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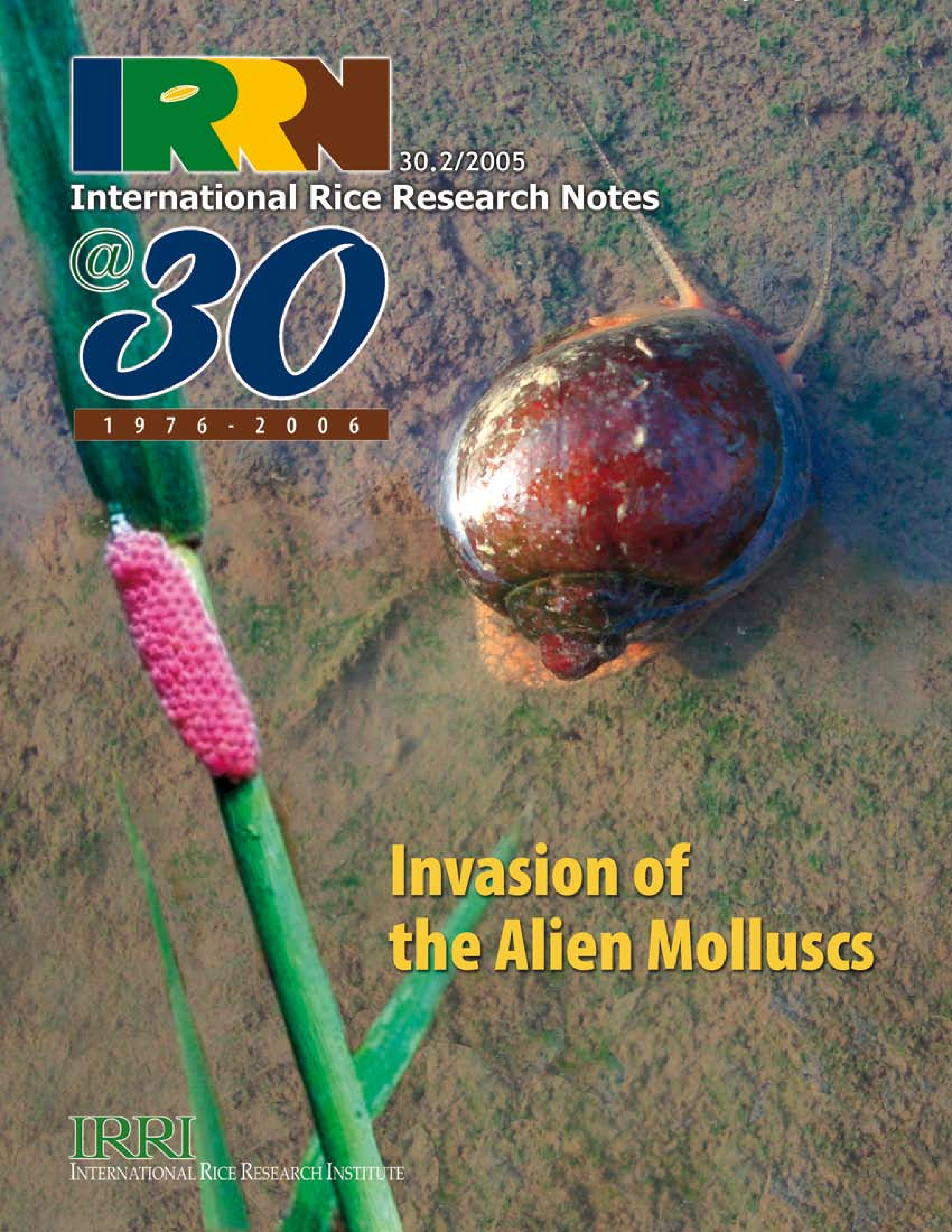

# Invasion of the Alien Molluscs

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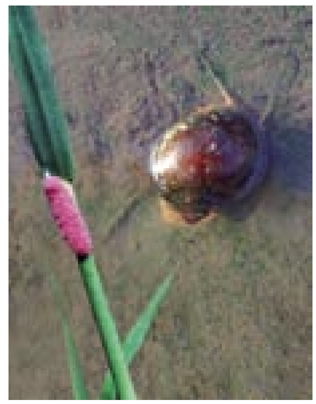

Cover photo: R. Joshi

## Soil, nutrient, & water management



## Crop management & physiology

MINI REVIEW

# Managing invasive alien mollusc species in rice

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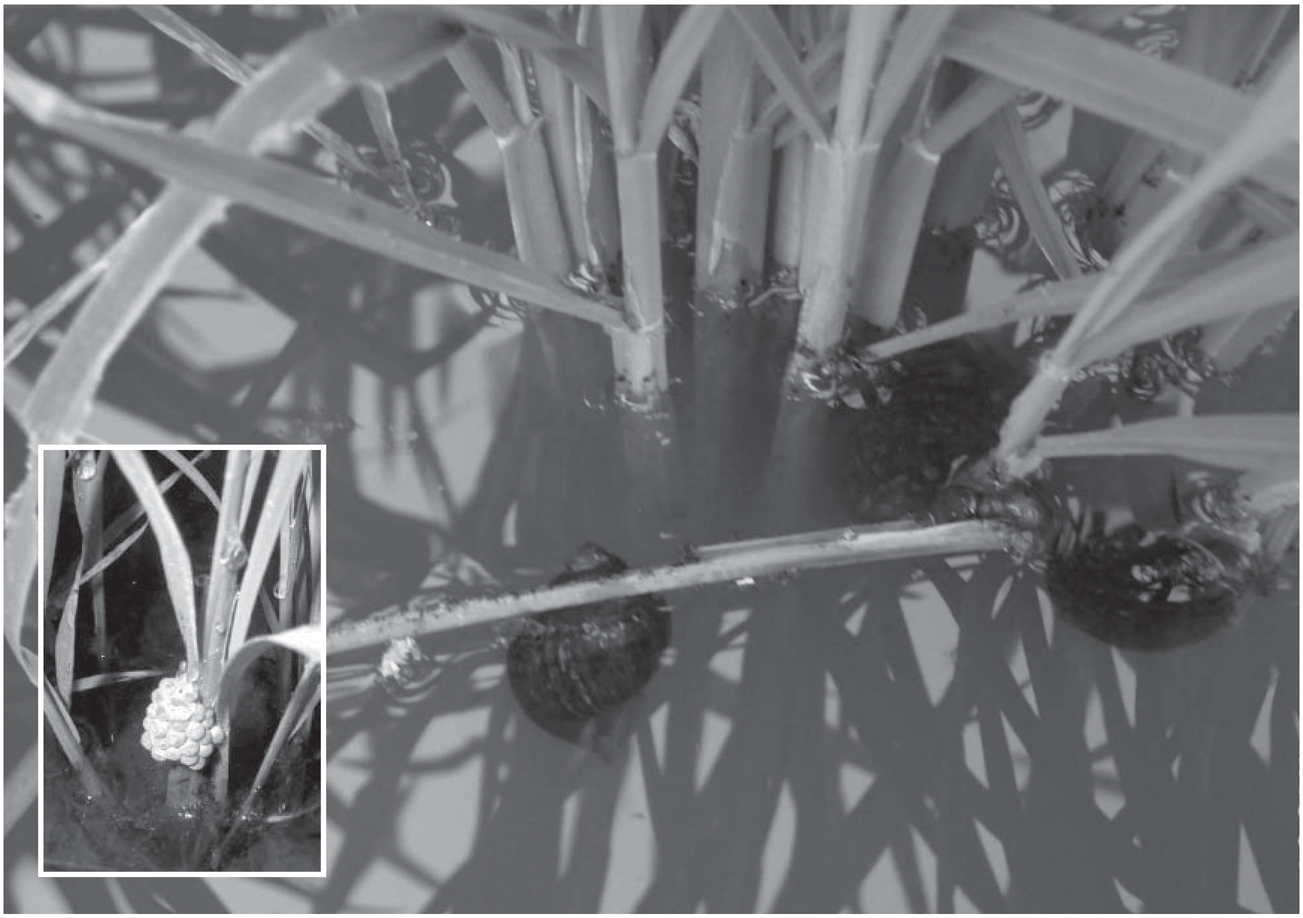


**Golden apple snail and its pink-colored egg mass attached to the rice plant.**

The golden apple snail (GAS) *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae) is a freshwater mollusc that originated from the floodplains along the Paraguay and Paraná rivers that cut through Paraguay, Brazil, and Bolivia and that drain into the Atlantic in Argentina (Pain 1946). It is also known by its other common names: golden miracle snail, jumbo snail, Argentinean apple snail, channeled apple snail, mystery snail, and South American apple snail. Some of these names have been used for more than one species of ampullariid (Cowie and Thiengo 2003, Cowie and Hayes 2005). GAS, however, is the common term for the pest species in Asia (Joshi 2005).

## An invasive species and a possible host of deadly microorganisms

GAS is one of the world's 100 worst invasive alien species (ISSG, www.issg.org/database). The invasiveness is related to its inherent characteristics: a high reproductive rate, adaptability to harsh environmental conditions, ability to invade diverse habitats through multiple pathways, a wide host range and voracious appetite, and an ability to compete with the native snail species and native fauna (Halwart 1994a,b; Joshi 2005). In addition, there is lack of effective biological control agents in its new habitat.

GAS is difficult to manage once it invades new areas because of its biological and morphological characteristics. A female GAS can lay 50–500 eggs at one time, with an 80% hatchability rate. Incubation ranges from 10 to 15 d. GAS has a gill (ctenidium) and a lung-like organ, enabling it to survive in and out of water. It can withstand drought for several months by closing its operculum and bedding in the soil. It moves only when the water is half its shell height. In the field, approximately twice as many females occur, an indication that males do not live as long as females. Individual snails can live for more than 4 y (Andrews 1964, Mochida 1991, Estebenet and Cazzaniga 1992).

GAS is a highly voracious nocturnal herbivore. It can destroy newly transplanted or direct-seeded rice as long as there is water in the field. It cuts the base of young seedlings with its layered tooth (radula) and munches on the succulent tender sheath of rice.

The extent of damage to the rice crop depends on snail size and density and the growth stage of the rice plant (Schnorbach 1995). Three GAS in a square meter of the rice field can cause significant yield loss. GAS that are 20–40 mm are the most destructive, regardless of rice establishment method used (Joshi et al 2002). GAS also feeds on a wide variety of live host plants. Its other hosts and food include livestock feed, decaying matter, animal flesh, and other crops.

**GAS damage to lowland irrigated transplanted rice (top) and wet direct-seeded rice (bottom).**

GAS puts the health of farm workers at risk as it is a host of the nematode *Angiostrongylus cantonensis* [*Parastrongylus cantonensis*] that causes eosinophilic meningoencephalitis in humans (Mochida 1991). GAS is also a host of *Catadiscus pomacea* (Hamann 1992). Hence, the snails should be cooked thoroughly if they are to be eaten.

## Spread of GAS in Asia

GAS has become one of the most important rice pests in countries where direct seeding has become more popular than transplanted rice, such as the Philippines, Vietnam, and Thailand (Wada 2004). In Asia, GAS was first introduced to Taiwan in 1979. Many farmers cultured it, anticipating that it could replace the native snails. GAS, however, were abandoned in culture ponds as the taste did not meet consumers' preference. Mochida (1991) estimated that GAS occurred on 17,000 ha of rice fields in 1982; the area in 1986 was 151,444 ha. The area treated with molluscicides increased from 46,000 ha in 1983 to 90,000 ha in 1986. Estimated losses were $8.3 million and $30.9 million, respectively.

In Japan, the first GAS damage was reported in 1984 (Wada 1997; Yusa and Wada 1999, 2002). In the same year, the Japanese government declared GAS a quarantine pest. In 1998, GAS was found on 63,559 ha of rice fields, 7% of which were in Kyushu. By 2001, GAS occurred on 65,000 ha in Japan. About 70% of the area (45,000 ha) was on Kyushu Island, composing 20% of the total rice-growing area on the island.

In mainland China, GAS damage to rice has gradually increased with respect to the increasing level of direct-seeded rice production in southern China. In 1988, GAS was first recorded in 37 counties of Guangdong Province, affecting about 1,700 ha (Yu et al 2002).

Filipino farmers likewise consider GAS as a serious rice pest (Halwart 1994b). GAS-infested area expanded rapidly from 300 ha in 1986 to 426,000 ha in 1998 and more than 800,000 ha in 1995 (Cagauan and Joshi 2003). In 1990, all regions of the Philippines experienced GAS infestations (IRRI 1991). GAS infestation has decreased as a result of integrated management approaches being promoted through farmers' field schools (Cagauan and Joshi 2003) organized by the International Rice Research Institute (IRRI) and the Food and Agriculture Organization's (FAO) Intercountry Rice Program in South and Southeast Asia.

In Vietnam, GAS was introduced in 1988 and it became an endemic pest in 1994. In 1992, two local companies in southern Vietnam had a joint venture with a foreign company to set up two farms to raise GAS for export. In 1994, GAS invaded 260 ha of rice fields in Nghe An Province, with an average density of 200–250 snails $m^{-2}$. In Quang Tri Province, it heavily infested 4,000 ha of morning glory. A year later, GAS infestations were observed in 57 of the 61 provinces in the country (Cuong 2002, Huan and Joshi 2002, Ngoc 2002).

GAS became a major rice pest in Thailand in the early 1990s. Rice fields infested with GAS increased from 3,822 ha in eight provinces in 1990 to 64,623 ha in 43 provinces in 1996 (Aroonpol 1997, Sinives 2002).

In Sabah (East Malaysia), GAS was first seen in Keningau in 1992. It rapidly spread to other rice-growing areas. The cost of eradicating GAS up to 1998 was estimated at $590,000 (Jambari et al 1998). In Sabah, GAS was controlled through the use of natural enemies. The collared kingfisher (*Todirhamppus chloris chloroptera*), a frog (species not identified), and the fulvous whistling duck (*Dendrocygna bicolor*) were found effective against GAS (Teo 2004).

GAS also appeared in Vientiane, Lao PDR, around 1992. Nine of 10 villages reported great damage following the snail's appearance and all aquatic plants were affected (Carlsson 2004).

In 1995, only 12 districts in West Java, Indonesia, had rice fields attacked by GAS. Four years later, the number of districts invaded by GAS rose to 16. Its distribution became larger not only in poorly drained fields but also in fields with regulated irrigation systems (Suharto 2002).

In August 1995, a farmer in Svay Rieng, Cambodia, started to raise GAS in clay jars. But when he heard that it was a pest, he destroyed all the GAS he bought from Phnom Penh. In October 1995, Dr. Robert Cowie, a snail taxonomist at the Bishop Museum in Hawaii, was invited to Cambodia to identify the newly introduced snails. Dr. Cowie identified these to be *P. canaliculata* and *P. insularum*.

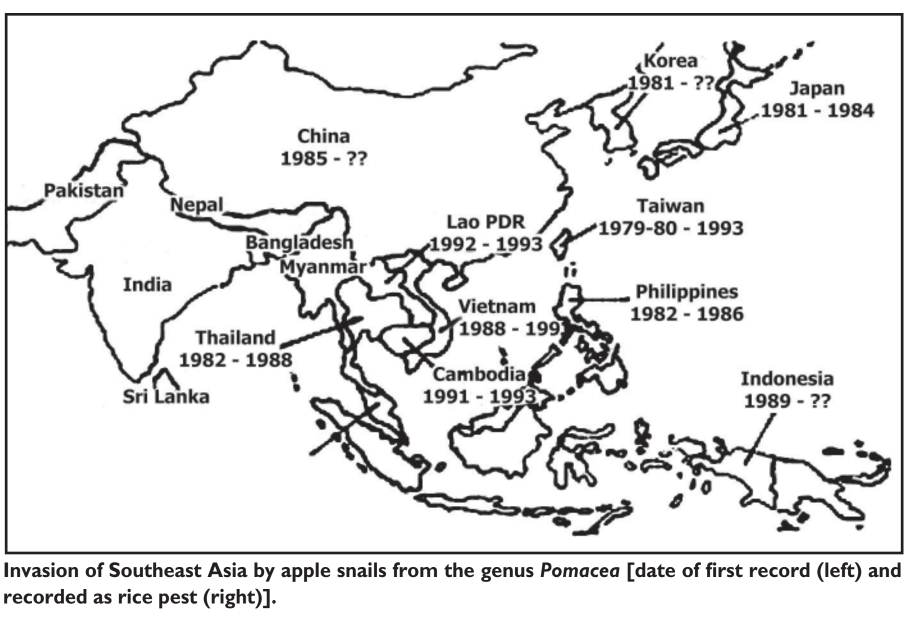
GAS continues to expand westward in Asia. Large rice-growing areas and water bodies of India, Bangladesh, Pakistan, and Australia face threats of GAS invasion.

## Spread of GAS in the United States and other countries

In Hawaii, GAS spread widely in the 1990s and caused significant damage to taro (Cowie 2002). GAS feeds on the corm and leaves of taro, resulting in low yield. It can even destroy the whole crop before harvest. Yields of taro for processing in 2003 reached a record low of 4.8 million pounds, down 17% from the previous year (HASS 2004), owing mainly to continued infestation of apple snails, adverse weather, and disease (Viotti 2004).

