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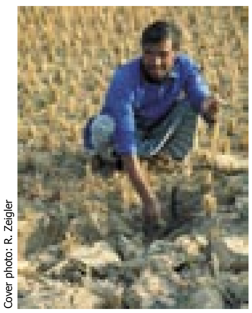

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MINI REVIEW

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Economic costs of drought and rice farmers' coping mechanisms

Sushil Pandey, senior scientist, agricultural economics, International Rice Research Institute

Climate-related natural disasters (drought, flood, and typhoon) are principal sources of risk and uncertainties in agriculture. These are important constraints affecting the production of rice—the staple crop of Asia. Although the production of rice has increased over time in the wake of the green revolution, major shortfalls caused by climatic aberrations such as drought and flood are frequent. At least 23 million ha of rice area (20% of total rice area) in Asia is estimated to be drought-prone.

The economic costs of drought can be enormous. For example, drought has been historically associated with food shortages of varying intensities, including those that have resulted in major famines in different parts of Asia and Africa. In India, major droughts in 1918, 1957-58, and 1965 resulted in famines during the 20th century. The 1987 drought affected almost 60% of the total cropped area and 285 million people across India. Similarly, the average annual drought-affected area in China during 1978-2003 is estimated to have been 14 million ha and the direct economic cost of drought is estimated to have been 0.5-3.3% of the agricultural sector gross domestic product. In Thailand, the drought of 2004 is estimated to have affected 2 million ha of cropped area and over 8 million people.

The effect of drought on human societies can be multidimensional. The effect of drought in terms of production losses and consequent human misery is well-publicized during years of crop failure. However, losses to drought of milder intensity, although not so visible, can also be substantial. Production loss, which is often used as a measure of the cost of drought, is only a part of the overall economic cost. Severe droughts can result in starvation and even death of the affected population. However, different types of economic costs arise before such severe consequences occur. Due to market failures, farmers attempt to 'self insure' by making costly adjustments in their production practices and adopting conservative practices to reduce the negative impact during drought years. Although these adjustments reduce the direct production losses, they themselves entail some economic costs in terms of opportunities for income gains lost during good years.

In rural areas where agricultural production is a major source of income and employment, a decrease in agricultural production will set off second-round effects through forward and backward linkages of agriculture with other sectors. A decrease in agricultural income will reduce the demand for products of the agro-processing industries that cater to the local markets. This will lead to a reduction in income and employment in this sector. Similarly, the income of rural households engaged in providing agricultural inputs will also decrease. This reduction in household incomes will set off further 'knock-on' effects. By the time these effects have been fully played out, the overall economic loss from drought may turn out to be several times more than what is indicated by the loss in production of agricultural output alone. The loss in household income can result in a loss in consumption of the poor whose consumption levels are already low. Farmers may attempt to cope with the loss by liquidating productive assets, pulling children out of school, migrating to distant places in search of employment, and going deeper into debt. The economic and social costs of all these consequences can indeed be enormous.

Much of the current knowledge on drought is based mainly on arid and semiarid regions. Despite reasonably high rainfall, drought occurs frequently in the subhumid regions of Asia. However, the nature and frequency of drought in subhumid regions, its impact on farmer livelihoods, farmers' drought-coping strategies, and welfare implications of drought have not been adequately studied. Analyses of drought characteristics, drought impacts, and household-coping mechanisms are important for understanding the nature of risk and vulnerability associated with drought and for formulating various interventions for effective drought mitigation.

This article provides a synthesis of findings and recommendations based on a recent cross-country comparative study of the impact of drought and farmers' coping mechanisms. The countries included in the study were China, India, and Thailand. These countries vary in climatic conditions, level of economic development, rice yields, and institutional and policy contexts of rice farming. The specific regions selected for the study were southern China, eastern India, and northeast Thailand. In southern China, the provinces included were Hubei, Guangxi, and Zhejiang. Eastern India was represented by the states of Chattisgarh, Jharkhand, and Orissa. All provinces of northeast Thailand were included.

Drought: definition, coping mechanisms, and consequences

Conceptually, drought is considered to describe a situation of limited rainfall that is substantially below what has been established to be a "normal" value for the area concerned, leading to adverse consequences on human welfare. Although drought is a climatically induced phenomenon, its impact depends on social and economic context as well. Hence, in addition to climate, economic and social parameters should be also taken into account in defining drought. This makes developing a universally applicable definition of drought impractical. Three generally used definitions of drought are based on meteorological, hydrological, and agricultural perspectives.

Meteorological drought is defined as a situation in which the actual rainfall is significantly below the long-term average (LTA) for the area. This definition does not take into account factors other than rainfall. Hydrological drought is defined as the situation of depletion in surface and subsurface water resources due to shortfall in precipitation. The effect on depletion of water resources is the main concern in this definition.

Agricultural drought is said to occur when the soil moisture is insufficient to meet crop water requirements resulting in yield losses. As the effect of rainfall deficiency on crops also depends on soil and crop characteristics, the definition of agricultural drought requires consideration of actual and potential evapotranspiration, soil water deficit, and production losses simultaneously.

Risk-coping strategies can be classified into *ex-ante* and *ex-post*, depending upon whether they help to reduce risk or reduce the impact of risk after the production shortfall has occurred. Due to lack of efficient market-based mechanisms for diffusing the risk, farmers modify their production practices to provide "self-insurance" so that the likely impact of adverse consequences is reduced to an acceptable level. *Ex-ante* strategies help reduce the fluctuations in income and are also referred to as income-smoothing strategies. These strategies can, however, be costly in terms of forgone opportunities for income gains as farmers select safer but low-return activities.

Ex-ante strategies can be grouped into two categories: those that reduce risk by diversification and those that do so by imparting greater flexibility in decisionmaking. Diversification is simply captured in the principle of not putting "all eggs in one basket." The risk of income shortfall is reduced by growing several crops that have negatively or weakly correlated returns. This principle is used in different types of diversification common in rural societies. The examples include spatial diversification of farms, diversification of agricultural enterprises, and diversification from farm to nonfarm activities.

Maintaining flexibility is an adaptive strategy that allows farmers to switch between activities as the situation demands. Flexibility in decisionmaking permits farmers not only to reduce the chances of low incomes but also to capture income-increasing opportunities when they do arise. Examples are using split doses of fertilizers, temporally adjusting input use to crop conditions, and adjusting the area allocated to a crop, depending on the climatic conditions. While postponing agricultural decisions until uncertainties are reduced can help lower the potential losses, such a strategy can also be costly in terms of income forgone if operations are delayed beyond the optimal biological window. Other ex-ante coping mechanisms include maintaining stocks of food, fodder, and cash.

