	2.3	3.0	0.7	2.0	0.019	0.009	0.012	0.013	106	176	144	141.7	1.17	1.08	0.30	0.85		93
T_6	8.95	0.26	0.12	0.03	0.14	–	–	–	–	–	–	–	–	0.23	0.15	0.02	0.13		0
T_7	0.62	3.4	3.6	1.1	2.7	–	–	–	–	45	66	56	55.7	1.86	1.60	0.54	1.33	22.3	95
T_8	0.45	3.3	3.7	1.2	2.7	0.071	0.071	0.068	0.07	59	55	59	57.7	1.91	1.86	0.60	1.46	32.1	89
SE (m)+	–	2.28	1.74	1.74	1.3	–	–	–	–	–	–			–	–	–	–	–	–
CD (0.05)	–	6.92	5.26	5.28	3.81	–	–	–	–	–	–			–	–	–	–	–	–

[a]T_1—weeding by rake weeder, T_2—weeding by wheel finger weeder, T_3—weeding by rotary peg weeder, T_4—weeding by *gadi* (local weeder), T_5—hand weeding, T_6—weedy check, T_7—preemergence herbicide (butachlor), T_8—weeding by Phulbani dryland weeder.

ha^{-1}), saving nearly 57% labor compared with hand weeding (127 person-days ha^{-1}). It also had better weed control efficiency. Though herbicide use produced comparable rice yield, their use may be limited to the cropped field because of adverse effects on the environment. The Phulbani dryland weeder was cheap, making it very popular among Orissa farmers. It was concluded that the Phulbani dryland weeder should be recommended for weeding all crops. It can be used for crust breaking and for harvesting groundnut and potato.

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Adoption of preharvest interval in rice cultivation

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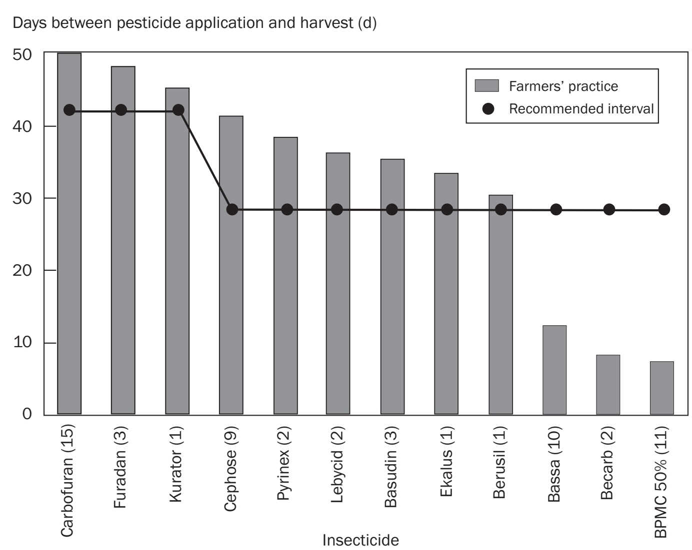
The problem of pesticide residues in food, especially in cereals, fruits, and vegetables, has spurred the implementation of certain policy measures to minimize this problem. It is well recognized that if pesticide is applied too close to harvesting date, toxic substances are probably retained in consumer food. In Sri Lanka, this situation can be prevented by adhering to a preharvest interval (PHI), which is mandated by law. The preharvest interval is a period that usually varies from 7 to 21 d, depending on the toxicity of the pesticides. The Pesticide Act of 1980 prohibits the harvesting or selling of any food crop treated with pesticide until the prescribed PHI is employed. Highly toxic pesticides have a longer PHI and less toxic ones have a shorter PHI. The recommended PHI is stated on the label of the pesticide bottle. Further, these PHIs are also disseminated through the country's extension system.

To identify how the PHI is practically applied in rice cultivation, a study was conducted in the low-country, dry zone of Sri Lanka. Two Grama Niladhari divisions (village-level administrative divisions where local extension workers are assigned), Koggala and Siyambalagaswila South in the Ambalantota agrarian service center area in Hambantota District, were selected for the study. Sixty farmers were randomly chosen for the field investigation. Farm visits and farmer interviews were conducted at the end of the 1997-98 maha season (the major rice cultivation season that starts in October and ends in February).