In South America, where GAS originated, no report describing rice damage by *P. canaliculata* was published until 2000, although another *Pomacea* sp. (*P. doliodes*) has been reported to infest rice in a few instances (Litsinger and Estaño 1993). In 1993, several hectares of wet-seeded young rice in Camaqua, Rio Grande do Sul State, southern Brazil, were infested and 30% of the rice seedlings disappeared. Thereafter, rice damage was sporadically observed every year and was subsequently found in all regions of the state in 1997.

In Argentina, GAS is not generally considered a rice pest. But, since the latter half of the 1990s, a few farmers experienced heavy damage to dry-seeded rice following heavy rain (Wada 1999). GAS is less




**Invasion of Southeast Asia by apple snails from the genus *Pomacea* [date of first record (left) and recorded as rice pest (right)].**

a problem for rice production in South America and Texas, USA, although damage has recently become more apparent (Neck and Shultz 1992, Howells and Smith 2002).

As GAS develops into a pest, the following were observed:

- It becomes a pest 4 y after it is introduced to a country.
- Local establishment is key to its invasion.
- Its establishment is stochastic.
- It is likely to persist once it has established itself.

## Conventional GAS management practices

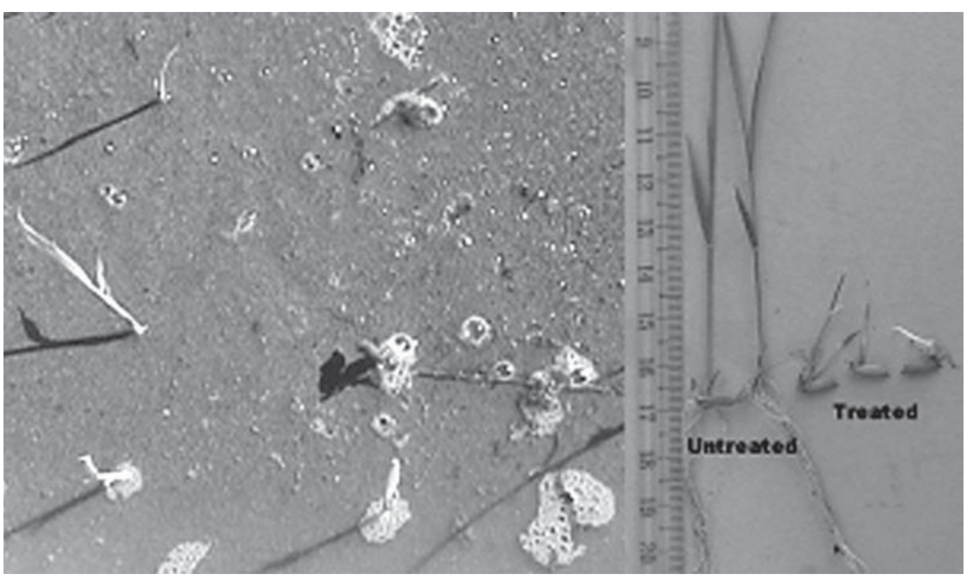
Molluscicides have been used to control GAS but they also kill the nontarget organisms such as fish and other beneficial organisms. In some countries, molluscicides have been banned. Niclosamide, endosulfan, camellia seed cake (residue), and copper sulfate, which are often used to control GAS in Asian countries, cannot be registered in Japan as they were deemed to have negative effects on the environment (Wada 2004). In our structured interviews and focus-group discussions, farmers from Hagonoy, Davao del Sur, Philippines, claimed to have stopped using molluscicides because of their cost and adverse effects on humans and animals. One farmer said that her carabao became almost blind when a small amount of niclosamide accidentally splashed on the eyes of the animal from a previously treated field (prior to harrowing). Some farmers said that their skin became itchy and their nails were damaged when they handled molluscicides.

Niclosamide 250 EC is preferred over metaldehyde by rice farmers because of its "quick kill" action on GAS. Unfortunately, niclosamide 250 EC is lethal to nontarget beneficial water-borne organisms such as frogs and fish. Recently, Joshi et al (2004) observed the detrimental effects of niclosamide 250 EC at preseeding in direct-seeded rice culture. Seedlings treated with niclosamide 250 EC had low and uneven emergence and were stunted. Uneven crop establishment also exposed the seedlings to GAS damage for a much longer time. Belowground effects on seedlings were marked reductions in root growth and development at all concentrations of niclosamide 250 EC.

Calcium cyanamide is an environment-friendly molluscicide that can be used against GAS in direct-sown rice in Japan. It was originally used as a fertilizer. Twenty-five kilograms of calcium cyanamide $ha^{-1}$ corresponds to 5 kg of N. Because it is phytotoxic, farmers have to apply it 7–10 d before sowing rice (Wada 2004).

Crude extracts from two botanicals, *Derris elliptica* and *Azadirachta indica*, were evaluated against GAS, but no molluscicide was developed (Maini and Rejesus 1993a,b). Recently, vulgarone B, a sesquiterpene from the plant *Artemisia douglasiana*, has reported molluscicidal activity against GAS (Joshi et al 2005b). Laboratory bioassays indicated that vulgarone B had activity comparable with that of the commercial synthetic molluscicide metaldehyde.

In 1989, FAO, IRRI, the Visayas State College of Agriculture (now Leyte State University), and DA-PhilRice launched a strategic extension campaign




**Effect of niclosamide 250 EC on germinating seeds of direct-seeded rice (left). Marked reductions in rice shoot and root length (right) were noted.**

(SEC). The SEC introduced the use of nonchemical methods such as duck pasture in rice fields after harvest, hand-picking and destroying egg clusters before final harrowing, transplanting older seedlings, and installing screens in water inlets. Most of these practices, however, remain untested in rainfed, direct-seeded, and hybrid rice production environments.

Moreover, farmers observed that no single tactic is superior to a "best mix" of various management options, as each option has some constraints (IRRI 1991, Cagauan and Joshi 2003). It is thus important that GAS damage be prevented through the use of low-cost, technically effective, and environment-friendly options to increase and stabilize rice production in direct-seeded and transplanted rice systems.

## Filipino rice farmers' knowledge, attitude, and practices with respect to GAS management

One hundred rice farmers from Nueva Ecija were interviewed using structured questionnaires in 1999. As recommended by a Philippine government-published primer on managing GAS (Tanzo et al 2000), their knowledge, attitude, and practices with respect to GAS were assessed. Some 51% of the farmer respondents practiced transplanting alone, 24% practiced direct seeding alone, and 19% used both methods (Table 1).

Moreover, only the direct seeders (86%) constructed depressed strips in their rice fields to make GAS management easier. Many of the farmers who transplanted (61%) did not use older seedlings (25–35 d) because they knew from experience that this practice will result in fewer productive tillers. Farmers who used transplanting (90%) and direct seeding (74%) did not put screens on the water inlets to restrict GAS entry as they found it ineffective. Screens became an area where GAS deposited their eggs and from where they could climb into the rice field. Placing bamboo sticks was also unpopular among transplanters (85%) and direct seeders (70%). Aside from being labor-intensive, the sticks became GAS egg habitats. This meant an additional expense for farmers who did not have bamboo plants.

Releasing ducks in rice fields 35–40 d after planting was also not practiced by transplanters (96%) and direct seeders (56%). Those who used transplanting said that the ducks destroyed the rice plants. Direct seeders said that ducks caused their skin to itch.

When asked about other GAS management practices, the respondents said that, aside from those mentioned in the GAS primer, transplanters (67%) and direct seeders (74%) sprayed nonselective molluscicides (Table 2). Other respondents said that they came up with their own concoctions of indigenous plant materials such as the use of *kakawate* (*Gliricida sepium)*, rice hull, mahogany seeds, or stems of papaya (*Carica papaya*) to inhibit, repel, or kill GAS.

The most effective method considered by transplanters (56%) and direct seeders (63%) to control GAS was the use of molluscicides (Table 3). Handpicking of GAS at any stage of the rice plant followed, but this was second. The transplanters reasoned that chemical spraying was easier to do than laborious handpicking.

## New strategies in managing GAS

GAS can also be a nutritious food for animals and humans. It can also be used to manage weeds in fields where it has already established its population.

**Table 1. GAS management practices used by farmers in Nueva Ecija, Philippines.**

| Management option[a] | Transplanting | | Direct seeding | |
|---|---|---|---|---|
| | Using (%) | Not using (%) | Using (%) | Not using (%) |
| High seeding rate in wetbed method | 82 | 16 | 74 | 24 |
| Raised seedbeds in wetbed method | 50 | 46 | – | – |
| Pasturing of ducks after harvest | 62 | 38 | 65 | 33 |
| Handpicking GAS shells before final harrowing | 53 | 47 | 61 | 37 |
| Destroying GAS egg clusters before final harrowing | 65 | 35 | 79 | 19 |
| Constructing depressed strips before final harrowing | 35 | 64 | 86 | 12 |
| Transplanting older seedlings | 39 | 61 | – | – |
| Installing screens in water inlets after crop establishment | 10 | 90 | 24 | 74 |
| Placing bamboo sticks along bunds | 15 | 85 | 28 | 70 |
| Releasing ducks in rice fields 35–40 d after transplanting | 4 | 96 | 42 | 56 |

[a]Totals in some responses do not add up to 100% as some respondents gave a "do not know" response.

**Table 2. Other GAS management methods used by farmers in Nueva Ecija, Philippines.**

| Management option[a] | Transplanting | | Direct seeding | | Total | |
|---|---|---|---|---|---|---|
| | Number | Percent | Number | Percent | Number | Percent |
| None | 25 | 18 | 16 | 19 | 41 | 18 |
| Spray chemicals | 95 | 67 | 63 | 74 | 158 | 71 |
| Use rice hull | 2 | 1 | 1 | 1 | 3 | 1 |
| Drain the field whenever GAS is observed | 4 | 3 | 1 | 1 | 5 | 2 |
| Apply common salt to GAS eggs | – | – | 1 | 1 | 1 | 0.4 |
| Practice dry seeding | – | – | 1 | 1 | 1 | 0.4 |
| Put kakawate leaves | 1 | 1 | – | – | 1 | 0.4 |
| Put mahogany seeds and soap | 1 | 1 | – | – | 1 | 0.4 |
| Mix chlorox with agrochemicals and drain field | 2 | 1 | – | – | 2 | 1 |
| Drain water from field | 3 | 2 | – | – | 3 | 1 |
| Apply fertilizer | 6 | 4 | – | – | 6 | 3 |
| Place papaya stems to attract GAS | 1 | 1 | – | – | 1 | 0.4 |
| Total | 140 | 99 | 83 | 97 | 223 | 99 |

[a]Multiple responses.

**Table 3. GAS management options regarded effective by farmers in Nueva Ecija, Philippines.**

| Management option | Transplanting | | Direct seeding | | Total | |
|---|---|---|---|---|---|---|
| | Number | Percent | Number | Percent | Number | Percent |
| Chemical application | 79 | 56 | 52 | 63 | 131 | 58 |
| Handpicking | 49 | 35 | 24 | 29 | 73 | 33 |
| Drying of land | 5 | 3 | 4 | 5 | 9 | 4 |
| Fertilizer application | 4 | 3 | – | – | 4 | 2 |
| Dry seeding | – | – | 1 | 1 | 1 | 0.4 |
| Irrigating a little only | 1 | 1 | – | – | 1 | 0.4 |
| None | 2 | 1 | 2 | 2 | 4 | 2 |
| Total | 140 | 99 | 83 | 100 | 223 | 99.8 |

*As food*

In Hawaii, a project focused on controlling GAS infestation by processing GAS into human food (Tamaru et al 2005). GAS were fed with five types of feed regimen (lettuce + chicken, chicken feed, catfish feed, trout feed, and mahimahi feed). In another field test, the snails were given taro tops, catfish feed, and trout + chicken feed.

The taste and texture of GAS were assessed through a taste test in a four-star hotel, the Princeville Resort, in Hanalei, Kauai. The chef was asked to prepare dishes at his discretion using the snails from the feeding trials. The dishes were prepared as appetizers. The snails given catfish feed were superior to all other snails in both taste and texture.

In the Philippines, PhilRice developed a recipe for *chicharon* (pork cracker). This is unique in that it produced a cracker that is devoid of water, has no offensive odor, has a longer shelf life, and can be used as an ingredient for other Filipino recipes (dela Cruz and Joshi 2000).

*As weed control*

Although GAS occurrence has many disadvantages, there are some positive aspects. In the transplanted rice system, GAS show promise as an agent for paddy weeding. In Japan, two to three snails per 1-$m^2$ area successfully controlled rice weeds (Okuma et al 1994a,b). GAS may be used as a "biological weeder" and is popular among organic and some nonorganic farmers in Japan, the Philippines, and South Korea who grow rice without herbicides to produce organic rice (Wada et al 2002).

Resourceful farmers have learned the technique of paddy weeding with snails from various articles in magazines. The use of GAS thus continues to spread among farmers who practice organic and inorganic farming. Benefits from using GAS as a biological weeding agent far exceed those obtained from using ducks or carp (Yusa et al 2003).

Joshi et al (2005a) evaluated the innovation introduced by Korean and Japanese farmers at the PhilRice Central Experimental Station (CES) fields—the use of large fields (0.25 ha each). GAS paddy-weeding effects were demonstrated in several farmers' fields in Nueva Ecija, Aurora, and Negros during the 2003 and 2004 dry (DS) and wet seasons (WS). In the first demonstration of paddy weeding by GAS at PhilRice CES in the 2003 DS, higher weed density was observed at 10 d after transplanting (DAT) in plots with GAS. This was because reentry of water after transplanting was not done. Interestingly, after water was introduced, weed densities at 30 and 45 DAT from plots with GAS were much lower than those in plots without GAS. This implied that the time of water release was an important factor in paddy weeding. No water was added into the field after transplanting for several days. Once weeds had sprouted and grown to 1 cm, water was released into the field. The GAS started to come out from underground to look for food. In the 2003 WS, water release was timed with the emergence of weeds; higher weed density was recorded in plots without GAS from 15 to 45 DAT. Similar patterns in weeding efficiency by GAS were observed during the 2004 DS and WS at PhilRice CES. Moreover, higher rice grain yields for the 2003 and 2004 cropping seasons were recorded in plots with GAS.

With this technology, GAS is converted from being a pest into an ally by altering its behavior so that it becomes a useful organism in the lowland irrigated transplanted rice system. It is necessary to level the field well to control the movement of GAS. Moreover, seedlings should be sturdy and at the three-leaf stage (21 d). This technology does not tell farmers to collect GAS and put them in their rice fields. The practice is not appropriate with direct-seeded rice as rice and weeds sprout at the same time. Moreover, it cannot be done in an upland environment (where GAS is inside the soil) and in flood-prone areas (where water depth is difficult to control).

We have documented through video the step-by-step deployment of *P. canaliculata* for paddy weeding in transplanted rice fields (see www.openacademy.ph/elearning/golden kuhol). All available GAS information was compiled on a readily accessible electronic format such as CD and at the Web site www.applesnail.net under the Pest Alert Section and at the National Biological Information Infrastructure GAS page, which includes the option to download the database at the following URL: www.invasivespecies.nbii.gov.goldenapplesnail.html).

## Summary and conclusions

Once GAS has established its presence, its control is not easy. The economic, health, and environmental problems caused by GAS invasion are irreversible and the cost to remedy these is enormous. Conventional management practices to manage GAS are labor-intensive, uneconomical, and nonsustainable, and many are harmful to the environment. New options, however, are now being introduced that are environment-friendly and cost-effective. For example, the use of GAS for paddy weeding is a promising management option in rice fields where GAS is already present. Moreover, GAS can be used as food for humans and animals.

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## Important GAS links

*Apple snail web site*
www.applesnail.net
www.applesnail.net\content\pest_alert\pest_alert.htm

*Aquatic Species Introductions Database from FAO*
www.fao.org/scripts/acqintro/query/retrive.idc

*CGIAR-SPIPM web site*
www.spipm.cgiar.org
www.runetwork.de/contribution. php?location=SPIPM_Interactive&language=english&cid=1755

*ECOPORT web site*
www.ecoport.org/EP.exe$PictShow?ID=35024

*Global Invasive Species Database from New Zealand*
www.issg.org/

*IRRI Knowledge Bank*
www.knowledgebank.irri.org/troprice/golden_apple_snail.htm

*National Biological Information Infrastructure (NBII)-USGS*
www.invasivespecies.nbii.gov
www.invasivespecies.nbii.gov/goldenapplesnail.html

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# PMK(R)3—an early-maturing, drought-tolerant rice variety for Tamil Nadu, India

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Rice is cultivated as a rainfed crop in the districts of Ramanathapuram and Sivaganga in southern Tamil Nadu. The success of rainfed rice cultivation depends on receiving sufficient rainfall at critical growth stages of the crop. Rice lands in Tamil Nadu often suffer from premature withdrawal of monsoons. The rice crop is thus subjected to varying degrees of drought stress, and this affects yield greatly. To minimize yield loss during years of significant deviation from normal rainfall, rice varieties with improved drought tolerance are needed.