Ex-post strategies are designed to prevent shortfall in consumption when the income drops below what is necessary for maintaining consumption at its normal level. Ex-post strategies are also referred to as consumption-smoothing strategies as they help reduce the fluctuations in consumption. These include migration, consumption loans, asset liquidation, and charity. Consumption shortfall can occur despite these ex-post strategies if the drop in income is substantial.

Farmers who are exposed to risk use these strategies in different combinations. Over a long period of time, some of these strategies are incorporated into the nature of the farming system and are often not easily identifiable as risk-coping mechanisms. Others are deployed only under certain risky situations and are easier to identify as responses to risk.

Opportunity costs associated with the deployment of various coping mechanisms can, however, be large. The climatic uncertainties often compel farmers, particularly those who are more risk-averse, to employ conservative risk management strategies that reduce the negative impact in poor years, but often at the expense of reducing the average productivity and profitability. For example, by growing drought-hardy but low-yielding traditional rice varieties, farmers may be able to minimize the drought risk but may end up sacrificing a potentially higher income in normal years. Also, poor farmers in high drought-risk environments may be reluctant to invest on seed-fertilizer technologies that could increase profitability in normal years but lead to a loss of capital investment in poor years. In addition to these opportunity costs, poor households that are compelled to sell their productive assets such as bullocks and farm implements will suffer future productivity losses as it can take them several years to reacquire those assets. A cut in medical expenses and children's education will impact on future income-earning capacity of the household. Such an impact may linger on to the future generation also. The loss of income and assets can convert transient poverty into chronic poverty, making the possibility of escape from poverty more remote.

Analytical results

The analysis of monthly rainfall data for the period 1970-2003 indicated that drought is a regular phenomenon in the regions included in the study in all three countries. The probability of drought varied in the range 0.1–0.4, with the probability being higher in eastern India relative to southern China and northeast Thailand (Fig. 1). The probability of late-

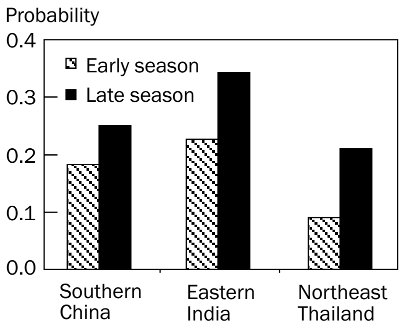

Fig. 1. Estimated probabilities of early- and late-season drought, in southern China (1982-2001), eastern India (1970-2000), and northeast Thailand (1970-2002).

season drought was found to be higher than that of the early-season drought generally. The late-season drought was also found to be spatially more covariate than the early-season drought. As rice yield is more sensitive to drought during flowering/grain-filling stages (i.e., during late season, according to the definition used here), the late-season drought is thus likely to have a larger aggregate production impact than the early-season drought.

The temporal instability in rice production as measured by the de-trended coefficient of variation of rice yield was found to be higher in eastern India relative to the other regions. The corresponding coefficients of variations for southern China and northeast Thailand were much lower, indicating that droughts in these regions are not as covariate spatially as in eastern India, with their effects being limited to some pockets. Given the nature of the temporal variability, the aggregate impact of drought on production is also likely to be higher in eastern India relative to the other two regions.

The estimated average loss in rice production during drought years for the three states of eastern India is 5.4 million tons. This is much higher than for northeast Thailand (less than 1 million tons) and southern China (around 1 million tons but not statistically significant). The loss (including any nonrice crops included) during drought years is thus 36% of the average value of production in eastern India. This represents indeed a massive loss during drought years (estimated at $856 million).

As droughts do not occur every year, the above estimate of production loss needs to be averaged over a run of drought and nondrought years to get an annual average loss estimate. Again for eastern India, this represents an annual average loss of $162 million (or 6.8% of the average value of output). For northeast Thailand and southern China, the losses were found to be much smaller and averaged at less than $20 million per year (or less than 1.5% of the value of output).

The estimates thus indicate that, at the aggregate level, production losses are much higher for eastern India than for the other two regions. Lower probability of drought, smaller magnitude of loss during drought years, and less covariate nature of drought together resulted in a lower production loss at the aggregate level in the other two regions relative to eastern India.

The overall economic cost of drought includes the value of production loss, the costs farmers incur in making adjustments in production systems during drought years, opportunities for gains forgone during good years by adopting ex-ante coping strategies that reduce losses during drought years, the generally lower productivity of drought-prone areas due to moisture deficiency, and the costs of government programs aimed at long-term drought mitigation. The public-sector provision of relief also involves large financial costs, but these are mainly transfer payments, and hence, do not involve an economic cost. The average annual cost for the three states of eastern India included in this study is in the neighborhood of $400 million. Overall, the cost of drought is a substantial proportion of the agricultural value added in eastern India.

The household-level impact of drought presented here is based mainly on the study in eastern India. Relative to eastern India, impact in northeast Thailand and southern China was found to be quite small and hence, is not discussed here.

Drought resulted in an overall income loss in the range of 24-58%. The drop in rice income was the main factor contributing to the total income loss. Earnings from farm labor also dropped substantially due to a reduced labor demand. Farmers attempted to reduce the loss in agricultural income during drought years by seeking additional employment in the nonfarm sector. This mainly included employment as wage labor in the construction sector for which farmers often migrated to distant places. The additional earning from nonfarm employment was, however, clearly inadequate to compensate for the loss in agricultural income.

Farmers relied on three main mechanisms to recoup this loss in total income. These were the sale of livestock, sale of other assets, and borrowing. These adjustment mechanisms helped recover only 6-13% of the loss in total income. Compared with the normal years, households still ended up with a substantially lower level of income despite all these adjustments. Thus, all the different coping mechanisms farmers deployed were found to be inadequate to prevent a shortfall in income during the drought years.

The incidence of poverty increased substantially during drought years. Almost 13 million additional people "fell back" into poverty as a result of drought (Fig. 2). This is a substantial increase in the incidence of poverty and translates into the increase in rural poverty at the national level by 1.8 percentage points. Some of the increase in poverty may be transitory, with households being able to climb out of poverty on their own. However, other households whose income and assets fall below certain threshold levels may end up joining the ranks of the chronically poor. The data collected, however, did not permit the estimation of the proportion of these two categories of households.

Overall, farmers do not seem to have much flexibility in making management adjustments in rice cropping in relation to drought. Other than delaying the crop establishment if the rains are late, replanting and resowing when suitable opportunities arise, and some reduction in fertilizer use, farmers mostly follow a standard set of practices irrespective of the occurrence of drought. This could partly be due to the fact that drought mostly occurs during the late season, by which time the opportunities for crop management adjustments to reduce losses are no longer available. The timing of drought (mostly late rather than early) and the lack of suitable technological options probably limited the flexibility in making tactical adjustments in crop management practices to reduce the losses.