Farmers were asked what was the last pesticide they applied in the field and how many days after pesticide application was the crop harvested. The results showed that farmers did not adhere to the PHI (days are calculated as averages for farmers who used a particular insecticide) (see figure). For BPMC, Bassa, and Bencarb, the recommended PHI is 14 d, but farmers harvested their crops just 4–7 d after



Difference between what is recommended and what is practiced.

pesticide application. Further investigation revealed that BPMC was used to control brown planthopper (BPH, *Nilaparvata lugens*) attack, which occurred at the milking stage. Farmers were compelled to use BPMC, leading to higher levels of BPMC residues in the rice grain. However, it was not clear whether BPH infestation close to harvest will cause a serious yield loss. This highlights the need for more farmer education programs that will raise awareness about the interaction between pest infestation and use of pesticides. Increased awareness on this could reduce unnecessary spraying of pesticides.

Input use and socioeconomic characteristics of rice farmers: gender dimensions and implications for smallholder agriculture in Nigeria

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The topic "women in development" has become increasingly prominent in the literature on rural development and the phrase "women component" has become a popular catchword among policymakers in recent years. As increasing attention is paid to world poverty, food shortages, and overpopulation, the important role of women can no longer be ignored. Researchers and practitioners are discovering that not only do women make up a large proportion of the world's poor, they are also the main provider of food and basic necessities for their families. These discoveries have had major implications in academic research and policymaking. In addition, the positive contributions made by women to their communities as well as to their national economies have been undervalued. In many instances, women have been viewed as a drain on scarce resources rather than an asset in economic development. This study examined the gender dimensions of the impact of input use and socioeconomic characteristics of farmers on their level of efficiency in rice cultivation in Kaduna State, Nigeria.

The study focused mainly on small-scale farmers cultivating less than 5 ha of land. Representative samples of equal numbers (40) of respondents were randomly selected in two villages from two local govern-ment areas in the state. The analytical approach involved descriptive statistics, and the estimation of a stochastic frontier model through maximum likelihood estimation procedure.

The stochastic frontier model specified output (Y) as a function of inputs (X) and a disturbance term (ε): $Yij = f(X_{1j} + X_{2j} + \ldots X_{nj}, A; \varepsilon)$, where Y_i is output by farmer i, X_{ij} is input j of n inputs, and A is a vector of parameters ("mu"). The disturbance term in stochastic frontier models consists of two components, $\varepsilon_i = V_i - U_i$, where $V_i \sim N(0, \sigma_v^2)$ and U_i is a one-sided error term. The one-sided term, U_i, represents technical inefficiency (TI) relative to the stochastic frontier. If $U_i = 0$, production lies on the stochastic frontier and production is technically efficient; if $U_i > 0$, production lies below the frontier and is inefficient.

Table 1 compares the male and female respondents in terms of their use of farm inputs. It can be noted that there was no

Table 1. Mean values of input use per hectare and socioeconomic characteristics of farmers.

Input/characteristic	Aggregate	Male	Female
Input			
Farm size (ha)	3.15	4.74	1.48
Family labor (person-days)	125.99	112.75	130.55
Hired labor (person-days)	25.81	25.75	25.67
Traction (h)	4.77	4.91	4.32
Agrochemicals (L)	3.21	2.43	5.78
Seed (kg)	99.88	67.31	90.46
Fertilizer (kg)	76.71	95.62	114.02
Yield (t)	1.8	1.1	039
Farmer characteristics			
Age (y)	40.33	45.62	34.77
E ducation (y)	6.81	8.00	5.55
Contact with extensive agents (No)	9.41	9.95	8.85
Estimated farm income (Naira)	73, 2523.60	43,522.80	73,2523.60
Farming experience (y)	22.62	24.91	20.22
Household size (no.)	6.76	8.23	5.22

significant difference in their level of input use, except for the size of land cultivated, where female farmers worked on a much smaller area. This has significant implications in terms of efficiency. Because of their inability to expand farm area due to restrictive policies on land ownership and the tenure system, female farmers were forced to cultivate the same area every year, thereby depleting soil fertility and affecting output.

The results of the stochastic production frontier model validated this observation. The production function estimate indicated that one of the critical inputs to the attainment of high yield was land input. The estimated coefficient of farm size was 0.31 and it was very significant (Table 2). The other critical inputs that were significant were labor and agrochemical inputs. But, for the other inputs, the level of use was almost the same for male and female farmers.

Table 2. Regression results of the stochastic frontier and socioeconomic model.[a]

Variable	Coefficient	Standard error	t ratio
Stochastic frontier model			
Constant	2.31	0.22	10.66**
Farm size	0.31	0.57	5.34**
Family labor	1.00	0.009	1,114.82**
Hired labor	0.14	0.03	4.19**
Traction	0.03	0.05	0.61
Agrochemicals	0.14	0.05	2.67**
Seed	–0.004	0.009	–0.41
Fertilizer	0.004	0.006	0.60
d^2=du/dv	1.33	0.21	6.28**
Socioeconomic model			
Constant	0.38	0.18	2.14**
Age	0.02	0.01	4.27**
Education	0.01	0.01	0.30
Contact with extension agent	0.01	0.01	1.54
Farm income	5.89	5.93	0.99
Farming experience	–0.01	0.01	–1.12
Household size	–0.01	0.01	–0.13
Sex	–0.28	0.09	3.11**

[a]Log likelihood function =–616.83.