PMK(R)3 (Paramakudi), an early-maturing (107–118 d) rice variety developed at TNAU, is capable of fulfilling this need. Derived from UPLRi /CO 43, it has recorded a mean grain yield of 3.0 t $ha^{-1}$ from 83 trials. These trials were conducted across years and locations, with a 13% and 17% yield increase over local drought-tolerant check varieties PMK 2 and TKM 11, respectively (Table 1). Under direct-sown conditions in the national coordinated trials, it gave the highest yields in 1995-96 and 1998-99, 12% and 26% more than the early-maturing national checks, Annada and Tulasi. PMK(R)3 was released as a new variety for cultivation in Tamil Nadu.

This semidwarf (100–110 cm), nonlodging variety is ideal for areas where there is occasional flooding during the later phase of crop growth. It tolerates leaf blast and sheath rot under field conditions and is resistant to whitebacked planthopper under laboratory conditions. It also has higher field tolerance for leaffolders and stem borers than local check PMK2 (data not shown).

PMK(R)3 has glumes that are purple at flowering and that turn golden yellow with purple streaks at maturity. Kernels are white. Grain type is long bold (length-breadth ratio of 3.12), resulting in high endosperm yield (70%) after milling. Its amylose content is high (27%). There is good consumer preference because of its highly acceptable organoleptic characters. PMK(R)3 is suitable in drought-prone areas, as evidenced by its superior performance in eight crop seasons from 1992 to 2002 (Table 2). In 1998-99, PMK(R)3 recorded a maximum yield increase of 33% over check variety PMK2.

Monsoon rains greatly influence rice productivity in the rainfed ecosystem. Under such circumstances, varieties should be able to perform well under varied drought-stress conditions. PMK(R)3 possesses good stress tolerance and has quick recovery and high yield potential with stability across seasons. It was found to be highly suitable for cultivation by Tamil Nadu's resource-poor farmers.

**Table 1. Performance of PMK(R)3 in different variety trials.**

| Trial | Trials (no.) | Grain yield (t $ha^{-1}$) | | | % increase over check | |
|---|---|---|---|---|---|---|
| | | PMK(R)3 | PMK2[a] | TKM11[a] | PMK2 | TKM11 |
| On-station | 8 | 2.8 | 2.4 | – | 18 | – |
| Multilocation trials (rainfed) | 7 | 2.3 | 2.2 | 2.3 | 7 | –1 |
| Multilocation trials (semidry) | 5 | 2.4 | 2.2 | 2.0 | 10 | 23 |
| Adaptive research trials | 40 | 3.8 | 3.5 | 2.9 | 8 | 30 |
| On-farm trials | 23 | 3.7 | 3.2 | – | 19 | – |
| Mean | 3.0 | 2.7 | 2.4 | | 13 | 17 |

[a]Drought-tolerant check varieties.

Table 2. Performance of PMK(R)3 at Agricultural Research Station, Paramakudi, TNAU, India.

| Year | Seasonal rainfall (mm) | Rainfall | | Dry-spell occurrence–standard weeks | Growth stage at which stress occurred | Mean yield of PMK(R)3 ($t\ ha^{-1}$) | Mean yield of check PMK2 ($t\ ha^{-1}$) | % increase over check |
|---|---|---|---|---|---|---|---|---|
| | | Received during critical phase (mm) | Deviation from the mean (%) | | | | | |
| 1992-93 | 523.9 | 341.8 | 23 | 50th–52nd | Grain filling | 2.5 | 2.3 | 5 |
| 1993-94 | 897.2 | 541.8 | 95 | 50th–52nd | Grain filling and ripening | 3.0 | 2.7 | 10 |
| 1994-95 | 433.2 | 87.6 | −68 | 47th–52nd | Postflowering | 2.2 | 2.2 | 1 |
| 1997-98 | 862.2 | 422.9 | 53 | 51st–52nd | Ripening | 2.9 | 2.5 | 18 |
| 1998-99 | 661.1 | 445.1 | 61 | 51st | Grain filling | 3.0 | 2.3 | 33 |
| 1999-2000 | 595.7 | 128.5 | −54 | 46th–49th | Flowering, grain filling | 2.8 | 2.2 | 27 |
| 2000-01 | 554.1 | 272.0 | −2 | 44th–46th, 49th–51st | Flowering, grain filling | 3.0 | 2.5 | 20 |
| 2001-02 | 493.0 | 312.85 | 13 | 48th–50th | Grain filling, dough | 3.5 | 2.9 | 21 |

# Hardinath 1, an early-maturing rice genotype released in Nepal

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In Nepal, rice, with an annual production of 4.45 million t from 1.56 million ha, ranks first among the crops grown in the country (MOAC 2004). Early-maturing genotypes are grown mainly during *chaite* (spring) and *bhadaiya* (summer) seasons under irrigated conditions. Nearly 21% of total cultivated land is under irrigation.

Cultivation of chaite-season rice is limited because of poor quality and low yield. However, a single variety, Ch 45, has been planted since the late 1950s in most parts of the country.

In 1998, brown planthopper damaged the monocrop, causing heavy losses in Chitwan District. In 2002, neck blast affected Ch 45 in 40% of the rice area in Chitwan. To improve production and productivity, suitable, early-maturing, and high-yielding genotypes with better grain quality were required in these areas.

Adoption of early-maturing genotypes contributed to the total increase in rice production in most Asian countries in the last two decades. So far, eight early-maturing rice genotypes have been released for chaite and bhadaiya cultivation in Nepal. These genotypes, however, were not popular among farmers because of their poor quality. In 2004, Sri Lankan variety BG1442 (BG951//3348/BW-288-1-3) was released as Hardinath 1, after being evaluated in the International Irrigated Rice Observational Nursery in 1997. It produced a grain yield of 4.5 $t\ ha^{-1}$ and was subsequently evaluated in three locations for a year.

The performance of Hardinath 1 was superior to that of popular checks Ch 45 and Chaite 4 in terms of grain yield, disease reaction, and quality. The overall mean yield of Hardinath 1 was 4.6 $t\ ha^{-1}$; that of Ch 45 was 3.7 $t\ ha^{-1}$ (Table 1).

Table 1. Mean yield ($t\ ha^{-1}$) performance at various locations and disease reaction of different genotypes.

| Characteristic | BG1442 | Ch 45 | Chaite 4 |
|---|---|---|---|
| *Yield* | | | |
| Parwanipur | 4.5 | 3.7 | 3.6 |
| Naldung | 5.1 | 4.0 | 4.0 |
| Syangja | 4.2 | 3.3 | 3.1 |
| Overall mean | 4.6 | 3.7 | 3.6 |
| *Disease reaction* | | | |
| Leaf blast | Resistant | Susceptible | Resistant |
| Neck blast | Resistant | Moderately susceptible | Resistant |
| Bacterial leaf blight | Moderately resistant | Moderately susceptible | Resistant |

Both Hardinath 1 and Chaite 4 have slender grains, intermediate amylose, and low alkali value. Hardinath 1 has 65.8% milling recovery and 64.9% head recovery (Table 2). It is resistant to leaf blast and neck blast, and moderately resistant to bacterial leaf blight (Table 1). Hardinath 1 is becoming popular in the terai (plain area), valleys, and river basins because of its high yield, disease resistance, and suitability for double-rice and rice-vegetable cropping systems. This variety is fast replacing Ch 45 in Chitwan and Jhapa districts.

**Table 2. Grain quality characteristics of different genotypes.**

| Characteristic | BG1442 | Ch 45 | Chaite 4 |
|---|---|---|---|
| Milling (%) | 65.8 | 69.5 | 62.4 |
| Head recovery (%) | 64.9 | 65.3 | 55.6 |
| Kernel length (mm) | 6.3 | 5.7 | 6.5 |
| Kernel breadth (mm) | 3.3 | 2.9 | 3.3 |
| Length/breadth | 1.9 | 2.0 | 2.0 |
| Alkali spreading value | 2.2 | 3.2 | 2.3 |
| Water uptake | 140 | 157 | 148 |
| Amylose (%) | 26.2 | 25.2 | 23.9 |

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# Kadous: an aromatic, high-yielding variety with good cooking quality

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In Iran, rice is an important source of carbohydrate, next to wheat. In recent years, rice production in Iran increased from 2.4 million t (2000) to 3.3 million (2003). This came from an area of 615,000 ha. This sudden increase in rice production and productivity is attributed to the wide-scale adoption of improved varieties. Furthermore, with Iran's economic boom, consumer preference has been toward premium-quality rice. Therefore, rice breeders needed to develop varieties with superior cooking quality features that match those of traditional landraces such as Hashemi, Musa Tarom, and Hassani, while keeping the yield level close to that of improved semidwarf varieties. Through this strategy, it is possible to partially replace traditional landraces (60% of the country's total area) with improved rice varieties having the same cooking quality.

IRRI bred 185 superior-quality advanced generation materials and these were sent to Iran in 1994 through the Iran-IRRI project. The evaluation of yield, cooking, and adaptability traits was conducted at the rice research institutes of Iran, Rasht, and Amol.

Kadous IR64669-153-2-3 was a product of careful and rigorous evaluation carried out for nearly 10 y. It is a new high-yielding variety with superior grain and cooking quality identified from the 185 advanced generation materials received from IRRI. This entry came from a single plant selection of IR64669, which in turn was a selection derived from a cross between Pusa 615-140-10-1 and IR54781-309-3-3-3-3. The materials received went through observational nursery and preliminary yield trials (PYT) during 1994-95.

In the PYT, Kadous yielded 5.8 t $ha^{-1}$, higher than the yields of improved varieties Khazar (5 t $ha^{-1}$) and Bejar (5.2 t $ha^{-1}$).

At six sites in Guilan and Mazandaran provinces, entry IR64669-153-2-3 was evaluated under multienvironment yield trials for 2 consecutive years (1996-97). Pooled analysis of these trials (averaged over sites and number of years) revealed significant differences ($P \leq 5$) in yield (Table 1). IR64669-153-2-3 performed consistently, yielding an average of 5.6 t $ha^{-1}$ at three on-farm trial sites (data not shown); this was a 12.5% yield advantage over Khazar (improved variety) (Table 2) and 20.2% over Binam (traditional check variety).

The Eberhart and Russell (1966) method was adopted to verify the yield stability of this entry. The agronomic package involved a hill spacing of 25 cm row-to-row and 25 cm hill-to-hill, and 90-50-50 kg NPK ha$^{-1}$. Grain yield was 2 t ha$^{-1}$, which was more than that of local traditional landraces. Its maturity duration (125 d) was 1 wk earlier than Khazar's. Kadous was released for cultivation in Iran's Guilan and Mazandaran provinces in 2004 by the Ministry of Agriculture and the Agricultural Research and Education Organization. It is an aromatic, semidwarf (110 cm), blast-resistant, and medium-duration variety (125 d) with 18 productive tillers, 127 grains per panicle, and good grain and cooking quality (Table 3). However, for grain quality traits, Kadous was much closer to traditional landrace Hashemi. Interestingly, the cooked and uncooked kernels of Kadous were longer but narrower than Hashemi's. This indicates a better phenotype that appeals to both consumers and millers. In addition, the gel consistency and gelatinization temperature values of Kadous explain its characteristic softness upon cooking, a trait much preferred by Iranian consumers.

**Table 1. Pooled analysis of variance for yield data under adaptive research trials conducted at six different sites over 2 y.**

| Source of variation | Degrees of freedom | Mean square[a] |
|---|---|---|
| Year | 1 | 87.715 ns |
| Site | 5 | 148.224 ns |
| Year × site | 5 | 45.064** |
| Error (1) | 36 | 0.580 |
| Variety | 8 | 1.004* |
| Variety × year | 8 | 0.701 ns |
| Variety × site | 40 | 0.491 ns |
| Variety × year × site | 40 | 0.455** |
| Error (2) | 288 | 0.188 |
| CV % | | 7.80 |

a*,** = significant at the 5% and 1% level, respectively; ns = nonsignificant.

**Table 2. Yield performance of Kadous in adaptive research trials conducted at six different sites, 1996-97.**

| Site | Av yield (t ha$^{-1}$) (2 y) | | |
|---|---|---|---|
| | Kadous | Khazar (check) | % increase over check variety |
| Rasht | 4.98 | 4.01 | 24.1 |
| Fouman | 3.69 | 3.09 | 19.3 |
| Astaneh | 4.33 | 3.17 | 36.4 |
| Amol | 6.19 | 6.06 | 2.2 |
| Tonkabon | 7.00 | 6.58 | 6.4 |
| Sari | 7.29 | 6.86 | 6.3 |
| Mean | 5.58 | 4.96 | 12.5 |

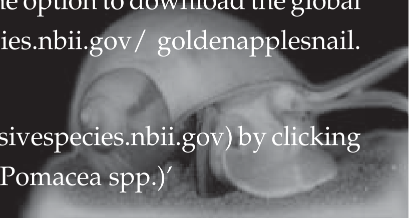
## Reference

Eberhart SA, Russell WL. 1966. Stability parameters for comparing varieties. Crop Sci. 6:36-40.

**Table 3. Agronomic and grain quality characteristics of Kadous in comparison with those of traditional and improved checks.**

| Characteristic[a] | Kadous | Hashemi[b] | Khazar[c] |
|---|---|---|---|
| Agronomic traits | | | |
| Plant height (cm) | 110 | 140.6 | 119 |
| Productive tillers plant$^{-1}$ (no.) | 18 | 11.1 | 13.2 |
| Maturity (d after sowing) | 125 | 125 | 132 |
| Grains panicle$^{-1}$ (no.) | 127 | 90.2 | 140.2 |
| Grain quality traits | | | |
| Total milled rice recovery (%) | 67.00 | 68.53 | 67.36 |
| Milled head rice recovery (%) | 51.00 | 53.15 | 52.21 |
| Broken rice (%) | 16.00 | 15.38 | 15.15 |
| Shape | Long slender | Long slender | Long slender |
| Aroma (present/absent) | Present | Present | Absent |
| Grain length (mm) | 10.9 | 9.9 | 9.8 |
| Kernel length (mm) | 8.06 | 7.41 | 7.14 |
| Kernel width (mm) | 1.86 | 2.04 | 1.94 |
| Kernel length/width | 4.33 | 3.63 | 3.68 |
| Cooked kernel length (mm) | 12.32 | 11.88 | 10.62 |
| Cooked kernel width (mm) | 2.86 | 2.9 | 2.88 |
| Cooked kernel length/width | 4.30 | 4.09 | 3.69 |
| Elongation ratio (lengthwise) | 1.53 | 1.60 | 1.49 |
| Amylose (%) | 23.8 | 21 | 22 |
| Gel consistency (gel length in mm) | 52 | 45 | 55 |
| Gelatinization temperature (alkali spreading value score) | 3.3 | 3.5 | 4.2 |

[a]All traits measured according to IRRI's (1996) *Standard evaluation system for rice.* [b]Hashemi = traditional landrace check. [c]Khazar = improved varietal check.



**Good news** for GAS researchers in the rice world! Check out the new NBII Invasive Species Information Node website and the links to the golden apple snail (GAS, Pomacea spp.-IAS.

You can find the NBII's golden apple snail (GAS) page, which includes the option to download the global information database on GAS at the following URL: http://invasivespecies.nbii.gov/ goldenapplesnail.html

And you can also navigate to this page from the home page(http://invasivespecies.nbii.gov) by clicking 'data' then databases' then 'Information Database on Golden Apple Snail (Pomacea spp.)'

# Purification of Sahdyari rice hybrid parental lines through paired crosses for nucleus seed production

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The availability of genetically pure and good-quality seed is a primary prerequisite for exploiting the potential of hybrids. Lack of purity in parental lines and improper isolation conditions in seed production result in poor hybrid seed quality. Chinese scientists reported that, with every 1% decrease in the purity of hybrid seed, the eventual yield loss in $F_1$ hybrids would be about 100 kg $ha^{-1}$ (Sharma 1995).

In 1998, RARS-Karjat identified and released a rice hybrid from the cross IR58025A/BR827-35-3-1-1-1R—Sahdyari—for commercial cultivation in Maharashtra State. Maintaining or improving the purity of the parental lines of Sahdyari was a major challenge. Thus, efforts were made to purify the three parental lines of Sahdyari through paired crosses.