Since rice is the staple food, a loss in its production can be expected to result in major adjustments in consumption. Such adjustments may range from reduced sale of rice, reduced quantity retained as seeds for the following year, increased amounts purchased, substitution of other crops for rice, supplementation of food deficit by other types of food not normally consumed, and in the worst-case scenario, a reduction in consumption.

Farmers made all these types of adjustments to a varying degree. Despite these various adjustments, most farmers were unable to maintain consumption at the pre-drought level. They reduced both the number of meals taken per day as well as the quantity consumed per meal. As a result, the average number of meals taken per day dropped from close to three to close to two, with 10-30% of the households reducing their frequency of food intake to one meal per day. A large proportion (60-70%) of the households also reduced the quantity of

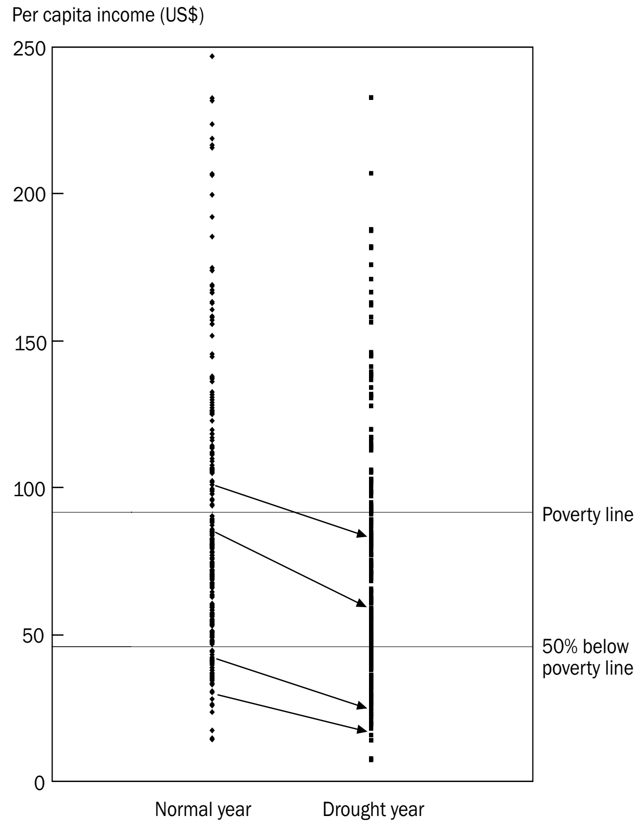

Fig. 2. Effect of drought on incidence and severity of poverty phenomenon, Jharkhand (each dot refers to a household).

food consumed per meal. In addition, households consumed other "inferior" food items that were not normally consumed.

The interruption and/or discontinuation of children's education is a disinvestment in human capital, which will most definitely reduce their future earning potentials in most cases. An important pathway for escape from poverty may be foreclosed as a result of drought. More than 50% of the farmers reported curtailing children's education.

Relative to eastern India, the economic costs in southern China and northeast Thailand were found to be small, both in absolute and relative terms. The production losses at the aggregate level in these two regions were relatively small due to a lower frequency and less covariate nature of drought. In addition, rice accounted for a smaller proportion of the household income due to a more diversified income structure. The differences in the rice production systems, the level of income diversification, and the nature of drought in these two latter regions are hence, the major factors determining the relative magnitudes of economic losses.

In the case of eastern India, rice accounts for around 40% of the total household income. The share of rice in the total household income in southern China and northeast Thailand is about half that in eastern India. Eastern Indian farmers thus lose proportionately more income during drought years. Due to limited diversification of farm income, which is generated mainly from rice, the household-level consequences of drought in eastern India are thus more severe relative to the other two regions. In both northeast Thailand and southern China, agricultural income is more diversified. In addition, the share of nonfarm income in the total income is much higher. Thus, a more commercialized agriculture and a greater diversification of farm incomes seem to have contributed to a smaller consumption consequence of drought in southern China and northeast Thailand relative to eastern India by weakening income correlations and improving the effectiveness of coping mechanisms. The effect of these factors on household-level impact is stylized in a summary form in Figure 3.

Drought mitigation options

Improved rice technologies that help reduce the losses to drought can play an important role in long-term drought mitigation. Important scientific progress is being made in understanding the physiological mechanisms that impart tolerance for drought. Similarly, progress is being made in developing drought-tolerant rice germplasm through conventional breeding and the use of molecular tools. The probability of success in developing rice germplasm that is tolerant of drought is likely to be substantially higher now than what it was 10 years ago. Complementary crop management research to manipulate crop establishment, fertilization, and general crop care for avoiding drought stress, better utilization of available soil moisture, and enhancing the plant's ability to recover rapidly from drought can similarly help reduce the losses.

The late-season drought is more frequent and tends to have more serious economic consequences for poor farmers than the early-season drought. In addition to having to deal with consequences of low or no harvest, farmers also lose their investments in seeds, fertilizers, and labor if the crop is lost due to late-season drought. Although early-season drought may prevent planting completely, farmers can switch early to other coping strategies such as wage labor and migration to reduce income losses in such years. Thus, the poverty impact of technology is likely to be higher if research is focused on developing technologies that help plants better tolerate the late-season drought.

Crop diversification is an important drought -coping mechanism of farmers. Rice technologies that promote, not constrain, such diversification are, hence, needed. In rainfed areas, shorter duration rice varieties can facilitate planting of a second crop using the residual moisture. Similarly, rice technologies that increase not just the yield but also the labor productivity will facilitate crop and income diversification. Higher labor productivity in rice production will help relax any labor constraint to diversification that may exist. Examples of such technologies are selective mechanization, direct seeding, and chemical weed control.

Development of water resources is an important area that is emphasized in all three countries for providing protection against drought. Opportunities of large-scale development of irrigation schemes that were the hallmark of green revolution are limited now due to high costs and increasing environmental concerns. However, there are still substantial opportunities to provide some protection from drought through small and minor irrigation schemes and through land use approaches that generally enhance soil moisture and water retention. Similarly, watershed-based approaches that are implemented in drought-prone areas of India provide opportunities for achieving long-term drought proofing by improving the overall moisture retention within the watersheds.