The technical inefficiency portion of the model indeed showed that male farmers were more technically efficient than female farmers. The sex variable had a negative coefficient and was significant. The only other significant coefficient was age, which indicates that the older the farmer, the more inefficient he or she is.

Comparative analysis of costs incurred by seed growers and nonseed growers

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The annual rice seed requirement of Sri Lanka approximates 1 million t. The state farms were unsuccessful in supplying the required amount in the past for various reasons. Hence, the government inter-vened to expand production of certified seed by private growers. However, this approach has certain limitations: difficulty in maintaining the standards, marketing problems, and not-so-established differences in cost of production. This study aimed to identify differences in production cost between seed growers and nonseed growers.

The study was carried out in Hambantota, a major rice-growing district. Forty-two private seed producers were chosen as respondents. The same number of growers was randomly selected from five agricultural service centers (Yodhakandiya, Lunawa, Weeeraketiya, Netolpitiya, and Meegahajadura). Cultivation cost for the 2001-02 maha season was obtained employing pretested questionnaires (see table).

Seed producers entailed extra expenses removing off-types and for drying, winnowing, and processing to maintain high quality standards. The results demonstrate that the difference in production cost was not significant, though seed producers reported a slightly higher figure. The seed producers obtained a higher average yield. Certified seeds were sold at the farm-gate price of Rs 17.75 kg^{-1} in contrast to the normal Rs 15.12 kg^{-1}. In fact, seed growers received an extra profit margin of Rs 29,420 ha^{-1} $season^{-1}$. This will result in an extra net income of Rs 4,900 ha^{-1} $month^{-1}$, which is hardly insufficient to promote the seed-growing industry. Moreover, many farmers cultivated small plots (<0.5 ha) and some were sharecroppers who had to leave 1/3 of the harvest as land rent.

Differences in cost of production.[a]

Item	Seed growers (Rs ha^{-1})	Percent of cost component	Nonseed growers (Rs ha^{-1})	Percent of cost component
Seed	3,583	6.6	3,812	6.6
Land preparation and plant establishment	11,680	19.7	11,794	20.5
Fertilizer application	5,590	9.4	5,504	9.5
Weed, pest, and disease control	4,544	7.6	5,209	9.0
Tenancy and lease arrangements	10,313	17.4	10,275	17.8
Special activities for seed production	2,095	3.5	Not applicable	0
Registration	1,000	1.6	Not applicable	0
Av cost (Rs ha^{-1})	59,196		57,479	0
Av yield (kg ha^{-1})	7,177		6,366	
Av price (Rs)	17.75		15.12	
Gross returns (Rs)	127,392		96,253	
Profit (Rs ha^{-1})	68,196		38,775	

[a]US$1 = Rs 98.

Hence, seed growers do not receive even the above-mentioned real income. The price received for certified seed was rather low. Further, seed farmers encountered marketing problems at the beginning of the season. This has become a common problem, necessitating policies to buy rice seed above Rs 20 kg^{-1}.

International Year of Rice 2004

Last year, the United Nations General Assembly declared 2004 as the International Year of Rice. The International Year of Rice aims to "promote the ecological, social, and cultural diversity of rice-based production systems as a prism through which key global concerns can be addressed, such as poverty and hunger alleviation, undernourishment, food safety, environmental protection, and other important issues."

The Food and Agriculture Organization (FAO) of the UN will facilitate the implementation of activities related to the celebration through a network of stakeholders that include donors, a global working group, regional working groups, national working groups, and community working groups including farmers' groups, nongovernment organizations, and the private sector.

The initiative for the celebration was spearheaded by a Philippine-led resolution cosponsored by 43 member countries to promote awareness on sustainable development of this staple food for more than half of the world's population. Through increased awareness of the rice system, food and agricultural policy and technical, economic, social, and development goals will be better focused by all stakeholders involved in the sustainability of food systems.

The International Year of Rice logo—Rice is life—aptly captures the essence of this important staple food. The official launching of the event will be held on October 31 in New York.

As a member of the International Year of Rice Committee, IRRI is already initiating several projects that involve all rice sectors in the celebration, starting with the *IRRN* Best Article Awards and the publication of *Graindell*, a children's storybook.

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