The purification program through paired crosses took place from 1999 to 2003. The crosses made in the 1999, 2000, 2001, 2002, and 2003 kharif were evaluated during the 2000, 2001, 2002, and 2003 kharif, and during 2003-04 rabi, respectively. The paired crosses of Sahdyari rice hybrid were made by using its parental lines—IR58025A, IR58025B, and BR827-35-3-1-1-1R. The paired crosses made in 1999, 2000, 2001, 2002, and 2003 were 103, 100, 112, 140, and 130, respectively. Every year, A × B and A × R crosses were made using the selected plants of A, B, and R lines of Sahdyari rice hybrid on a plant-to-plant basis. Around 100 crossed seeds were produced from each pair of A × B and A × R crosses. An individual plant from each line was used as the female parent in making A × B and A × R crosses, and plants from a bulk of selections in the preceding cycles were used in making paired crosses. Half the quantity of seed from each A × B cross was sown in the identification nursery, whereas the remaining half was kept for sowing in the multiplication nursery (21 d later). All paired A × B and A × R crosses were grown in progeny rows of 20 plants each at 20 × 15-cm spacing. The standard agronomic practices and plant protection measures were followed in raising the crop. Data on spikelet fertility were collected on all paired-cross progenies in the identification nursery. One panicle from each plant was bagged before flowering, the anthers were squashed in 1% iodine-potassium solution, and then the sterile and fertile pollens were screened under a microscope to estimate pollen fertility. In the multiplication nursery, the remaining seeds of A × B were sown 21 d after seeding in the identification nursery. Seedlings of A lines were planted in an isolated plot along with the respective maintainer (B) lines. Based on observations on A × B and A × R crosses of Sahdyari rice hybrid in the identification nursery, appropriate plants were tagged. The plants and respective lines that lacked uniformity in growth, deviated in flowering behavior, and showed instability for complete male sterility in A × B crosses and complete fertility in A × R crosses were identified and removed, along with the corresponding B and R lines before flowering. The remaining A × B and A × R pairs (and their maintainers and restorers) were allowed to cross-pollinate; supplementary pollination was done to enhance the seed set. The bulked seeds of A × B were retained as nucleus seeds of the cytoplasmic male sterile (CMS) lines. The B and R lines were harvested separately to get the nucleus seed of the maintainer and restorer lines, respectively.

The table shows an evaluation of the progeny of paired crosses of Sahdyari rice hybrid parental lines from 2000 to 2003-04. In 1999 kharif, the sterility in base plants of IR58025A was 90%. The following years, 95.2% spikelet sterility was noted in IR58025A lines and 96.8% fertility was observed in the $F_1$ seed of Sahdyari rice hybrid. Spikelet sterility then increased to 100% in subsequent paired-cross cycles of 5 y. Similarly, spikelet fertility improved from 96.8% to 99.2% in Sahdyari $F_1$ seed. The percentages of sterility and fertility were calculated on the basis of number of sterile/fertile individuals among the plants observed. The pure seed produced through paired crosses in each year was used to effect further paired-cross cycles. Maximum sterility (100%) was observed in all progenies after a 5-y successive paired-cross cycle (A × B). Maximum fertility (99.2%) was observed in $F_1$ (A × R) Sahdyari rice hybrid seed during 2003-04 rabi. On the other hand, maximum impurity (4.9%) in line IR58025A was observed in the 2000 paired-cross evaluation, which dropped to 0% during 2003-04 rabi after five paired-cross cycles. The 100% pure IR58025A plants were used for nucleus seed multiplication. To maintain IR58025A line and Sahdyari $F_1$ seed production, pure seed obtained from selected B and R plant progenies was used, respectively. The maximum yield potential was obtained from using 100% pure seed of the A line. The amount of pure seed of A, B, and R lines produced from each paired-cross cycle is shown in the table. The nucleus seed produced through paired-cross cycles of the respective parental lines of Sahdyari rice hybrid was used for further breeder seed production of the respective lines every year. This procedure was successful in improving the purity of the parental lines of Sahdyari.

**Evaluation of paired crosses of Sahdyari rice hybrid parental lines from 1999 to 2003-04.**

| Year | Cross combination | Paired crosses (no.) | Plants from paired-cross progenies evaluated for fertility and sterility (no.) | Sterile plants observed (%) | Fertile plants observed (%) | Impurity observed (%) | Seed quantity obtained from paired-cross progenies (kg) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | A (A × B) | $F_1$ (A × R) | B | R |
| 1999 kharif | a) IR58025A / IR58025B | 103 | – | – | – | – | – | – | – | – |
| | b) IR58025A / BR827-35-3-1-1-1R | 103 | – | – | – | – | – | – | – | – |
| 2000 kharif | a) IR58025A / B | 100 | 2,060 | 95.2 | – | 4.9 | 0.5 | – | 1.8 | – |
| | b) IR58025A / BR827-35-3-1-1-1R | 100 | 2,060 | – | 96.8 | 3.2 | – | 0.8 | – | 2.5 |
| 2001 kharif | a) IR58025A / IR58025B | 112 | 2,000 | 96.0 | – | 4.0 | 1.7 | – | 3.9 | – |
| | b) IR58025A / BR827-35-3-1-1-1R | 112 | 2,000 | – | 96.7 | 2.4 | – | 1.1 | – | 2.3 |
| 2002 kharif | a) IR58025A / IR58025B | 140 | 2,240 | 98.0 | – | 2.0 | 1.5 | – | 4.4 | – |
| | b) IR58025A / BR827-35-3-1-1-1R | 140 | 2,240 | – | 97.6 | 2.9 | – | 1.6 | – | 4.6 |
| 2003 kharif | a) IR58025A / IR58025B | 130 | 2,800 | 99.3 | – | 0.7 | 2.2 | – | 5.2 | – |
| | b) IR58025A / BR827-35-3-1-1-1R | 130 | 2,800 | – | 98.6 | 1.5 | – | 2.4 | – | 5.9 |
| 2003-04 kharif | a) IR58025A / IR58025B | – | 2,600 | 100.0 | – | 0.0 | 1.9 | – | 4.7 | – |
| | b) IR58025A / BR827-35-3-1-1-1R | – | 2,600 | – | 99.2 | 0.8 | – | 2.2 | – | 4.9 |

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# Evaluation of sulfonylurea herbicides to control weeds in transplanted rice

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Rice is an important food crop in India, but its average yield is rather low. It faces various production constraints, including competition from weeds that can reduce yield by 25–53%. Infestation commonly occurs 15–45 d after transplanting (DAT) (Subhaiah and Sreedevi 2000).

In recent years, a number of preemergence herbicides, including butachlor and thiobencarb, were applied to control weeds. These herbicides effectively controlled many grass weeds, except for some sedges and broadleaves.

Repeated use of herbicides may have resulted in weeds developing resistance and shifts in weed flora, leading to low weed control efficiency (Kathiresan 2001). The current study examined a wider range of herbicides.

An experiment was done during the 2001-02 rainy season at the IAS research farm to find the efficacy of low doses of herbicides on the different weed flora in transplanted rice. Soil at the experimental site was sandy clay loam with pH 7.3, 0.44% organic carbon, and 205 kg N $ha^{-1}$, 6.6 kg P $ha^{-1}$, and 193.4 kg available K $ha^{-1}$. The study included 16 weed control treatments: metsulfuron methyl (MSM; Algrip: 20% WP at 4, 6, and 8 g ai $ha^{-1}$); chlorimuron ethyl (CME; Cloben: 25% WP at 10, 15, and 20 g ai $ha^{-1}$); MSM + CME; (2,4-D) Almix: 20% WP at 15, 20, and 25 g ai $ha^{-1}$); MSM + 2,4-D ester (Algrip + Knockweed at 4 + 500 g ai $ha^{-1}$); CME + 2,4-D; Cloben + Knockweed at 10 + 500 g ai $ha^{-1}$); MSM + CME + 2,4-D (15 + 500 g ai $ha^{-1}$), anilofos (400 g ai $ha^{-1}$); anilofos + 2,4-D (400 + 500 g ai $ha^{-1}$); hand weeding (20, 40, and 60 DAT); and weedy check. The field was flooded after dry-plowing twice. It was then puddled twice with a disc harrow, followed by planking. The experiment was laid out in a randomized block design with three replications.

Variety Sarju 52 was used in the experiment. One-third of the recommended dose of N (40 kg $ha^{-1}$) and the full doses of P (26.4 kg $ha^{-1}$) and K (49.8 kg $ha^{-1}$) were applied before transplanting. The remaining amount of N was topdressed in two equal splits at active tillering and at panicle initiation.

Herbicides were applied as preemergence 8 DAT using 500 L of water $ha^{-1}$ with a knapsack sprayer fitted with a flat fan nozzle. During herbicide application, water-level depth in the field was maintained at 5 ± 2 cm throughout crop growth. Data on total weed population and weed biomass were taken during harvest from 0.5 m × 0.5-m quadrats at two randomly selected places.

The results for 2001-02 were not significantly different and were pooled for analysis. The most important weed species found in the experimental field were *Echinochloa crus-galli, E. colona, Cynodon dactylon, Cyperus rotundus, Cyperus difformis, Fimbristylis miliacea, Amaranthus viridis, Ludwigia parviflora,* and *Ammania baccifera*. All weed control treatments significantly reduced the weed population of grasses, sedges, and broadleaf weeds as compared with the unweeded check (Table 1). MSM + CME + 2,4-D (15 + 500 g ai $ha^{-1}$) reduced the population of *E. colona* and *E. crus-galli* and was superior to other chemical treatments in controlling grass weeds.

MSM + CME (25 g ai $ha^{-1}$) was effective against sedges *C. difformis, C. rotundus*, and *F. miliacea*, and significantly better than other herbicide treatments, except for MSM + CME + 2,4-D. In controlling *A. baccifera*, MSM + CME (20 and 25 g ai $ha^{-1}$) was effective and on a par with MSM + CME + 2,4-D (15 + 500 g ai $ha^{-1}$), and was better than other herbicide treatments.

All weed control treatments significantly reduced total weed density and dry matter. MSM + CME + 2,4-D (15 + 500 g ai $ha^{-1}$) reduced both total weed number (by 79%) and weed weight (by 78%) compared with the weedy check. At lower doses, the MSM and CME treatments recorded the highest total weed density because of their poor efficacy on grasses and sedges. This confirms the findings of Mukherjee and Bhattacharya (1999).

Herbicide application resulted in significantly higher grain and

**Effect of treatments on distribution of weed flora, weed biomass, and grain and straw yields in transplanted rice (pooled data of 2 y).**

| Treatment | Dose (g ha$^{-1}$) | Grasses (no. m$^{-2}$) | | Sedges (no. m$^{-2}$) | | | Broad-leaved weed (no. m$^{-2}$) | | Total weed density (no. m$^{-2}$) | Total weed biomass (g m$^{-2}$) | Grain yield (t ha$^{-1}$) | Straw yield (t ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Echinochloa colona* | *E. crus-galli* | *Cyperus rotundus* | *C. difformis* | *Fimbristylis miliacea* | *Ammania baccifera* | *Ludwigia parviflora* | | | | |
| Unweeded | – | 5.8 | 3.2 | 7.5 | 4.9 | 2.8 | 5.2 | 3.6 | 14.0 | 105.5 | 3.2 | 4.2 |
| Hand weeding (20, 40, and 60 DAT) | – | 2.1 | 1.0 | 2.1 | 1.6 | 1.6 | 1.9 | 1.8 | 5.5 | 24.2 | 5.9 | 7.2 |
| MSM | 4 | 4.3 | 3.4 | 5.9 | 3.4 | 2.9 | 2.4 | 2.2 | 10.5 | 48.6 | 3.6 | 4.7 |
| MSM | 6 | 3.8 | 2.8 | 5.7 | 3.3 | 2.5 | 2.4 | 2.0 | 10.1 | 44.1 | 4.2 | 5.5 |
| MSM | 8 | 3.4 | 2.6 | 5.6 | 3.1 | 2.9 | 1.7 | 1.5 | 9.6 | 38.1 | 4.5 | 6.1 |
| CME | 10 | 3.6 | 2.7 | 5.8 | 3.3 | 2.7 | 2.4 | 2.0 | 10.2 | 46.2 | 3.8 | 5.3 |
| CME | 15 | 3.6 | 2.6 | 5.3 | 3.0 | 2.3 | 2.2 | 1.6 | 9.3 | 39.5 | 4.2 | 5.7 |
| CME | 20 | 3.3 | 2.6 | 5.3 | 2.7 | 2.3 | 1.7 | 1.4 | 8.8 | 32.3 | 4.8 | 6.0 |
| MSM + CME | 15 | 3.8 | 3.1 | 5.8 | 3.2 | 2.9 | 2.2 | 1.6 | 10.5 | 40.7 | 4.0 | 5.6 |
| MSM + CME | 20 | 3.2 | 2.5 | 3.7 | 3.0 | 2.4 | 1.1 | 1.3 | 8.3 | 28.7 | 5.3 | 6.6 |
| MSM + CME | 25 | 2.7 | 2.1 | 2.4 | 2.1 | 1.7 | 0.9 | 1.5 | 7.2 | 21.2 | 5.4 | 6.7 |
| MSM + 2,4-D | 4 + 500 | 3.7 | 2.6 | 4.8 | 2.9 | 2.4 | 1.6 | 1.6 | 9.3 | 38.2 | 5.0 | 6.3 |
| CME + 2,4-D | 10 + 500 | 3.4 | 2.4 | 4.7 | 2.8 | 2.4 | 1.6 | 1.5 | 8.9 | 30.8 | 5.1 | 6.4 |
| MSM + CME + 2,4-D | 15 + 500 | 1.9 | 1.4 | 3.9 | 2.8 | 1.7 | 1.2 | 1.2 | 6.4 | 22.3 | 5.8 | 7.1 |
| Anilofos | 500 | 3.8 | 2.7 | 4.0 | 2.9 | 2.4 | 2.5 | 1.8 | 9.4 | 36.2 | 4.4 | 5.7 |
| Anilofos + 2,4-D | 400 + 500 | 3.0 | 1.9 | 4.5 | 2.7 | 2.1 | 2.2 | 1.5 | 8.5 | 30.3 | 5.3 | 6.4 |
| CD ($P$ = 0.05)[a] | | 0.34 | 0.24 | 0.23 | 0.35 | 0.72 | 0.46 | 0.32 | 0.32 | 4.21 | 0.12 | 0.23 |

[a]CD = critical difference.

straw yield (see table). Among herbicide treatments, maximum grain yield (5.8 t ha$^{-1}$) was obtained with MSM + CME + 2, 4-D (15 + 500 g ai ha$^{-1}$), similar to that obtained with hand weeding. Straw yield followed a similar trend, further confirming previous reports (Bhattacharya et al 2002, Rekha et al 2002).

In India, herbicide usage is increasing because of the high labor requirement for hand weeding (50 labor d ha$^{-1}$ × US$1.10) and the scarcity of labor at peak periods of weeding. MSM + CME + 2,4-D (15 + 500 g ai ha$^{-1}$), when applied as preemergence at 8 DAT, can provide good weed control over a range of weed species in transplanted rice.

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# Arbuscular mycorrhizal fungi associated with upland rice in a rotational shifting cultivation system

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A rich diversity of arbuscular mycorrhizal (AM) fungi has been found associated with pada (*Macaranga denticulata* Muell. Arg.), a pioneer tree species used for fallow enrichment in rotational shifting cultivation in the mountainous region of mainland Southeast Asia (Rerkasem et al 2002, Yimyam et al 2003, Youpensuk et al 2004). Association with AM fungi greatly enhanced nutrient uptake in pada growing in an acidic (pH 4.9) and infertile (4 ppm P by Bray II) soil. When N was not limiting, pada plants with AM fungi were found to take up five to six times as much N, P, and K as those without the symbiosis. This paper reports on the diversity of the AM fungi associated with the roots of upland rice growing in a rotational shifting cultivation system at Tee Cha village, Mae Hong Son, northern Thailand (19° 78′ N, 93° 84′ E, altitude 800 m).

From a field of upland rice, local cv *Bue Bang*, just before maturity (October), rhizosphere soil and fine root samples of the rice were collected from four replicated locations with two pada densities (determined at soil/root sampling): dense (6.6 plants $m^{-2}$) and sparse (3.3 plants $m^{-2}$). The rice was grown in a rotational-shifting cultivation system of one in a 7-y cycle (pada was the dominant fallow species). Last February, when the 7-y-old fallow was slashed and burned to prepare for upland rice sowing, the average pada density was 0.4 plant $m^{-2}$ in the dense patches and 0.1 plant $m^{-2}$ in the sparse patches. The root samples were washed over a 2-mm sieve under running water and cut into pieces (1–2 cm length, cleared in 10% KOH at 121 °C for 15 min, and rinsed with water on a fine sieve). Cleared roots were stained with 0.05% trypan blue in lactoglycerol solution at 121 °C for 15 min (Brundrett et al 1996). Thirty pieces of fine roots were randomly taken from each sample and mounted on microscopic slides to assess root colonization (McGonigle et al 1990). Spores of the AM fungi were separated from 2 × 25 g of each soil sample by wet sieving and 50% sucrose centrifugation (Brundrett et al 1996). The spores in the supernatant were then poured onto sucrose before vacuum filtration on filter paper with gridlines. The spores were counted using a stereomicroscope. Taxa were identified through a compound microscope and published AM spore descriptions (Schenck and Perez 1988, INVAM Web pages).