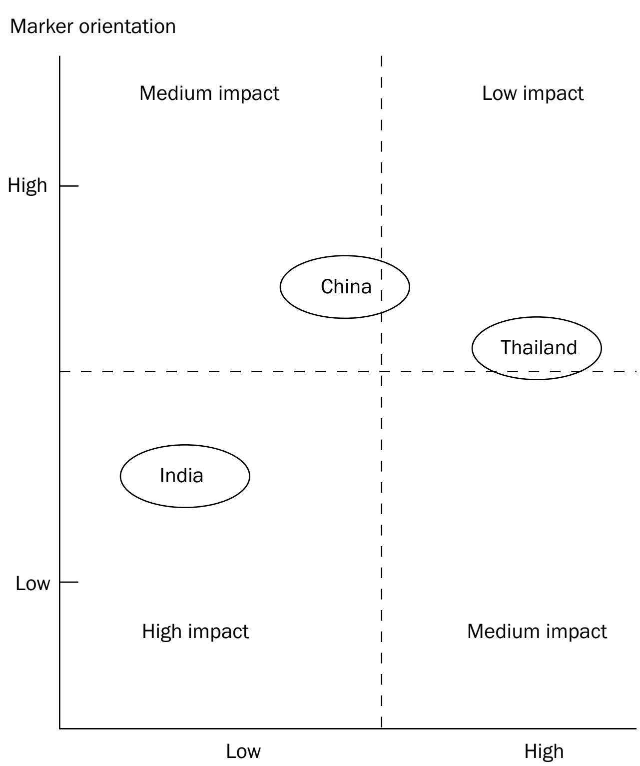

Fig. 3. Household-level impact of drought.

In all three countries studied, a major response to drought has been to provide relief to the affected population. India has the most elaborate institutional setup for providing drought relief, which mainly takes the form of employment generation through public works. Affected people are also provided with some inputs and credit. While the provision of relief is essential to reduce the incidence of hunger and starvation, the major problems with the relief programs are slow response, poor targeting of beneficiaries, and limited coverage due to budgetary constraints. A 'fire-fighting' approach that underlies the provision of drought relief cannot provide a long-term drought proofing despite the large amount spent during the drought years. It is important that the provision of relief during drought years is complemented by a long-term strategy of investing in soil and water conservation and utilization, policy support, and infrastructure development to promote crop and income diversification in drought-prone areas.

The scientific advances in meteorology and informatics have made it possible now to forecast drought with reasonable degrees of accuracy and reliability. Various indicators such as the Southern Oscillation Index are now routinely used in several countries to make drought forecasts. Suitable refinements and adaptations of these forecasting systems are needed to enhance drought preparedness at the national level as well as to assist farmers in making more efficient decisions regarding the choice of crops and cropping practices.

While technological interventions can be critical in some cases, this is not the only option for improving the management of drought. There is a whole gamut of policy interventions that can improve farmers' capacity to manage drought through more effective income- and consumption-smoothing mechanisms. Improvements in rural infrastructures and marketing that allow farmers to diversify their income sources can play an important role in reducing the overall income risk. Investment in rural education can similarly help diversify income. In addition, such investments contribute directly to income growth that will further increase farmers' capacity to cope with various forms of agricultural risks. Widening and deepening of the rural financial markets will also be a critical factor for reducing fluctuations in both income and consumption over time. Although the conventional forms of crop insurance are unlikely to be successful due to problems such as moral hazard and adverse selection, innovative approaches such as rainfall derivatives and international re-insurance of agricultural risks can provide promising opportunities. However, these alternative schemes have not yet been adequately evaluated. There are important challenges in employing weather-risk markets in developing countries. More work is needed for developing and pilot testing new types of insurance products and schemes suited to hundreds of millions of small farmers of Asia who grow rice primarily for subsistence.

Concluding remarks

Even in subhumid rice-growing areas of Asia, drought is clearly an important climatic factor that has large economic costs, both in terms of the actual economic losses during drought years and the losses arising from the opportunities for economic gains forgone. The provision of relief has been the main form of public response to drought. Although important in reducing the hunger and hardship of the affected people, the provision of relief alone is clearly inadequate and may even be an inefficient response for achieving longer term drought mitigation. Given the clear linkage between drought and poverty as demonstrated in this study, it is critically important to include drought mitigation as an integral part of the rural development strategy. Policies that in general increase income growth and encourage income diversification also serve to protect farmers from the adverse consequences of risk, including that of drought.

The scientific progress made in understanding the physiology of drought and in the development of biotechnology tools have opened up promising opportunities for making a significant impact on drought mitigation through improved technology. However, agricultural research in general remains grossly underinvested in developing countries of Asia. This is a cause for concern, not only for drought mitigation, but for promoting an overall agricultural development.

This is an overview of the book ***Economic costs of drought and rice farmers' coping mechanisms*** edited by S. Pandey, H. Bhandari, and B. Hardy. See back cover for details.

Time of day of flowering in wild species of the genus *Oryza*

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Potentially, the most consistent and damaging consequences of climate change for rice could come through the yield-depressing effects of high temperature (Sheehy et al 2006). Anthesis is very susceptible to damage in the 35–40 °C temperature range and exposure for a matter of a few hours during flowering can reduce floral reproduction (Satake and Yoshida 1978, Nishiyama and Satake 1981, Baker et al 1992). A simple model (Sheehy et al 2005) was used to validate the hypothesis that flowering close to dawn or at night could make plants much less vulnerable to high temperature-induced sterility (Nishiyama and Blanco 1980). The time of day when flowering commenced (TDF) in the main stems of 91 *Oryza sativa* and 5 *O. glaberrima* cultivars was studied by Sheehy et al (2005). *O. glaberrima* (Marori) had the earliest TDF of 0830. Of the *O. sativa* cultivars, Chhalangpa had the earliest TDF of 0915.

We decided to determine whether wild rice species flowered close to dawn (0500–0600). Consequently, a total of 61 accessions were selected from IRRI germplasm to represent a wide range of countries with hot climates. Each of the wild species of *Oryza* was included in the study; *O. neocaledonica* was unavailable. Because wild rice cannot be grown in the field, the accessions were grown in a screenhouse at IRRI following appropriate protocols. The seedlings were transplanted at a spacing of 20 cm × 20 cm into plastic buckets (45.5 cm in diameter and 62.5 cm in height) containing lowland soil. A basal application of 18.2 g per bucket of complete fertilizer (NPK) was applied. Subsequently, 2 g of N were added monthly and the soil was kept saturated throughout the experiment. The main stems of four replicates were observed for TDF on the first and final days of flowering; the difference in the number of days was the time a panicle took to complete (CPF). The time taken for the spikelets to close following flowering (anthesis) was also recorded. To test the consistency of TDF across years, the experiment was conducted in 2002, 2003, and 2004. In 2002, it was found that more accessions could have been observed, so the number of accessions to be germinated was increased from 54 to 61 in 2003. However, in both 2003 and 2004, several of the accessions failed to grow.

In the 3 years of the experiment, seven of the accessions from six wild rice species consistently had TDFs earlier than 0700 (see table). Only one species (*O. alta*) flowered at night. Anthesis lasted for about 2 h; the average for all the accessions in all the years was 114 ± 6 min. A linear regression between TDF on the final day of flowering (y) and TDF on the first day of flowering (x) across all accessions and years ($y = 1.019x - 0.008$; $P < 0.001$) showed that these TDFs were almost identical. This result suggests that TDF does not vary significantly for a panicle on each of its days of flowering; the panicles took between 3 and 9 d to complete flowering (see table). The study showed that wild rice species are a potential source of early TDF genes.

References

Baker JT, Allen LH Jr, Boote KJ. 1992. Effects of CO_2 and temperature on growth and yield of rice. J. Exp. Bot. 43:959-964.

Nishiyama I, Blanco L. 1980. Avoidance of high temperature sterility by flower opening in the early morning. JARQ 14:116-117.

Nishiyama I, Satake T. 1981. High temperature damage in rice plants. Jpn. J. Trop. Agric. 25:14-19.

Satake T, Yoshida S. 1978. High temperature-induced sterility in indica rice at flowering. Jpn. J. Crop Sci. 47:6-17.

Sheehy JE, Elmido AE, Centeno HGS, Pablico PP. 2005. Searching for new plants for climate change. J. Agric. Meteorol. 60:463-468.

Sheehy JE, Mitchell PL, Allen LH, Ferrer AB. 2006. Mathematical consequences of using various empirical expressions of crop yield as a function of temperature. Field Crops Res. 98:216-221.

Mean and standard error of the earliest time of day when flowering commenced (TDF) and the number of days a panicle took to complete flowering (CPF) of wild rice species. (Observations made in 3 different years; data arranged from early to late TDF in 2002.[a])

Accession no.	Wild rice species	2002				2003				2004			
		TDF (h)		CPF (d)		TDF (H)		CPF (day)		TDF (H)		CPF (d)	
		Mean	SE[b]	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
80740	*O. granulata*	0500	0	7	0.7	0611	7	8	1	0600	0	6	0.0
100820	*O. ridleyi*	0528	10	9	2.4	0600	0	5	0				
101424	*O. eichingeri*	0545	4	4	1.0	0557	1	5	0	0600	0	6	0.7
104985	*O. latifolia*					0541	3	5	1	0600	0	7	0.0
105144	*O. grandiglumis*	0600	0	9	0.7	0600	0	5	0				
105156	*O. grandiglumis*	0600	0	7	1.2					0730	44	5	1.0
106241	*O. grandiglumis*	0600	0	7	0.7					0631	1	6	0.0
80720	*O. officinalis*	0600	0	4	0.6	0601	0	4	0	0600	0	7	0.0
101414	*O. officinalis*	0600	0	7	0.6	0937	3	5	0	0915	0	6	0.0
100974	*O. longiglumis*	0630	14	9	0.9	0712	5	5	1				
101081	*O. minuta*	0650	8	5	0.8	0700	0	6	1	0700	0	6	0.0
103912	*O. barthii*	0705	10	5	0.5	0830	0	4	0	1032	1	7	0.0
103421	*O. rhizomatis*	0705	5	7	0.8								
100885	*O. latifolia*	0712	29	5	0.6	0541	2	6	1	0600	0	5	0.0
100930	*O. longistaminata*	0808	2	5	0.3	0935	6	5	0	0951	12	7	0.7
89245	*O. eichingeri*	0820	12	5	0.6	0715	3	5	0	0700	0	7	0.3
104117	*O. barthii*	0825	3	3	0.3	1018	2	5	1	1006	10	4	0.3
104981	*O. barthii*	0836	13	3	0.0	0906	12	4	0				
104119	*O. barthii*	0843	11	3	0.3	0956	1	5	0	1022	8	5	0.3
102175	*O. nivara*	0845	19	3	0.3	1007	9	5	1	1000	0	6	0.8
104084	*O. barthii*	0845	17	4	0.0	1003	1	6	0	1026	33	4	0.3
86541	*O. meridionalis*	0905	17	9	5.5	0945	6	6	0	1030	0	4	0.3
102167	*O. nivara*	0905	15	4	0.6	0955	4	6	1	0932	1	3	0.0
105666	*O. glumaepatula*	0907	8	5	0.5					1046	14	6	0.6
102176	*O. nivara*	0912	20	3	0.3	1131	11	5	1	1050	20	6	0.6
105570	*O. brachyantha*	0919	23	3	0.3					0921	3	5	0.0
102163	*O. nivara*	0921	15	4	1.8	1004	3	4	0	0600	0	5	0.0
103534	*O. barthii*	0922	11	3	0.3	1000	12	4	0	1020	8	4	1.7
104433	*O. rufipogon*	0922	16	5	0.5	0945	6	5	0	1007	2	7	0.3
100940	*O. barthii*	0925	2	3	0.0	0933	2	4	0	1001	8	4	0.3
105925	*O. nivara*	0925	0	4	0.0	0832	1	5	0				
104447	*O. rufipogon*	0927	34	6	1.7	0927	7	4	0	0933	1	6	0.6
104112	*O. barthii*	0937	8	4	0.3	0915	6	5	1	0942	15	6	0.3
102113	*O. barthii*	0942	16	4	0.3					0930	0	5	0.0
104408	*O. nivara*	0957	29	5	1.0	0922	5	5	0	1100	0	5	0.0
104061	*O. barthii*	1003	30	4	0.3	0945	18	4	0	1007	16	5	1.3
104405	*O. nivara*	1010	2	3	0.0	0921	11	5	0				
89145	*O. barthii*	1030	81	7	0.3	0937	3	5	0	0600	0	6	0.0
106207	*O. barthii*	1030	14	3	0.3	0959	2	4	0	1035	0	4	0.0
104402	*O. nivara*	1031	19	3	0.3	1000	0	5	1	1043	5	5	0.0
104399	*O. sativa/O. nivara*	1050	6	5	0.6	0933	4	4	0	1045	0	5	0.0
105607	*O. punctata*	1052	12	4	0.6	1048	6	5	0	1001	1	4	0.0
103897	*O. punctata*	1056	4	6	1.3	1057	12	6	1	1041	1	6	0.3
88796	*O. glumaepatula*	1107	14	5	0.3	1010	4	6	0	1030	0	5	0.8
105180	*O. punctata*	1108	9	4	0.6	1107	2	6	0	1130	0	6	0.0
104976	*O. longistaminata*	1116	30	6	0.7	1330	10	5	0				
105424	*O. rufipogon*	1135	73	4	0.3	1104	1	5	0				
101236	*O. brachyantha*	1141	42	5	0.6					0958	15	4	0.0
103913	*O. longistaminata*	1148	63	3	0.3	1311	4	5	0				
105206	*O. longistaminata*	1215	70	4	0.7								
105563	*O. longistaminata*	1220	63	4	0.0								
101198	*O. longistaminata*	1232	71	4	0.0	1334	7	6	1				
106454	*O. longistaminata*	1330	0	5	0.3	1307	3	4	0				
100882	*O. australiensis*	1600	26	5	0.9					1551	1	5	0.5
100161	*O. alta*	2145	0	4	0.0	2233	2	4	1				
105273	*O. australiensis*					1556	10	5	1	1505	0	6	0.0
106001	*O. barthii*					1000	2	5	0	1026	4	4	0.3
100931	*O. barthii*					1041	7	3	0	1025	7	4	0.0
101429	*O. eichingeri*					1100	0	5	0	1052	2	6	0.0
101411	*O. meridionalis*					1128	1	6	0	1032	1	4	0.3
105623	*O. nivara*					1113	3	4	0	1127	1	6	0.7