A total of 17 species of AM fungi (five genera) were identified in the upland rice rhizosphere (Table 1). In the rhizosphere of pada, 29 species of AM fungi (six genera) were identified (Youpensuk et al 2004). In pada, *Glomus* was the dominant genus, followed by *Acaulospora*. All species found in the rhizosphere of upland rice were also present in the rhizosphere of pada. Although the AM population in the upland rice rhizosphere was less diverse than the one in pada, it was more diverse compared with the eight types of AM spores seen in upland rice fields in Indonesia (Hartadi 1982). The degree of root colonization by the AM fungi and their spore density in the rhizosphere of upland rice were also less than those in pada (Table 2).

The benefits of the AM fungi on pada have been previously established. When inoculated with a particular population of AM fungi, pada growing on acidic and low-P soil produced five times more dry matter than did uninoculated plants (Youpensuk et al 2004). The presence of pada at high density in the fallow significantly enhanced upland rice yield (Yimyam et al 2003). Upland rice growing in pada patches with a mean density of 0.4 plant $m^{-2}$ before slash-and-burn yielded an average of 3 t $ha^{-1}$ (eight fields, six farms), with a yield of 4.5 t $ha^{-1}$ from one field.

**Table 1. Arbuscular mycorrhizal fungi in the rhizosphere of upland rice and pada, an associated fallow-enriching tree.**

| Genus (no.) | Mycorrhizal fungi species | |
|---|---|---|
| | Upland rice | Pada[a] |
| *Acaulospora* | 4 | 6 |
| *Archaeospora* | 0 | 1 |
| *Gigaspora* | 1 | 2 |
| *Glomus* | 10 | 17 |
| *Paraglomus* | 1 | 1 |
| *Scutellospora* | 1 | 2 |
| Total | 17 | 29 |

[a]Adapted from Youpensuk et al (2004).

**Table 2. Root colonization and spore numbers of arbuscular mycorrhizal fungi in the rhizosphere of upland rice in upland rice fields associated with dense and sparse stands of pada.[a]**

| | AM colonization (%) | | Spore density (spores $g^{-1}$ soil) | |
|---|---|---|---|---|
| | Dense | Sparse | Dense | Sparse |
| Upland rice | 61.0b | 48.5c | 17b | 9c |
| Pada[b] | 83.3a | 81.8a | 32a | 37a |

[a]Means with the same letter are not significantly different at P = 0.05. [b]Adapted from Youpensuk et al (2004).

The mean grain yield of upland rice from sparse pada patches (0.1 plant $m^{-2}$) was only 1 t $ha^{-1}$. Such a beneficial effect of pada on rice yield was observed in fields that completed the 7-y-rotation cycle, but not with fallow fields slashed and burned after 3 y. The study concluded that the effect of pada was cumulative and that 3 y was insufficient. Furthermore, spore density and root colonization in upland rice were higher in dense than in sparse pada patches. Those in pada had no difference, regardless of pada density (Table 2). The AM fungi were also observed to increase nutrient uptake and shoot and root growth in rice (Solaiman and Hirata 1997a,b). In addition, in terms of enhancing the fallow-enriching properties of pada, symbiosis with AM fungi may enhance growth and yield of upland rice. We are investigating the development of symbiosis between the local population of AM fungi in rainfed and upland rice and assessing the effects of this symbiosis on rice nutrient uptake, growth, and yield.

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# Drought-induced shifting of stem borer species in shallow deepwater rice

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The yellow stem borer (YSB) *Scirpophaga incertulas* Walker is a major and ubiquitous rice pest of either deep/semideep or irrigated rice. This species is dominant among the pyralids. A severe drought during the 2002 wet season (WS) (446.5 mm rainfall vs 1,200 mm average) drastically reduced the total adult moth population. From July to September, light trap collections decreased by 93.7%. In spite of these conditions, the semideepwater (SDW) entries showed heavy white ear infestation. We examined the reasons for these variations at the NDUAT research station.

Observations were recorded after panicle emergence in SDW and upland (UL) situations from a similar set of entries transplanted in 3 × 2 m plots in a randomized block design with four replicates. White ear infestation was recorded visually after splitting rice stems obtained from 10 randomly selected hills (see table). Tillers were categorized into three: those with ears and larvae inside the stems are considered hidden infestation (HI); those without borer larvae are regarded as healthy ears (HE); and those having unfilled grains are regarded as white ears (WE). In the split stems, YSB was surprisingly absent; the infestation was dominated by pink stem borers *Sesamia inferens* Wlk. (PSB). This could be explained by the fact that PSB originally prefers a dry environment (Senapati and Panda 1999). An increase in PSB population has also been reported from the drier regions of northern India (DRR 2002). Also, during the 2003 WS, when rainfall improved to 953.3 mm, borer composition again changed under a SDW situation.

Infestation determined visually in different genotypes varied from 4.0–12.5% in SDW to 7.5–32.5% in UL (see table). In the stem-splitting studies under SDW, the highest number of healthy plants was obtained in NDR 4184 (78.6%) and the lowest in NDR 4062 (24.1%). In contrast, %WE was highest in NDR 4062 (35.8%) and lowest in Jal lahri (7.3%). HI was highest in NDR 4201 (39.4%) and lowest in NDR 4184 (7.1%). However, under UL, they performed differently. The highest %HE was noted in NDR 4204 (64.7%) and the lowest in NDR 4008 (14.6%), while the highest %WE was seen in NDR 4008 (50.1%) and the lowest in NDR 4182 (14.8%). HI was highest in Jal lahri (38.7%).

Overall WE was more than double in UL (20.3%) vs SDW (9.4%) because the same larvae can infest more than one shoot under favorable environments. However, NDR 4207, Jal lahri, and NDR 4112 had low infestation levels (7–15%) and behaved similarly in both environments. In contrast, NDR 4008 showed more than three times higher infestation in UL (32.5%) than in SDW (10.0%). Under SDW, the overall mean HI was 30.0% (highest in NDR 4062 [40.1%], lowest in NDR 4184 [7.1%]).

NDR 4112, NDR 4182, NDR 4201, and NDR 4204 were the only genotypes that had >50% HE in both environments. The best genotype under SDW was NDR 4184 (>78% HE). In UL, NDR 4204 performed best (>64.7% HE). These varieties can be used in breeding for tolerance for these pests under different agroecosystems.

**Stem borer infestation (%) in semideep rice genotypes under UL and SDW situations, CRS, Masodha, Faizabad.**[a]

| Genotype | Upland | | | Semideep water | | | Visual infestation | |
|---|---|---|---|---|---|---|---|---|
| | HE | WE | HI | HE | WE | HI | UL | SDW |
| NDR4008 | 14.6 | 50.1 | 35.3 | 50.8 | 13.1 | 36.1 | 32.5 | 10 |
| NDR4062 | 29.5 | 37.4 | 33.1 | 24.1 | 35.8 | 40.1 | 19 | 4 |
| NDR4105 | 30.6 | 36.1 | 33.3 | 48.7 | 18.9 | 32.4 | 27.5 | 12.5 |
| NDR4106 | 37.5 | 34.1 | 28.4 | 57.1 | 17.8 | 24.2 | 20 | 7.5 |
| NDR4110 | 34.2 | 27.4 | 38.4 | 57.6 | 18.2 | 25.1 | 17.5 | 11 |
| NDR4111 | 53.8 | 33.7 | 12.5 | 47.4 | 17.5 | 37.1 | 25 | 11 |
| NDR4112 | 56.8 | 15.1 | 28.1 | 57.4 | 23.1 | 19.5 | 10 | 8.5 |
| NDR4182 | 52.9 | 14.8 | 32.3 | 59.3 | 7.4 | 33.3 | 15 | 9.5 |
| NDR4184 | 49.4 | 31.2 | 19.4 | 78.6 | 14.3 | 7.1 | 25 | 6 |
| NDR4201 | 56.5 | 26.1 | 17.4 | 51.5 | 9.1 | 39.4 | 25 | 5.5 |
| NDR4204 | 64.7 | 25.1 | 10.2 | 55.6 | 14.8 | 29.6 | 27.5 | 12.5 |
| NDR4207 | 47.3 | 40.9 | 11.8 | 52.9 | 20.6 | 26.5 | 15 | 15 |
| NDR4209 | 51.1 | 25.4 | 23.5 | 35.7 | 28.6 | 35.7 | 17.5 | 11 |
| Jal lahri | 41.9 | 19.4 | 38.7 | 58.5 | 7.3 | 34.2 | 7.5 | 7 |
| Mean | 44.3 | 29.8 | 25.9 | 52.5 | 17.5 | 30 | 20.3 | 9.4 |

[a]UL = upland, SDW = semideep water, HI = hidden infestation, WE = white ears, HE = healthy ears.

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# Phosphorus requirements of *Azolla microphylla*

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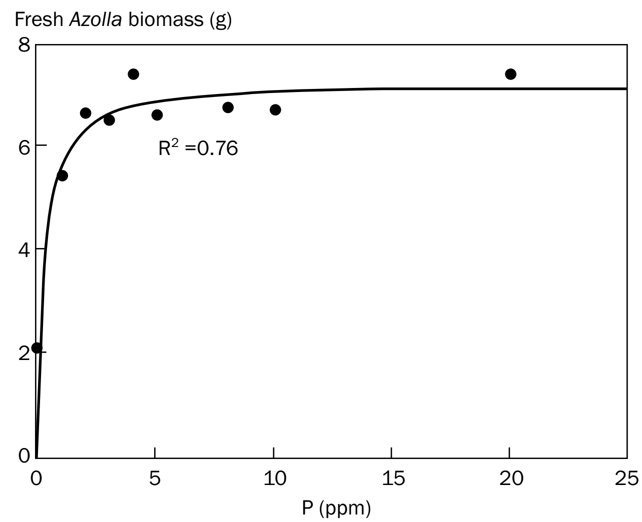
*Azolla*, a free-floating, $N_2$-fixing aquatic fern, is an established N biofertilizer for flooded rice. Phosphorus (P) is the most critical and limiting input for *Azolla*-rice cultivation (Majumdar et al 1993). *Azolla* absorbs P from the floodwater and makes it available to the plant. Different species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

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

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




**Growth of *Azolla microphylla* at different P concentrations.**

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

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

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

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

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# Evaluating sodicity tolerance in rice hybrids


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

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

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

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

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

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

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

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

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

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

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

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

# Can rhizobial inoculation promote rice growth through nitrogen fixation?

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

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

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

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

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

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

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

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

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

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

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

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

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

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


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

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

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

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

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

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

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

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

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

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

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

[a]ns = nonsignificant.

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

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

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

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# Phosphorus nutrition reduces brown spot incidence in rainfed upland rice


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

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

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

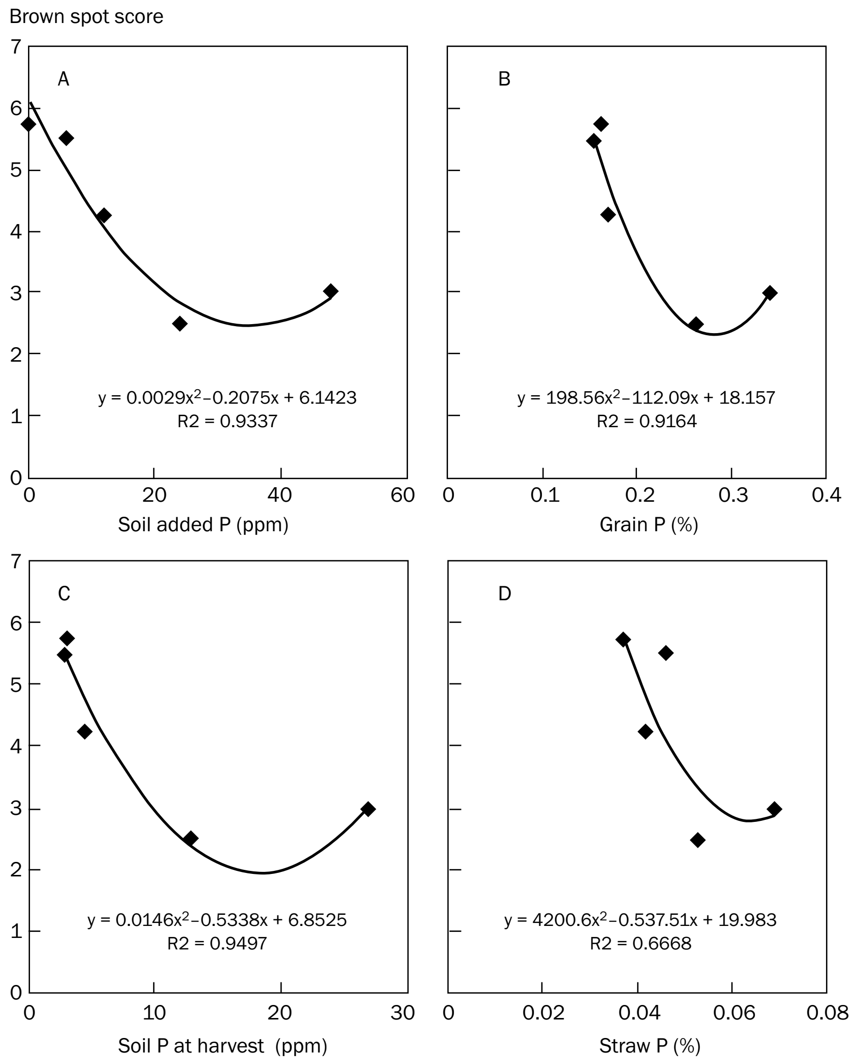
It was found that brown spot incidence was affected significantly by P nutrition in the drought year. The disease declined drastically with an increase in P concentration from 0 to 96 kg ha$^{-1}$. The minimum brown spot incidence was noted at 48 kg P ha$^{-1}$ applied in soil. Results also showed that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

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

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

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

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




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

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# Basal N fertilization increases productivity of rainfed upland rice

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

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

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

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

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

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

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

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

[a]ns = nonsignificant.

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

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

[a]ns = nonsignificant.

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# Short-duration rice varieties adaptable to sodicity


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

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

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

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

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

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

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

**Table 2. Environmental index of tested environments.**

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

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

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

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

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

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# Effect of low-light stress at various growth phases on yield and yield components of two rice cultivars

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Solar radiation has a profound impact on crop growth and productivity. During the rainy season, photosynthesis is generally impaired because of the reduction in light intensity and duration brought about by the excessively cloudy weather. This constitutes a major constraint to rice productivity and production in the tropics (Yoshida 1981, Singh 2000). The solar radiation requirements of a rice crop differ at various growth phases (Yoshida and Parao 1976). Shading during the vegetative growth phase slightly affects rice growth and yield, while shading during the reproductive phase has a pronounced effect on sink capacity (spikelet number per panicle and per unit land area). During ripening, shading markedly reduces grain yield because of a spurt in spikelet sterility (Yoshida 1981).

Rice cultivars adapted to various geographical conditions also differ in their light requirements. Cultivars that are traditionally being grown in the tropics are supposed to have greater tolerance for low-light stress than recently introduced cultivars. Thus, identification of such rice cultivars will be essential in developing high-yielding varieties that can survive in low-radiation conditions during the wet season.

Two rice cultivars—one, a traditional tall variety grown locally (C14-8) and the other, a modern semitall variety (Mansarover)—were evaluated for their growth and yield performance under low-light stress at different growth phases.

Thirty-day-old seedlings of the two cultivars were transplanted in cement pots (30 × 30 cm); these were prepuddled and fertilized with half a dose of N and full doses of P and K during the wet season at CARI. The transplanted pots were kept in the open until the seedlings were established. The drainage holes of all pots were closed to prevent water and nutrient losses during the growing period. The pots were watered daily. After seedling establishment, five pots of each cultivar (Mansarover and C14-8) were subjected to 60% and 40% light intensity (300 W $m^{-2}$) exclusively at the vegetative, reproductive, and ripening growth phases, using as a basis the phenological development records from previous studies. As a control, five pots of each cultivar were kept under normal light conditions. Low-light stress conditions (60% and 40%) were created by covering the pots with different layers of muslin cloth. The experiment was conducted in a completely randomized design. Thermal regimes, under both low-light stress and control ambient conditions, were recorded during the entire growing period (Table 1).

Low-light stress usually caused a significant increase in height and spikelet sterility in both cultivars, while it reduced biological and economic yields because of fewer grains per panicle and lower harvest index. Thousand-grain weight was least affected by low-light conditions in both cultivars.