[a]If data were absent in 2003 and 2004, it was because the accession failed to grow. *O. meyeriana* failed to grow in each of the years. The flowering pattern of *O. schlecteri* was too erratic to include in this table. [b]Standard error in minutes.

New cytoplasmic male sterile lines developed in Maharashtra State, India

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The successful use of hybrid vigor in rice largely depends on the availability of local cytoplasmic male sterile (CMS) and restorer lines. In India, many IRRI-bred CMS lines from wild abortive (WA) sources are being used to develop rice hybrids. This could lead to genetic vulnerability. The use of local CMS lines will help alleviate this problem and develop locally adaptable, heterotic hybrids. We screened several hundred elite genotypes with diverse genetic backgrounds for their maintaining ability at RARS.

Six effective maintainers for WA cytoplasmic sources were identified and successfully converted into local lines through backcrossing. The lines with complete pollen sterility identified from BC_6 to BC_8 were designated as KJTCMS 1A (IR68888A RTN-24-WA source), KJTCMS 2A (Coms 9A IR22896-225-WA source), KJTCMS 3A (PMS 11A Indrayani-WA source), KJTCMS 4A (IR 68897A RDN-93-1-3-WA source), KJTCMS 6A (UR58025 A Indrayani-WA source), and KJTCMS 7A (IR68886A Indrayani-WA source) in 2004-05. These lines, along with IRRI-bred CMS line IR58025A, were evaluated for their agronomic and floral traits and natural outcrossing potential during 2005 kharif. The experiment was laid out in a randomized block design with three replications during the 2005 wet season at five locations in Maharashtra State. Plants were transplanted at 20 × 20-cm spacing in a 4-m^2 plot. Five plants from the central row in each replication were observed. To study natural outcrossing potential, the CMS lines were planted adjacent to the corresponding maintainer lines. Good flowering synchrony was achieved. Seed set was attained without resorting to any supplementary pollination technique. Data on 10 characters were statistically analyzed (see table).

KJTCMS 1A, an early-duration (115–120 d) CMS line with WA cytoplasm, has these characteristics: short slender grain, dwarf stature, moderate vigor (7–10 tillers $plant^{-1}$), high spikelet number per panicle (210), and good stigma (45.2%) and panicle exsertion (70.40 %). It showed 100% pollen and spikelet sterility with around 25% outcrossing.

KJTCMS 2A is an early-duration (115–120 d), long, bold-grain type with WA cytoplasm. This dwarf line has medium vigor (7–10 tillers $hill^{-1}$), high spikelet number per panicle, and high panicle sterility, with 34.2% outcrossing.

KJTCMS 3 A, KJTCMS 6A, and KJTCMS 7A are medium-duration CMS lines with WA cytoplasm. They are semidwarf and have good panicle exsertion (64.13–67.5%) and stigma

Agronomic and floral traits of newly developed CMS lines in rice.[a]

Genotype	Plant height	Days to (d) flowering (cm)	Panicles (no.)	Panicle length (cm)	Spikelets $panicle^{-1}$ (no.)	Panicle exsertion (%)	Stigma sterility (%)	Pollen exsertion (%)	Spikelet sterility (%)	Outcrossing (%)
KJTCMS 1A	73.49	88.80	6.94	23.05	218.53	70.40	45.2	100.0	100.0	24.6
KJTCMS 2A	70.49	91.27	6.45	23.89	178.93	66.76	49.4	100.0	100.0	34.2
KJTCMS 3A	71.47	96.33	7.29	22.82	191.53	64.13	53.3	100.0	100.0	41.8
KJTCMS 4A	75.13	85.80	9.51	22.85	207.40	68.08	41.52	100.0	100.0	23.4
KJTCMS 6A	74.37	93.20	7.44	22.25	197.27	67.51	43.8	100.0	100.0	30.0
KJTCMS 7A	70.78	98.00	7.81	23.42	196.80	66.65	59.1	100.0	100.0	39.6
IR58025 A										
(check)	68.76	96.07	7.27	22.43	180.27	66.41	52.07	99.2	98.9	30.4
SE +	2.96	1.80	0.48	0.42	9.81	1.98	3.49	0.54	0.54	1.23
CD (0.05)	8.22	5.0	1.34	1.19	27.20	5.49	9.67	1.50	1.50	3.43
CV %	7.91	4.23	14.76	4.11	11.26	5.77	15.49	1.23	1.23	9.09

[a]All seven genotypes had white and shriveled anthers.

exsertion (43.8–59.1%). All three showed 100% pollen and spikelet sterility, with good outcrossing rate (30–41.8%).

KJTCMS 4A is an early-duration dwarf CMS line with medium slender grains. It has WA cytoplasm for male sterility. The plants showed good vigor (10–15 tillers plant^{-1}), high spikelet number per panicle (207), and good panicle (68.1%) and stigma exsertion (41.5%). This line recorded 100% pollen and spikelet sterility, with 23% outcrossing.

The WA cytoplasm from different donor CMS lines is transferred by conventional backcross breeding into commercially and popularly grown varieties/lines that have good grain quality. These lines could be used in developing new rice hybrid combinations with good grain and cooking quality.

Loktantra—a high-yielding, blast-resistant rice variety for Nepal's rainfed lowland areas

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Rice, the major food crop in Nepal, is grown under diverse environments—from plain tarai (<100 m asl) to high hills (>2000 m). Altitude and rainfall are the major variable factors in Nepal agriculture (Upadhyay et al 1996). The tarai and inner tarai (<500 m) and foothills (500–1,000 m) constitute 80% of the rice area in Nepal. They receive a medium rainfall of 200–500 mm. Suitable rice varieties with drought tolerance and blast resistance are needed for such areas.

Masuli (Mahsuri) was the most dominant variety in favorable rainfed areas (<500 m) from the 1980s to the 1990s. Its popularity brought about a definite grade of rice grain in the national market. However, late maturity and blast susceptibility contributed to a decline in Masuli area and production. Its adaptation decreases at altitudes >500 m because of delayed maturity. It also has poor performance in drought-prone rainfed lowland areas, even in places below 500 m.

Loktantra was released in May 2006 for the rainfed areas of tarai, inner tarai, and rainfed to partially irrigated areas of the foothills (<800 m). (It was named Loktantra [full democracy] to commemorate the peaceful movement in April 2006 that restored democracy in the country.) It is a uniform line selected and improved over various generations from the F_2 bulk of IR55072 (Mahsuri/IR4547-6-2-2) that was introduced from IRRI in 1986. The pedigree was named NR1487-2-1-2-2-1-1 and was evaluated from 1996 to 2002 for grain yield, various agronomic quality traits, and disease resistance across target locations. Radha 4 (IR8423-156-2-2-1), a popular rainfed lowland variety, was used as a check. Loktantra is a semidwarf, coarse-grained variety and it responds to higher N application. It matures in 125–130 d and yields >3.0 t ha^{-1} in on- and off-station trials (Table 1) (Khatiwada 2006). It is similar to Radha 4 in grain yield and tillering ability. It is taller and gives a higher straw yield, a trait farmers in the inner tarai and foothills prefer as they need more livestock feed.

Table 1. Performance of Loktantra over the years in on- and off-station multilocation trials.

Trait	Testing years	Loktantra		Radha 4	
		Tarai and inner tarai (<500 m)	Foothills (500–800 m asl)	Tarai and inner tarai (<500 m)	Foothills (500–800 m)
On-station trials (no.)	1996-1998	9	2	9	2
Days to heading		99	103	100	116
Plant height (cm)		123	115	99	84
Panicles m^{-2} (no.)		227	240	230	288
1,000-grain weight (g)		20.1	20.0	25.4	24.8
Grain yield (t ha^{-1})		3.75	3.0	3.73	3.2
On-farm trials (no.)	1998-2000	6	4	6	4
Grain yield (t ha^{-1})		3.33	3.25	3.5	3.52

Grain husk color and cooking and eating qualities were comparable with those of Masuli. Loktantra matures 2–3 wk earlier than Masuli, giving sufficient time for growing winter crops. It has superior grain quality (Table 2), more preferable cooking quality, better taste, and a more acceptable appearance of cooked rice than Radha 4. In greenhouse tests, it was found resistant to blast and moderately resistant to moderately susceptible to bacterial blight, and has field tolerance for stem borers (Table 2). The 2000 and 2001 research results showed grain yield comparable with that of Radha (4.0 and 4.4 t ha^{-1}) with the application of 60 and 90 kg N ha^{-1}, respectively. It yielded 5.0 and 4.0 t ha^{-1} (higher than Radha 4) with transplanting of 35- and 45-d-old seedlings, respectively. This is a much preferred characteristic as transplanting is often delayed in such an environment. Seed demand is increasing every year—the foundation seed sold among farmers increased from 300 kg in 2002 to 2,000 kg in 2005.

Table 2. Grain quality and disease/insect resistance of Loktantra.

Genotype	Grain quality					Disease/insect resistance[a]		
	Milled grain length (mm)	L/B	Shape	Milling recovery (%)	Protein (%)	Blast	Bacterial blight	Stem borer
Loktantra	5.48	2.57	Medium	68.0	6.8	HR	MR-MS	Field tolerance
Radha 4	6.16	2.69	Medium	70.0	6.1	MR	MR-MS	Field tolerance
Masuli	5.17	2.66	Medium	71.2	6.5	S	MR-MS	Field tolerance

[a] HR = highly resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible.

References

Khatiwada SP. 2006. Proposal document for the release of NR1487-2-1-2-2-1-1 as a commercial variety. Submitted to the National Seed Board, Crop Variety Releasing Committee, Seed Quality Control Centre, Harihar Bhawan, Nepal.

Upadhyay HK. 1996. Rice recommendation domains and implications for biotechnology initiatives in Nepal. In: Khush GS, editor. Rice genetics III. Proceedings of the Third International Rice Genetics Symposium. Manila (Philippines), International Rice Research Institute. p 971-977.

Release of four new interspecific varieties for the rainfed lowland in Burkina Faso

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Burkina Faso has three major rice ecologies—upland (10% of land area with 5% of the country's rice production), irrigated (23% of area and 53% of production), and rainfed lowland (67% of area and 42% of production) (Sié 1999). Rainfed lowland is the major rice ecology in the country, combining the characteristics of upland and irrigated systems. The declining and unpredictable rainfall pattern has led to the disappearance of traditional *Oryza sativa* cultivars. Consequently, farmers now cultivate *O. glaberrima*, which has good agronomic traits—i.e., acceptable grain quality, plant vigor, and resistance to major biotic and abiotic stresses (Pham 1992, Besançon 1993, Adeyemi and Vodouhe 1996, Sie 1999). To meet the demand of rice farmers and consumers, the rice research program in Burkina Faso started evaluating intra- and interspecific lowland progenies obtained from WARDA, Senegal, in 2000. This study aimed to identify, through a participatory approach, high-yielding varieties with resistance to biotic and abiotic stresses as well as tolerance for climatic and edaphic factors.

The study was conducted in Burkina Faso during the 2000-03 wet season. The plant materials comprised nine interspecific lines (*O. glaberrima* × *O. sativa indica*) and six intraspecific (*O. sativa* × *O. sativa*) line, including the check. Seeds were sown directly, three seeds per hill, at a spacing of 0.25 m within and between rows. The Fisher randomized complete block design with three replications was used with 16 rows of 5 m and plot area was 20 m^2. Plants in the 12 middle rows in each plot were harvested, leaving one border row on each side. The *IRRI Standard evaluation system for rice* was used to score morphological traits and disease and insect pest damage. Quantitative characters and reaction to biotic and abiotic stresses were noted (Table 2). Participatory varietal selection (PVS) was also carried out.

After 4 years of evaluation by INERA and by farmers (through PVS), four of the interspecific progenies that consistently showed good performance were released (Table 1). The characteristics of these four varieties are compared with those of local check FKR 54 (Table 2). They are shorter than the local check and thus are more resistant to lodging. They are not inferior to FKR 54 in terms of days to maturity. The new varieties, FKR 60N and FKR 62N, have longer grains. All four varieties had greater 1,000-grain weight and yield potential than the check (Table 2).