**Table 1. Thermal regimes (monthly mean) under normal and low-light conditions at various growth phases of rice.**

| Growth phase | Mean monthly temperature (°C) at different months | | | | | |
|---|---|---|---|---|---|---|
| (% sunlight) | Jul | Aug | Sep | Oct | Nov | Dec |
| Vegetative phase | | | | | | |
| 100 | 27.1 | 26.2 | – | – | – | – |
| 60 | 26.8 | 26.0 | – | – | – | – |
| 40 | 26.5 | 25.8 | – | – | – | – |
| Reproductive phase | | | | | | |
| 100 | – | – | 26.1 | 26.0 | – | – |
| 60 | – | – | 26.0 | 26.0 | – | – |
| 40 | | | 25.8 | 25.6 | – | – |
| Ripening phase | | | | | | |
| 100 | – | – | – | – | 25.6 | 25.4 |
| 60 | – | – | – | – | 25.5 | 25.2 |
| 40 | – | – | – | – | 25.4 | 25.0 |

The number of panicles per pot in Mansarover decreased drastically when it was subjected to low radiation during the vegetative growth phase, but it increased during the reproductive phase (Table 2) because of greater tiller mortality under control conditions to support higher grains per panicle on the remaining shoots. The number of panicles per pot increased slightly in C14-8, following its exposure to low-light stress in all three growth phases. Irrespective of cultivar, low light intensity at the reproductive phase caused a significant reduction in the number of grains per panicle. Plant exposure to low radiation at ripening caused high spikelet sterility in Mansarover. In C14-8, however, high sterility was observed when plants were subjected to low radiation during the reproductive growth phase. The low number of grains per panicle in C14-8 (despite the lowest spikelet sterility under low-radiation stress at ripening) was caused by the low number of spikelets per panicle owing to the higher number of panicles per pot under the same conditions in the same cultivar. Between the two cultivars, Mansarover showed higher economic and biological yield reduction when subjected to low radiation at ripening. C14-8, on the other hand, registered greater economic and biological yield reduction when exposed to low radiation at the reproductive phase. Exposure at the vegetative growth phase generally caused less reduction in economic and biological yields in both cultivars. Regardless of cultivar and growth phase, the magnitude of reduction in growth, yield, and yield parameters was greater with a decrease in light intensity. Grain yield reduction under low radiation was mainly attributed to increased spikelet sterility and decreased number of grains per panicle. C14-8 showed greater growth and yield stability under low radiation than with Mansarover (Table 2).

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Table 2. Effect of low-light stress on growth, yield, and yield components of two rice cultivars at various growth phases.

| Growth phase (% sunlight) | Plant height (cm) | Panicles (no. pot$^{-1}$) | Grains (no. panicle$^{-1}$) | 1,000-grain weight (g) | Spikelet sterility (%) | Economic yield (g pot$^{-1}$) | Biological yield (g pot$^{-1}$) | Harvest index (%) |
|---|---|---|---|---|---|---|---|---|
| ▫ | | | | | | | | |
| *Normal light*[a] | 121 | 28 | 117 | 24.5 | 17.6 | 88.0 | 190.5 | 46.5 |
| Vegetative phase | | | | | | | | |
| 60 | 130 | 24 | 102 | 28.3 | 20.2 | 80.4 | 185.2 | 45.3 |
| 40 | 131 | 21 | 108 | 25.5 | 16.0 | 68.7 | 160.7 | 42.0 |
| Reproductive phase | | | | | | | | |
| 60 | 123 | 37 | 82 | 25.3 | 17.0 | 70.3 | 188.3 | 37.1 |
| 40 | 121 | 37 | 71 | 25.0 | 18.7 | 55.7 | 156.2 | 36.0 |
| Ripening phase | | | | | | | | |
| 60 | 128 | 28 | 100 | 23.0 | 28.2 | 61.6 | 144.1 | 42.3 |
| 40 | 131 | 29 | 85 | 22.8 | 38.2 | 55.0 | 135.8 | 40.0 |
| ▫ | | | | | | | | |
| *Normal light* | 161 | 23 | 131 | 24.2 | 22.0 | 81.0 | 332.2 | 25.1 |
| Vegetative phase | | | | | | | | |
| 60 | 170 | 27 | 133 | 24.7 | 20.4 | 78.0 | 323.5 | 24.0 |
| 40 | 174 | 24 | 116 | 24.2 | 25.7 | 65.7 | 306.3 | 21.5 |
| Reproductive phase | | | | | | | | |
| 60 | 176 | 24 | 85 | 24.6 | 37.3 | 50.0 | 240.7 | 20.4 |
| 40 | 179 | 26 | 86 | 24.2 | 25.5 | 51.3 | 231.0 | 22.2 |
| Ripening phase | | | | | | | | |
| 60 | 163 | 26 | 118 | 24.3 | 11.2 | 75.0 | 300.0 | 25.0 |
| 40 | 168 | 27 | 117 | 24.5 | 14.1 | 72.1 | 271.8 | 26.4 |
| LSD (5%), Cv | 3 | 2 | 10 | ns[b] | ns | ns | 13.5 | 2.1 |
| Light % | 6 | 4 | 18 | 2 | 6.5 | 11 | 18.2 | 4.0 |
| Cv × light % | 9 | 6 | 22 | 3.2 | 10.5 | 16.2 | 35.7 | 5.6 |

[a]Normal light = plants kept under 100% light intensity throughout the growing period (planting to maturity). [b]ns = *n*onsignificant.

# Contribution of on-farm assessment of improved varieties and crop management to yield of deepwater rice

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Characterizing the deepwater rice-growing environment under a global area of 9 million ha vis-à-vis improved rice production technology can considerably enhance production and productivity (Setter et al 1998). Two prime constituents of this production technology—improved varieties and crop management—appear to be major contributors to enhanced grain yield. Improved crop management practices are needed for improved varieties to realize their yield potential (Ghosh 2002).

On-farm studies with farmers' participation were conducted during the 2001-02 wet season under typical deepwater situations in eastern Orissa. The experimental site usually experiences 0–100-cm water depth during the crop-growing period. The relative contribution of improved varieties and management practices to grain yield and production economics of deepwater rice was compared with that of traditionally grown local varieties and farmers' practices. Four treatment combinations were laid out in a randomized complete block design on 10 farms measuring 0.4 ha each (see table). Improved deepwater variety Durga (tall, long-duration, and photoperiod-sensitive) and local variety Panisahara (semitall, long-duration, and photoperiod-insensitive) were directly sown during the first week of June under both improved and farmers' practices. Improved management practices constituted dibble seeding (80 kg seed $ha^{-1}$) at 15 × 20-cm spacing against traditional broadcast seeding (50 kg $ha^{-1}$). NPK at 40-20-20 kg $ha^{-1}$ was applied basally and compared with farmers' application (20 kg N $ha^{-1}$ only, no P and K). Summer plowing (1 mo before sowing) was followed by application of preemergence herbicide butachlor (1.5 kg ai $ha^{-1}$). This was supplemented with one hand weeding at 25 d after sowing to control weeds and application of carbofuran (20 kg $ha^{-1}$) at 25 d after sowing to control insects. These were compared with the traditional practice of no weeding and no plant protection measures.

The crop was harvested at 80% maturity, while the conventional practice was to harvest the crop after all the leaves had dried. Seedling emergence and the subsequent stand remained satisfactory, following the onset of premonsoon shower in 2001. However, stand establishment suffered from an initial drought that occurred in 2002. Water started accumulating in the field from the first week of July and rose up to 100 cm in 2001, while it reached 75 cm in 2002 (maximum tillering stage). However, water depth mostly fluctuated between 50 and 70 cm in both years. Water started receding at the end of November, enabling crop harvest in mid-January.

The study revealed variable impacts of both varieties and crop management on rice performance (see table). Overall results showed a substantial impact of the improved variety and improved practices, either individually or in combination. In all plots, the local variety almost lodged with water recession, while the kneeing ability of the crop was marked in the improved variety. Panicle number declined substantially in both local and improved variet-

**Yield performance and production economics of deepwater rice cultivation as influenced by variety and crop management, Cuttack, India, 2001-02.**

| Treatment | Panicles (no. $m^{-2}$) | | Panicle weight (g) | | Grain yield (t $ha^{-1}$) | | Net income (Rs $ha^{-1}$) | | Cost:benefit | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 | 2001 | 2002 |
| Local variety + farmers' practice | 97 | 83 | 1.25 | 1.19 | 1.25 | 1.20 | 2,200 | 1,800 | 1:0.73 | 1:0.60 |
| Local variety + improved practice | 132 | 118 | 1.22 | 1.18 | 1.65 | 1.53 | 1,600 | 1,120 | 1:0.32 | 1:0.22 |
| Improved variety + farmers' practice | 178 | 162 | 3.85 | 3.81 | 1.88 | 1.72 | 4,520 | 3,880 | 1:1.51 | 1:1.29 |
| Improved variety + improved practice | 210 | 188 | 4.05 | 3.99 | 2.58 | 2.48 | 5,320 | 4,920 | 1:1.06 | 1:0.98 |
| CD ($P<0.05$) | 15 | 14 | 0.20 | 0.22 | 0.20 | 0.24 | – | – | – | – |

ies following farmers' practice. It significantly increased with improved crop management.

On the other hand, the improved variety had significantly more panicles than the local variety. Nonetheless, panicle development was the same, ensuring higher crop weight under improved crop management and with use of the improved variety. Consequently, the improved variety significantly outyielded (mean yield, 1.80 and 2.53 t $ha^{-1}$) the local variety (mean yield, 1.25 and 1.59 t $ha^{-1}$) under farmers' and improved practices, respectively. Improved crop management was beneficial to both local and improved varieties (mean yield, 1.59 and 2.53 t $ha^{-1}$) compared with that under farmers' practice (mean yield, 1.25 and 1.80 t $ha^{-1}$). Higher net income was obtained with the improved variety (mean, Rs 5,120 and 4,200); the local variety had less (mean, Rs 1,360 and 2,000) under improved and farmers' practices. Improved practices resulted in higher net income when combined with the improved variety (mean, Rs 5,120). This was not so with the local variety (mean, Rs 1,360). Again, a higher cost-benefit ratio was obtained with improved variety using both practices (mean, 1:1.40 and 1:1.20). A lower cost-benefit ratio was derived with the local variety using both practices (mean, 1:0.67 and 1:0.27). Therefore, improved management may not always be advantageous, particularly when traditional varieties are grown. On the other hand, farmers could get relatively more yield and net return from improved management with improved varieties. This implies that improved varieties are more responsive to management practices.

The relative contribution of varieties to grain yield showed that improved varieties ensured a 59% yield increase with improved management compared with farmers' practice. In contrast, improved management increased grain yield by 41% when used with improved varieties, but yield increased by only 27% when used with a traditional variety.

Improved varieties can therefore ensure better grain yield in deepwater situations. Nonetheless, improved crop management was also found to be more advantageous than farmers' practice.

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# Efficiency of physical barriers in maintaining isolation distance in hybrid rice seed production

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In spite of the success of hybrid rice, the nonavailability of affordable quality seed of hybrids, particularly those developed using the cytoplasmic male sterility system, remains a serious problem in India. Even achieving the minimum standard of isolation distance is a constraint to quality seed production in hybrid rice. This is mainly because the areas most suitable for hybrid rice seed production are also found in the mainstream of the rice belt. Shrinking natural resources, particularly cultivable land, resulted in growers not wanting to part with their land for other purposes. The only option for growing hybrid rice seed is either time isolation or physical barrier isolation.

Time isolation is not usually resorted to because of growers' preference in growing specific varieties. Therefore, the use of physical barriers is a better option. However, knowledge on barriers' efficiency is insufficient. This study investigated the efficiency of some physical barriers that could be used in hybrid rice seed production.

The experiment was conducted using the cross IR58025A/NDR3026-3-1 in a 5 × 6-$m^2$ plot, adopting a 2:8 planting ratio with two replications in a randomized block design at the Crop Research Station, Masodha, during 2003-04 kharif. The treatments consisted of growing *Sesbania aculeata* in 2-m- and 5-m-wide strips, and using a high-density polyethylene (HDPE) curtain (3 m high) separately around each plot (the plot without barriers is treated as a control). Ten rows were planted at 30 × 15-cm spacing in a 3-m strip around each type of barrier to provide sufficient contamination load. To synchronize flowering, parental lines were seeded on a staggered basis. A 21-day-old single seedling per hill was transplanted perpendicular to the wind direction. *Sesbania* was seeded 20 d before transplanting, whereas the HDPE curtain was installed before heading. The topping of *Sesbania* was done when it attained 3-m height; this was maintained throughout flowering. In the experimental field, an isolation distance of 100 m free all around was maintained to avoid any undesirable contamination. $GA_3$ at 90 g $ha^{-1}$ was sprayed on female lines at 5% heading. Leaf-clipping and rope-pulling measures related to supplementary pollination were also adopted. Seeds obtained from each treatment were used to raise progenies in succeeding seasons. The percentage of contamination was calculated by dividing the number of sterile plants by the total number of plants (hill basis) studied and then multiplying by 100.

Contamination in the control treatment was 27.50% (2003) and 31.21% (2004). The average was 29.35%. Less contamination (average of 12.63%) was observed with the treatment involving the 2-m-thick *Sesbania* barrier. But, the 5-m-thick *Sesbania* barrier lowered contamination to an average level of 2.41%. The least contamination was seen with the 3-m-high HDPE curtain (see table). No significant variation was found in the contamination values between the 5-m-thick *Sesbania* and the HDPE curtain. Similar results were reported by other centers (IARI 2004). It can therefore be inferred that high-quality hybrid rice seed could be produced by using barriers, either a 3-m-high HDPE curtain or a 5-m-wide strip of *S. aculeata* around the field.

**Effects of some physical barriers on contamination of IR58025B under the IR58025A/NDR3026-3-1 system.**

| Treatment | Contamination (%) | | |
|---|---|---|---|
| | 2003 | 2004 | Mean |
| Control (without barrier) | 27.50 | 31.21 | 29.35 |
| Sesbania barrier | | | |
| 2-m thick | 11.50 | 13.75 | 12.63 |
| 5-m thick | 2.25 | 2.56 | 2.41 |
| HDPE curtain | | | |
| 3-m high | 1.25 | 1.99 | 1.62 |
| LSD (0.05%) | 8.82 | 10.27 | 9.57 |

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# Productivity of irrigated rice as influenced by leaf color chart-based N management in the Tungabhadra Project (TBP) area in Karnataka, India

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The use of proper doses of nutrients, N in particular, is important to attain high yields and efficient nutrient use in intensive rice ecosystems. Poor N-use efficiency by rice is largely because of N losses in the rice ecosystem through $NH_3$ volatilization, denitrification, runoff, and leaching. Any method that promotes N-use efficiency would help rice farmers immensely by reducing their N fertilizer cost. In a survey conducted in the Tungabhadra Project (TBP) area, it was found that farmers applied a high dose of N (230 kg $ha^{-1}$) and only 35.2 kg P $ha^{-1}$ and 24.9 kg K $ha^{-1}$. Too much N application, along with inadequate P and K fertilizers, led to an imbalance in fertilizer use in the TBP area. This practice resulted in higher pest and disease incidence and serious lodging in rice. Unbalanced fertilizer use led to high pesticide use to control pests, which translated into more pesticide expenditures. Lodging caused reduced yield and poor grain quality. In addition, the excess N leached, polluting water sources over time. This has been occurring in the TBP area in recent years.

To avoid guesswork in N fertilization, the International Rice Research Institute introduced the leaf color chart (LCC). The LCC determines the right time of N application to the rice crop by measuring leaf color intensity, which is related to leaf N status. In addition, it also helps optimize N use at reasonably high yield levels, regardless of N source. Identifying the correct threshold values of the LCC is essential as they differ according to location, season, variety, and rice ecosystem. Our investigation was conducted to study crop need-based N management using the LCC in irrigated rice.

Field experiments were conducted at the ARS during the 2000-01, 2001-02, and 2002-03 wet seasons. The experiment was laid out in a split-plot design with three replications on vertisols. The treatment combinations were three genotypes as main plots (BPT5204, Early sona, and KRH2) and four levels of LCC as subplots (4, 5, 6, and the recommended dose of nitrogen, RDN). During 2000-01 kharif, LCC-6 was dropped and LCC-3 was used. In the subsequent seasons, the experiment was again modified by discontinuing LCC-3 and reintroducing LCC-6 (Table 1). The RDN was 150-33-62.2 kg NPK $ha^{-1}$ in the TBP area.

Ten randomly selected fully opened youngest leaves in each treatment were used to measure leaf color intensity. This was done by holding the LCC and placing the middle part of the leaf on top of a color strip for comparison. The average of 10 plants was taken at 7–10-d intervals to decide whether there was a need to topdress N fertilizer. The N levels were applied at different growth stages as per suggested recommended doses (CREMNET 1999). Table 1 shows the quantity of N applied and frequency of application in different seasons. Because rice yields in 2001 were severely affected by drought at the reproductive stage, the 2001 data were not presented.

Rice genotype and LCC-based N management significantly influenced rice yield and yield components (Table 2). Among the genotypes, the rice hybrid KRH2 produced higher yield in all three seasons. Although hybrid superiority in yield was proven in the current study and in another (Nagappa et al 2002), farmers were slow in adopting the hybrids in the TBP area. BPT5204 and Early sona, which are cultivated extensively in the TBP area, were next in terms of yield performance. Among the different N management schemes, LCC-5 recorded the highest grain yields in 3 y. Although LCC-6 showed a higher yield in 2002, it was not significantly different from that of LCC-5. The interaction between genotype and N management was not significant. As in grain yield, straw yield and other yield attributes followed a similar trend. During 2001, severe moisture stress was encountered during the grain-filling stage, thereby affecting yield and other yield parameters.

**Table 1. Total quantity, frequency, agronomic efficiency of N applied, and benefit-cost ratio of different N management treatments, Tungabhadra Project area, Karnataka, India, 2000-02.**

| Treatment | Total N applied (kg $ha^{-1}$) | | Frequency of N application (no.) | | Agronomic efficiency of applied N (kg yield increase $kg^{-1}$ N applied) | | Benefit-cost ratio | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | 2002 | 2000 | 2002 | 2000 | 2002 | 2000 | 2002 |
| LCC-3 | 105 | – | 3 | – | 38 | – | 1.15 | – |
| LCC-4 | 150 | 125 | 4 | 4 | 35 | 35 | 1.47 | 1.33 |
| LCC-5 | 225 | 169 | 6 | 5 | 26 | 27 | 1.55 | 1.38 |
| LCC-6 | – | 169 | – | 5 | – | 29 | – | 1.41 |
| Recommended N | 150 | 150 | 3 | 3 | 35 | 27 | 1.46 | 1.19 |

**Table 2. Effect of genotype and N management on yield-attributing characters and yield of irrigated rice in the Tungabhadra Project area, Karnataka, India, 2000-02.**

| Treatment | Grain yield (t $ha^{-1}$) | | Straw yield (t $ha^{-1}$) | | Panicles (no. $m^{-2}$) | | 1,000-grain weight (g) | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | 2002 | 2000 | 2002 | 2000 | 2002 | 2000 | 2002 |
| *Genotype* | | | | | | | | |
| BPT5204 | 5.0 | 4.4 | 6.6 | 5.8 | 795 | 585 | 13.6 | 16.0 |
| KRH2 | 5.6 | 5.0 | 7.4 | 6.8 | 810 | 500 | 22.0 | 23.2 |
| Early sona | 4.6 | 4.0 | 6.2 | 5.3 | 785 | 460 | 17.2 | 18.0 |
| CD (0.05) | 0.3 | 0.8 | 0.7 | 0.8 | 85 | 115 | 0.9 | 0.7 |
| *N management* | | | | | | | | |
| LCC-3 | 4.0 | – | 5.6 | – | 575 | – | 17.4 | – |
| LCC-4 | 5.3 | 4.4 | 6.9 | 6.2 | 800 | 510 | 17.5 | 18.7 |
| LCC-5 | 5.8 | 4.6 | 7.7 | 6.0 | 970 | 530 | 17.8 | 19.5 |
| LCC-6 | – | 4.8 | – | 6.4 | – | 555 | – | 19.0 |
| Recommended N | 5.2 | 4.0 | 6.8 | 5.2 | 855 | 465 | 17.6 | 19.3 |
| CD (0.05) | 0.3 | 0.4 | 0.3 | 0.5 | 50 | nsa | ns | 0.7 |

[a]ns = not significant.

This study showed that the current RDN was inadequate in achieving higher yields of irrigated rice in the TBP area. Values of agronomic efficiency of applied N (AEN) (calculated as the increase in rice yield per kg of N applied) were generally higher at lower LCC threshold values. A look at the economics angle indicated a higher benefit-cost ratio for LCC-5 than with RDN. The critical leaf color reading for N topdressing in the different varieties may range from three to four (CREMNET 1999). The results of a study by Sheoran et al (2004) suggest that, in scheduling N application, LCC-4 may not be uniformly applicable for all rice varieties. In contrast, Budhar and Tamilselvan (2003) reported that the use of LCC-4 with short-duration varieties in Tamil Nadu was best for realizing high yields and high NUE. In Karnataka, Angadi et al (2002) determined that the optimum LCC threshold value for rainfed Abilash was 5.0 and that for Intan was 3.5. Results from our study indicate that an LCC value of 5 resulted in high yield, consistent with efficient N use in the TBP area of Karnataka.

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# Effect of rice crop establishment methods on hybrid rice productivity in northwest India


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Nonavailability of irrigation water and a shortage of labor during peak periods increase labor wages and make transplanting and manual weeding costly, invariably causing delays in farm operations. Moreover, puddling as a prerequisite for transplanting deteriorates the soil. Land preparation becomes difficult and requires more energy to achieve proper soil tilth for succeeding crops. To solve this problem, many farmers switch to direct-seeding under unpuddled conditions.

Direct-seeding can reduce the labor requirement, shorten crop duration by 7–10 d, and provide grain yield comparable with that of transplanting (De Datta 1986). Because of the need to develop appropriate rice crop establishment methods to improve rice yield, this study was carried out to assess the effect of different establishment methods on hybrid rice productivity.

A field experiment was conducted during the rainy seasons of 2003-04 at PDCSR (an elevation of 237 m above mean sea level at 29°4′ N latitude, 77°46′ E longitude) to assess the effects of various crop establishment methods of rice—direct-seeding under dry conditions (aerobic), drum-seeding (wetbed unpuddled), mechanical transplanting (puddled), mechanical transplanting (unpuddled), and manual transplanting (puddled)—on hybrid rice productivity. The experiment was set up in a randomized block design with three replications. Gross and net plot sizes were 33 × 4 and 31 × 3 $m^2$, respectively. Soil at the test site was a sandy loam, with pH 8.1, 0.51% organic C, 7.4 Mg available $NO_3$-N $kg^{-1}$, 12.6 Mg available Olsen P $kg^{-1}$, 69.1 mg available K $kg^{-1}$, and 1.46 mg $m^{-3}$ bulk density. Hybrid rice variety PHB 71 was sown at 20-cm row-to-row spacing. The seeding rate was 60 kg $ha^{-1}$ in mechanical transplanting (puddled), mechanical transplanting (unpuddled), and manual transplanting (puddled) conditions. In the direct-seeding treatment, planting was done on 15 Jun. Sprouted seeds were sown on 17 Jun in

**Effects of rice crop establishment method on yield and yield attributes of hybrid rice.**

| Treatment | Grain yield ($t\ ha^{-1}$) (no.) | | Effective tillers $m^{-2}$ at harvest (g) | | Panicle weight (g) | | 1,000-grain weight (g) | |
|---|---|---|---|---|---|---|---|---|
| | 2003 | 2004 | 2003 | 2004 | 2003 | 2004 | 2003 | 2004 |
| Direct-seeding (dry bed, aerobic) | 7.84 | 8.53 | 361 | 364 | 3.45 | 3.51 | 26.8 | 27.4 |
| Drum-seeding (wet bed, unpuddled) | 8.11 | 8.71 | 381 | 384 | 3.72 | 3.80 | 27.1 | 28.3 |
| Mechanical transplanting (puddled) | 7.75 | 8.45 | 352 | 356 | 3.30 | 3.37 | 26.4 | 27.0 |
| Mechanical transplanting (unpuddled) | 7.33 | 7.73 | 297 | 301 | 3.00 | 3.08 | 26.0 | 26.6 |
| Manual transplanting (puddled) | 7.46 | 7.93 | 332 | 335 | 3.17 | 3.22 | 26.2 | 26.8 |
| CD at 5% | 0.38 | 1.90 | 10.89 | 10.12 | 0.15 | 0.09 | 0.73 | 1.15 |

the drum-seeding treatment and on 8 Jul in the mechanical and manual transplanting methods in both years. Fertilizer doses were applied at these rates: 150 kg N $ha^{-1}$, 60 kg P $ha^{-1}$, 60 kg K $ha^{-1}$, and 5.5 kg Zn $ha^{-1}$. P, K, and Zn were applied as basal with N applied in four splits (1/4 basal dressing, 1/4 at mid-tillering, 1/4 at active tillering, and 1/4 at panicle initiation). Two sprays of $FeSO_4$ at 0.2% solution at 30 and 40 d after planting were also given in direct-seeding and drum-seeding to correct iron deficiency. Harvesting was done on 15 Oct (direct-seeding and drum-seeding) and on 25 Oct (mechanical and manual transplanting). Data were analyzed by standard analysis of variance and treatment means were compared using the CD test at the 5% level of significance.

Generally, rice yield was higher in 2004 than in 2003 because of better crop growth (as evidenced by yield attributes). The grain yield of hybrid rice was significantly higher with drum-seeding (unpuddled), followed by direct-seeding (dry bed) and mechanical transplanting (unpuddled). Manual transplanting (puddled) and mechanical transplanting (unpuddled) had lower yields in both years. Yield attributes such as effective tillers, panicle weight, and 1,000-grain weight had a trend similar to that of yield. Sharma and Gangwar (2001) reported that all crop establishment methods resulted in similar yields and yield-contributing characters in the 1994-95 rainy seasons. However, transplanting resulted in higher grain yield than direct seeding under unpuddled conditions, but the latter produced higher grain yield in succeeding crops.

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# Effect of the system of rice intensification on hybrid rice performance and yield


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The system of rice intensification (SRI) was developed by Father Henri de Laulanie in Madagascar in the early 1980s. He was a Jesuit priest who spent over 30 y working with farmers in this country (Barkelaar 2001). Because it is a set of recommended practices, SRI is considered a *system* rather than a technology. Rather than being simply adopted, practices associated with SRI should always be tested and varied, according to local conditions (Uphoff et al 2002). Reported results with SRI methods were remarkable.

In some areas in Madagascar with the poorest soils and where yields of 2 t $ha^{-1}$ are known, farmers using SRI get yields averaging more than 8 t $ha^{-1}$, with some getting 10–15 t $ha^{-1}$ (Barkelaar 2001). Yuan (2002) stated that, if inbred varieties can obtain such a high yield, it is quite possible that hybrid rice, especially super hybrid rice, can yield even higher using SRI methods. This belief is based on two considerations. First, hybrid rice varieties have greater yield potential than inbred varieties under the same conditions. Second, traditional Chinese cultivation methods are similar to SRI in some respects, such as the use of organic fertilizers, wide spacing between plants, manual weeding (instead of using herbicides), keeping soil wet, and alternate drying and flooding.

Data on SRI are limited in Bangladesh. A field experiment was thus conducted to evaluate the performance of hybrid rice under SRI during 2002 boro (dry season) and T. aman (wet season) at BRRI. The first released hybrid rice variety, BRRI Hybrid Dhan 1, was used in this trial. Along with SRI, six different crop establishment methods were compared. The treatments were $M_1$ = broadcasting, $M_2$ = line sowing with row spacing of 25 cm, $M_3$ = recommended transplanting (20 × 15 cm), $M_4$ = SRI (30 × 30 cm), $M_5$ = SRI (40 × 40 cm), and $M_6$ = SRI (50 × 50 cm). In the 2002 T. aman season, M6 was not included. The experiment was laid out in a randomized complete block design with three replications. Sprouted seeds of BRRI Hybrid Dhan 1 were sown in a seedbed for $M_3$ and in plastic trays for $M_4$, $M_5$, and $M_6$ (24 Dec 2001 for boro and 31 July 2002 for T. aman). On the same day, seeds were sown in the main experimental plots for $M_1$ and $M_2$. Thirty-day-old seedlings ($M_3$) and 15-d-old-seedlings ($M_4$, $M_5$, and $M_6$) were transplanted at one seedling per hill in a 15-$m^2$ plot. Fertilizers (270 kg urea $ha^{-1}$, 130 kg triple superphosphate $ha^{-1}$, 120 kg muriate of potash $ha^{-1}$, and 70 kg gypsum $ha^{-1}$) were applied. In T. aman, urea was reduced to 180 kg $ha^{-1}$. Urea was applied in four equal splits—basal, 20 d after transplanting, at panicle initiation, and at flowering. The SRI treatment plots were given 7.5 kg of decomposed cow dung per plot and these plots were given alternate wetting and drying, following the SRI concept. Herbicides were applied to control weeds in $M_1$ and $M_2$ plots. The other plots were weeded manually. All other agronomic practices were done as needed. At maturity, six representative hills from each transplanted plot and plants from a 0.2-$m^2$ area per direct-seeded plot were sampled for yield component analysis. Grain yield (adjusted to 14% moisture content) was determined from a 5-$m^2$ area from each plot.

Plant height was the same in the different crop establishment methods, except in the broadcast method, which had the shortest plants. With the increase in plant spacing, tillers per hill increased but tillers per unit area decreased (Tables 1 and 2). The highest number of tillers $m^{-2}$ was observed in both transplanting and line-sowing methods. Similar results were observed in the number of panicles $m^{-2}$. No significant differences were observed in the number of filled spikelets per panicle. Larger spikelets were found in plants grown in SRI plots compared with those in transplanted and direct-seeded plots. The highest sterility was observed in $M_6$ (SRI, 50 × 50-cm spacing, dry season) and $M_5$ (SRI, 40 × 40-cm spacing, wet season). This was because of different maturity levels in the SRI plots. No significant yield differences were observed among the recommended transplanting, line-sowing, and SRI (30 × 30-cm spacing, dry season) methods, although line sowing had the highest grain yield in the wet season. The recommended transplanting and SR (30 × 30-cm) plots produced identical grain yield. The lowest grain yield was observed in SRI with 50 × 50-cm spacing, which was identical to that of SRI with 40 × 40-cm spacing and broadcast plots in the dry season. Under wider spacing, the number of til-

**Table 1. Effect of the system of rice intensification and different crop establishment methods on the yield and yield attributes of BRRI Hybrid Dhan 1, BRRI, Gazipur, Bangladesh, 2002 dry season.[a]**

| Treatment | Plant height (cm) | Tillers $hill^{-1}$(no.) (no.) | Tillers $m^{-2}$ (no.) | Panicles $m^{-2}$ (no.) | Filled spikelets $panicle^{-1}$ | 1,000-grain weight (g) (no.) | Sterility (%) | Grain yield (t $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| $M_1$ = broadcasting | 99 b | – | 344 b | 292 b | 98 a | 24.23 b | 36a b | 6.5 b |
| $M_2$ = line sowing with row spacing of 25 cm | 102 ab | – | 364 a | 315 a | 101 a | 24.41 b | 30 bc | 7.5 a |
| $M_3$ = recommended transplanting (20 × 15 cm) | 106 ab | 12 | 366 a | 323 a | 100 a | 24.41 b | 27 c | 7.7 a |
| $M_4$ = SRI (30 × 30 cm) | 109 a | 27 | 306 c | 288 b | 107 a | 25.21 a | 32 bc | 7.5 a |
| $M_5$ = SRI (40 × 40 cm) | 108 a | 43 | 268 d | 252 c | 103 a | 25.23 a | 32 bc | 6.6 b |
| $M_6$ = SRI (50 × 50 cm) | 108 a | 66 | 256 d | 226 d | 105 a | 25.13 a | 42 a | 6.1 b |
| CV (%) | 4.3 | – | 2.6 | 3.0 | 10.0 | 1.3 | 10.4 | 4.4 |

[a]In a column, means followed by the same letter(s) are not statistically significant at the 5% level by DMRT.

**Table 2. Effect of the system of rice intensification and different crop establishment methods on yield and yield attributes of BRRI Hybrid Dhan 1, BRRI, Gazipur, Bangladesh, 2002 wet season.[a]**

| Treatment | Plant height (cm) | Tillers $hill^{-1}$ (no.) | Tillers $m^{-2}$ (no.) | Panicles $m^{-2}$ (no.) | Filled spikelets $panicle^{-1}$ (no.) | 1,000-grain weight (g) | Sterility (%) | Grain yield (t $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| M1 = broadcasting | 90.0 b | – | 288 ab | 242 a | 74 a | 23.7 a | 39 a | 3.3 a |
| M2 = line sowing with row spacing of 25 cm | 90.7 ab | – | 296 ab | 249 a | 78 a | 23.9 a | 28 b | 4.2 a |
| M3 = recommended transplanting (20 × 15 cm) | 99.3 a | 14 | 355 a | 290 a | 71 a | 23.6 a | 36 a | 3.7 a |
| M4 = SRI (30 × 30 cm) | 97.3 ab | 24 | 264 bc | 244 a | 75 a | 24.1 a | 36 a | 3.6 a |
| M5 = SRI (40 × 40 cm) | 98.7 ab | 33 | 204 c | 187 b | 76 a | 24.3 a | 41 a | 3.2 a |
| CV (%) | 4.6 | – | 15.1 | 10.7 | 22.3 | 3.3 | 11.4 | 17.6 |

[a]In a column, means followed by the same letter(s) are not statistically significant at the 5% level by DMRT.

lers per hill was higher, although the total number of panicles per unit area was smaller, resulting in a yield reduction in the SRI treatments. The recommended transplanting and SRI treatments with 30 × 30-cm spacing produced identical grain yield, but the latter saved two-thirds the amount of seedlings used by farmers.

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# Rice seed priming


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Seed priming is a technique in which seeds are partially hydrated until the germination process begins, but radicle emergence does not occur (Bradford 1986). Priming allows the metabolic processes necessary for germination to occur without actual germination.

Primed seeds usually exhibit an increased germination rate, greater germination uniformity, and, at times, greater total germination percentage (Basra et al 2005). Increased germination rate and uniformity have been attributed to metabolic repair during imbibition (Bray et al 1989), buildup of germination-enhancing metabolites (Basra et al 2005), osmotic adjustment (Bradford 1986), and, for seeds that are not redried after treatment, a simple reduction in imbibition lag time (Bradford 1986). Other scientists have given excellent reviews on seed priming. Our review aims to sum up earlier work on rice seed priming.

Osmoconditioning or osmopriming is the term used to describe the soaking of seeds in aerated, low-water-potential solutions. In this special type of seed priming, polyethylene glycol (PEG) or salt solution is used to control water uptake and prevent radicle protrusion (Bray 1995). PEG is most commonly used because of its nontoxic nature and large molecule size, which lowers water potential without penetrating into the seeds during soaking. The salts used to lower water potential are $KNO_3$, KCl, $K_3PO_4$, $KH_2PO_4$, $MgSO_4$, $CaCl_2$, NaCl, and mannitol. Salts supply the seed with N and other nutrients needed for protein synthesis during germination. These salts, however, result in occasional toxicity, a disadvantage to the germinating seedlings. Seed soaking, sometimes followed by dehydration of seeds, has been demonstrated to improve subsequent germination of numerous vegetable seeds, especially under suboptimal conditions (Muhyaddin and Weibe 1989, Bradford 1986). More recently, osmoconditioning has been introduced successfully in cereals, including rice. Lee et al (1998a) conducted an experiment to find out the optimum water potential, temperature, and duration for rice seed priming. It was concluded that priming in water (0 MPa) for 4 d at 15 °C and for 1 d at 25 °C yielded the same results, whereas 4 d was the optimum priming time in a –0.6 MPa PEG solution, regardless of priming temperature. The same authors investigated the effects of priming on early emergence of rice seeds under excess soil moisture conditions. Rice seeds were primed by soaking in a –0.6-MPa PEG solution at 25 °C for 4 d. Germination and emergence rates and time from planting to 50% germination (T50) of primed seeds were less than those of untreated seeds by 0.9–3.7 d. Lee et al (1998c) suggested priming of rice seeds to ensure better seedling establishment under adverse soil conditions.

In a greenhouse trial, osmopriming ($CaCl_2$ and $CaCl_2$ + NaCl) improved seedling vigor index and seedling and stand establishment in flooded soil (Ruan et al 2002). Compared with $CaCl_2$ + NaCl priming solution, the addition of $GA_3$ to $CaCl_2$ + NaCl did not increase significantly the speed of emergence or stand establishment (Ruan et al 2002). Du and Tuong (2002) concluded that, when rice is seeded in very dry soil (near the wilting point), priming further increased plant density (especially with 14% KCl solution and saturated $CaHPO_4$ solution), tiller number, and grain yield. In drought-prone areas, seed priming reduced the need for a high seeding rate, although it can be detrimental if seeding takes place in soil that is at or near saturation (Du and Tuong 2002). Lee and Kim (2000) investigated the effects of osmoconditioning on germination of normal and naturally aged seeds by analyzing total sugar content and α-amylase activity. The normal seeds had a higher total sugar content and α-amylase activity than the aged seeds. Aged seeds that underwent osmoconditioning and hardening increased their total sugar and α-amylase activity. The latter was positively correlated with total sugar and germination rate. Basra et al (2005) had the same results when they evaluated the effects of osmoconditioning (–1.1 MPa $KNO_3$ for 24 and 48 h), traditional soaking, and toxic effects of $KNO_3$ osmopriming on fine rice. Increased α-amylase activity and sugar content were also reported in the treated seeds compared with the control.

The salts used to control water potential may cause toxicity and/or germination inhibition in rice (Basra et al 2003, 2005). In both studies, –1.1 MPa $KNO_3$ adversely affected the germinating seeds and seedlings.

Hardening (wetting and drying or hydration-dehydration) refers to repeated soaking in water and drying (Basra et al 2003). The hydration-dehydration cycle may be repeated several times (Lee and Kim 2000). The hardening treatment for 24 h proved to be better for vigor enhancement (Basra et al 2005) than osmopriming (–1.1 MPa $KNO_3$) for 24 and 48 h and traditional soaking (overnight soaking followed by saturated gunny bags up to radicle appearance). Basra et al (2003) also evaluated the effects of seed hardening for 24 and 18 h and reported that this resulted in better invigoration in hardened seeds of fine rice compared with osmoconditioning and the control. Greater α-amylase activity and higher sugar content were also reported in the hardened seeds than in the control.

Farooq et al (2005) introduced a new technique for rice seed invigoration, integrating both seed hardening and osmoconditioning. Seeds of coarse and fine rice were hardened in various salt solutions rather than in tap or distilled water. Osmohardening in $CaCl_2$ (with an osmotic potential of –1.5 MPa) solution was found to be better than with other salts and simple hardening (Farooq et al 2005).

Humidification is a presowing hydration treatment in which seeds are equilibrated under conditions of high humidity (Lee et al 1998b). Humidification of normal rice seeds with a high germination rate did not increase the germination rate, but did accelerate the germination rate of aged seeds, especially those under unfavorable soil conditions and suboptimal temperatures (Lee et al 1998a,c). Lee et al (1998b) investigated the effects of humidification on normal and aged rice seeds. Relative humidity (RH) and humidification duration were found not to affect germination rate, but they reduced the time to 50% germination of normal seeds. Humidification at 60% RH did not affect germination rate or time to 50% germination of aged seeds, but that at 80% RH reduced germination percentage and increased the time to 50% germination.

Incorporating plant growth regulators as part of presoaking, priming, and other presowing treatments of many crops resulted in improved seed performance (Miyoshi and Sato 1997). $GA_3$ is well known to activate α-amylase for the breakdown of starch stored in the seed that will be used by the growing embryo during germination. $GA_3$ and ethylene stimulate the elongation of the mesocotyl, coleoptile, and internodes of rice seedlings after germination. Abscisic acid, on the other hand, promotes elongation of the mesocotyl of rice seedlings (Lee et al 1999).

Miyoshi and Sato (1997) applied kinetin and gibberellins on dehusked seeds of indica and japonica rice to study their effects on germination under aerobic and anaerobic conditions. Stimulatory effects of gibberellin were found under both conditions. Under anaerobic conditions, the responses of dehusked indica and japonica rice seeds to kinetin and gibberellin differed—response to kinetin, negative; response to gibberellin, positive. Under aerobic conditions, the stimulatory effects of kinetin on the germination of dehusked seeds were greater than those of gibberellin.

Dry-heat treatment of seeds is done for two reasons: (1) to control external and internal seed-borne pathogens, including fungi, bacteria, viruses, and nematodes; and (2) to break seed dormancy. Generally, the high temperature in the treatment reduces seed viability and seedling vigor, but the optimum temperature for breaking dormancy promotes seed germination and seedling emergence in rice (Lee et al 2002). Farooq et al (2004) exposed coarse and fine rice seeds to dry-heat treatment—40 °C for 72 h and 60 °C for 24 h—and chilling (–19 °C) treatment for 72 h. In fine rice, dry-heat treatment at 40 °C for 72 h resulted in decreased T50 and increased radicle and plumule length, root length, root/shoot ratio, root fresh and dry weight, radicle and plumule growth rate, and shoot fresh weight. In coarse rice, none of the treatments improved germination and seedling vigor.

Recent research on a range of crop species showed faster germination, early emergence, and vigorous seedlings achieved by soaking seeds in water for some time, followed by surface drying before sowing, which may result in higher crop yield (Harris et al 2000). This soaking practice is termed on-farm seed priming—a simple, cheap, and low-risk method of promoting rapid seedling establishment and vigorous early growth. The duration of soaking is critical and should be less than the safe limit for each crop cultivar. (The safe limit is defined as the maximum length of time that farmers should prime seeds; if exceeded, this can result in seed or seedling damage brought about by premature germination [Harris et al 2000].) This concept of safe limit differentiates on-farm seed priming from pregermination. Primed seeds will not continue to germinate, unless they are placed in a moist soil environment. If primed seeds are sown onto a seedbed with inadequate moisture, these will not germinate unless moisture subsequently becomes available (e.g., rainfall). In contrast, seeds soaked longer than the safe limit will continue to germinate even in the absence of an external moisture source. The use of pregerminated seed has inherent risks, whereas the use of primed seed has an advantage—the primed seed behaves as dry seed if sowing is delayed or seedbed conditions are suboptimal.

Soaking overnight was also successful in rice and proved to be highly cost-effective, resulting in better stand, earlier maturity, and higher yields at little cost (Harris et al 2002). The same study noted that primed rice seed uniformly and vigorously germinated and emerged faster (by 1–3 d), leading to a wide range of phenological and yield-related benefits. In direct-seeded rice, on-farm seed priming resulted in better emergence (91% vs 61%), earlier flowering (71 vs 74.7 d), taller plants (108 vs 94 cm), longer panicles (22.4 vs 20.3 cm), and more panicles per plant (5.7 vs 4.9).

Traditionally, rice seedlings are widely transplanted in nurseries, thereby increasing production cost and water requirements. The rising labor cost and the looming water crisis are the challenges being faced by the rice-producing world, including Pakistan. Direct seeding could be an alternative, but poor germination, uneven crop stand, and high weed infestation are constraints that prevent the adoption of direct-seeded rice (Du and Tuong 2002). Effective herbicides are currently available for weed control, but poor germination and poor crop establishment remain a concern. Seed priming has the potential to overcome this problem since invigoration persists under less optimum conditions such as salinity and excessively high and low temperature (Muhyaddin and Weibe 1989, Bradford 1986). The need for research in this area is more strongly felt now than in the past.

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Apply these rules, as appropriate, to all research notes:

### *Methodology*

- Include an internationally known check or control treatment in all experiments.
- Report grain yield at 14% moisture content.
- Quantify survey data, such as infection percentage, degree of severity, and sampling base.
- When evaluating susceptibility, resistance, and tolerance, report the actual quantification of damage due to stress, which was used to assess level or incidence. Specify the measurements used.
- Provide the genetic background for new varieties or breeding lines.
- Specify the rice production systems as irrigated, rainfed lowland, upland, and flood-prone (deepwater and tidal wetlands).
- Indicate the type of rice culture (transplanted, wet seeded, dryseeded).

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- If local terms for seasons are used, define them by characteristic weather (dry season, wet season, monsoon) and by months.
- Use standard, internationally recognized terms to describe rice plant parts, growth stages, and management practices. Do not use local names.
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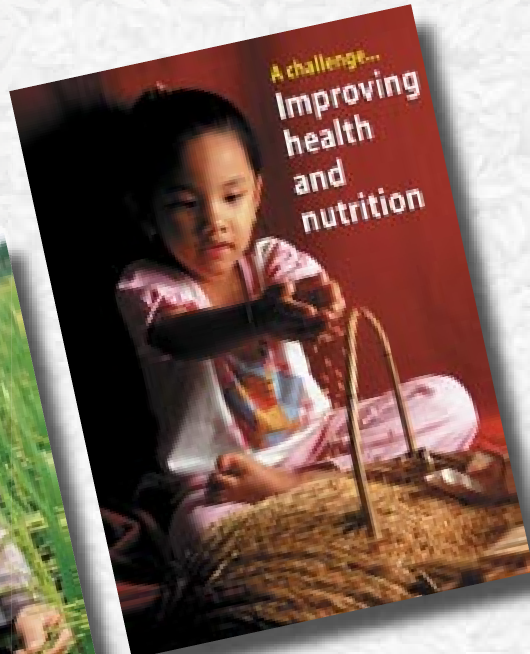





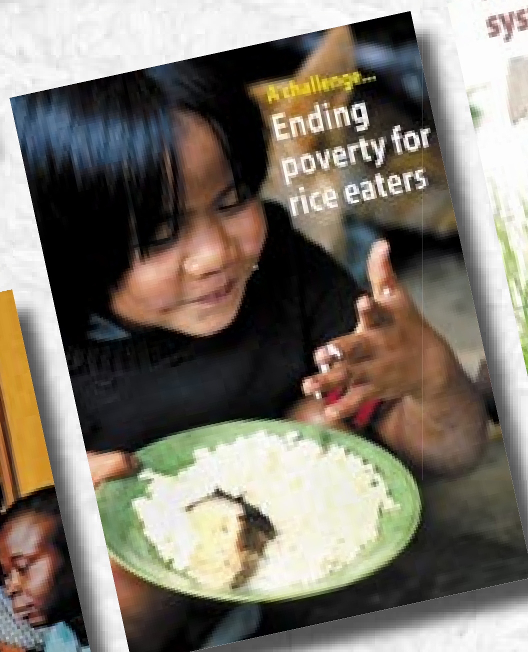


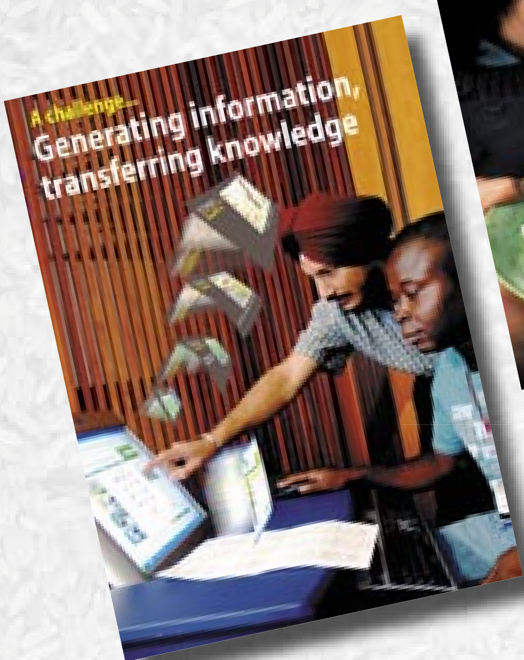

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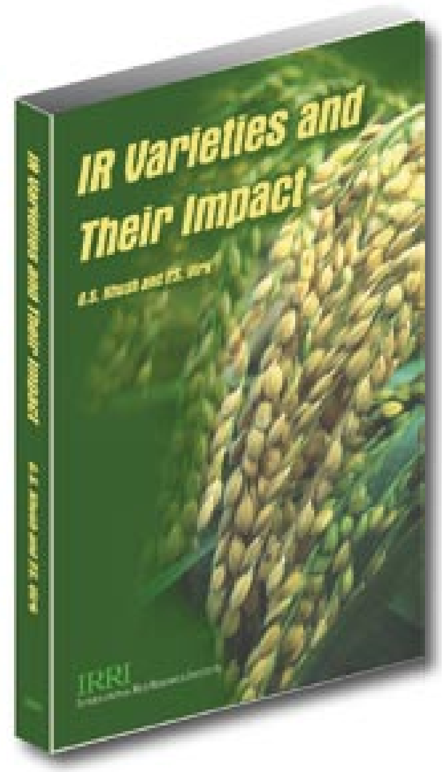
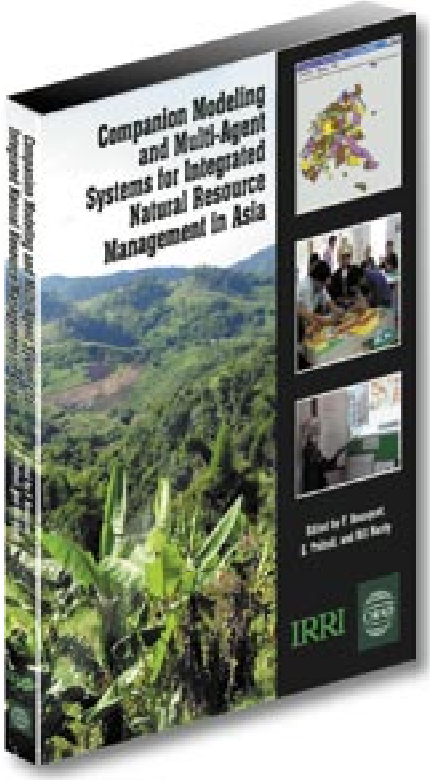
**IR Varieties and Their Impact**, by Ghurdev Khush, former IRRI principal plant breeder and 1996 World Food Prize Laureate, and Parminder Virk, IRRI senior plant breeder, is a comprehensive list of all the high-yielding "IR" rice varieties released by the institute. The book includes information on 34 IR varieties as well as 328 IR breeding lines that were released as 643 varieties in 75 countries. In a foreword to the book, IRRI Director General Robert Zeigler says, "Rice scientists, journalists, and historians often search for information on Green Revolution varieties of rice. This information is buried in plant breeders' field books and records of plant pathologists and entomologists. […] I hope that this publication will serve as a source of information on varieties that had such a significant impact on food security and poverty alleviation and fostered economic development."




**Companion Modeling and Multi-Agent Systems for Integrated Natural Resource Management Systems in Asia,** edited by François Bousquet, Guy Trébuil, and Bill Hardy, examines the relatively new research approach of companion modeling, which covers spatial modeling and adaptive management of renewable resources. The book follows a joint effort in 2001-04 by IRRI and the French Agricultural Research Center for International Development (CIRAD) that led to the implementation of a Thailand-based companion modeling project with a regional mandate. The goal was to create and train a regional network of national agricultural research and extension systems (NARES) practitioners of companion modeling in Southeast Asia and to support these practitioners in the development of their own applications and case studies. This volume is one of the first collective outputs and its various contributions show work in progress. Its production benefited from strong support from the NARES involved in the project activities, particularly in Thailand. For more on companion modeling, see The game of life on pages 25-27 of Rice Today Vol.4, No.1.

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