References

Adeyemi P, Vodouhe SR. 1996. Amélioration de la productivité des variétés locales de *Oryza glaberrima* Steud. par des croisements intra et interspécifiques avec Linn in hybridations interspécifiques au Bénin. Bouaké (Côte d'Ivoire): ADRAO. p 159-175.

Besançon. 1993. Biotechnol. Appl. Biochem. 18:93-102.

Pham JL. 1992. Evaluation des resources génétiques des riz cultivés en Afrique par hybridation intra et interspécifique. Thèse docteur en sciences, Université de Paris XI ORSAY, France. 236 p.

Sié M. 1999. Caractérisation des hybrides interspécifiques (*O. glaberrima* × *O. sativa*) pour leur adaptabilité à la riziculture de bas-fond. Formulaire de requête d'un financement spécial pour un projet d'un groupe d'action. 6 p (non publié).

Sié M. 1991. Prospection et evaluation genetique des varietés traditionnelles de riz (*Oryza sativa* L. et *O. glaberrima* Steud.) du Burkina Faso. 118 p.

Table 1. Pedigree listing and origin of four new rainfed lowland interspecific varieties released in Burkina Faso.

Designation	Pedigree (parents)	Origin	Name
WAS 161-B-9-3	TOG5681/4*IR64 St Louis, Senegal	WARDA	FKR56N[a]
WAS 191-9-3	IR64/TOG5681//4*IR64 St Louis, Senegal	WARDA	FKR58N
WAS 122-IDSA-1-WAS-1-1-B	TOG5681/3*IR64 St Louis, Senegal	WARDA	FKR60N
WAS 122-IDSA-1-WAS-6-1	TOG5681/3*IR64 St Louis, Senegal	WARDA	FKR62N

[a]FKR = Farako-Bâ Rice; N = NERICA (New Rice for Africa).

Table 2. Characteristics of four new rainfed lowland interspecific varieties released in Burkina Faso.

Characteristic	FKR 56N	FKR 58N	FKR 60N	FKR 62N	FKR 54 (check)
Plant height (cm)	115	102	105	108	128
Days to flowering	86	86	85	88	78
Days to maturity	116	116	115	118	108
Tillering	Good	Good	Good	Good	Good
Grain length (mm)	9.46	9.77	10.35	10.77	9.81
Grain width (mm)	2.85	2.49	2.27	2.47	2.58
1000-grain weight (g)	25.65	27.16	28.20	28.98	25.52
Presence/absence of awns	Awnless	Awnless	Awnless	Awnless	Awnless
Hairiness	Hairy	Hairy	Hairy	Hairy	Hairy
Glume color	Brown	Brown	Brown	Brown	Deep brown
Resistance to blast	Moderately resistant	Moderately resistant	Moderately resistant	Moderately resistant	Moderately resistant
Flag leaf angle	Erect	Erect	Erect	Erect	Erect
Resistance to shattering	Fair	Fair	Fair	Fair	Fair
Apex color at maturity	Colorless	Colorless	Colorless	Colorless	Colorless
Response to N	Good	Good	Good	Good	Good
Yield potential (t ha^{-1})	5–7	5–7	5–7	5–7	5–6

AM3—an induced rice mutant with improved grain size and yield

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Abhilash (IET5882), a variety derived from CR63-6218/Pankaj, was released for cultivation in zones 8 (upland) and 9 (rainfed lowland) of Karnataka, India, in 1985. This improved variety has several acceptable agronomic traits: long duration (150 d), medium height (110 cm), high yield (5 t ha^{-1}), and tolerance for blast and major insect pests such as stem borers and leaffolders. Its only unacceptable feature is its long and medium bold grains. Therefore, through induced mutagenesis, an attempt was made to recover mutants with slender grains while retaining all other traits of Abhilash intact.

One thousand mature seeds (M_0) of Abhilash were exposed to γ (gamma) irradiation (25 kr) at Bhaba Atomic Research Centre, Mumbai, India. The M_1 seeds were grown in the field at the Agricultural Research Station (zone 9 of Karnataka) during the 2000 wet season (WS) (Jun-Dec). During harvest, care was taken to collect panicles only from the main tiller. The seeds were bulked (Joshua 2000) to grow the M_2 (10,000 plants) during the 2001 WS. Seeds from 74 selected individual plants were advanced to the M_4 generation. Eight mutants were finally selected and grown in 2 × 3-m plots with three replications to evaluate the stability of the mutant phenotype and other agronomic traits in the M5 generation during the 2005 WS. The parent variety (Abhilash) and a variety released for zones 8 and 9 in 1974 with superior grain size (Intan) were used as checks.

Table 1. Performance of Abhilash and its mutants at the Agricultural Research Station, Sirsi, Karnataka, India, 2005 wet season.

Parent/mutant/ check	Days to 50% flowering	Plant height (cm)	Kernel size (mm)			Grain yield (t ha^{-1})
			Length (L)	Breadth (B)	L/B	
AM3	124.00	97.80	7.37	2.33	3.16	4.7
Abhilash	124.00	96.07	6.90	2.80	2.47	4.5
AM68	131.33	77.13	5.33	2.67	2.00	4.5
Intan	124.00	109.60	6.97	2.23	3.12	4.3
AM46	135.33	79.80	5.80	2.97	1.96	4.1
AM36	140.00	91.67	5.67	2.70	2.10	4.0
AM23	125.00	93.27	6.97	2.57	2.72	3.9
AM31	121.33	114.00	7.57	2.50	3.03	3.5
AM49	124.33	95.40	7.50	2.43	3.09	3.2
AM4	115.33	97.87	8.13	2.10	3.88	3.1
CV	0.24	3.04	4.94	4.49	7.67	9.87

Preference for grain size and shape varied from one group of consumers to another. (For general consumption, kernel length-breadth ratio (L/B) between 2.5 and 3.0 is acceptable as long as kernel length is more than 6 mm [Kaul 1970].) In general, long grains are preferred in the Indian subcontinent. Four mutants (AM31, AM49, AM3, and AM4) with an L/B value significantly more than that of Abhilash were recovered (Table 1). These mutants had kernel length more than 7 mm. Compared with Abhilash, AM3 and AM49 did not show any significant difference in terms of days to 50% flowering and plant height. Interestingly, AM3 had a marginally higher yield than the parent and Intan. Therefore, it looks most promising with its improved kernel shape and size, and marginal yield advantage over the parent. Because AM3 has all the other desirable agronomic characters, it could be highly acceptable to consumers. AM4, with exceptionally slender (L/B of 3.95) and long kernels (8.13 mm), might be prone to breakage during milling. AM3 was tested in five different locations for agronomic and yield traits

Table 2. Performance of AM3 in five locations, Karnataka, India, 2006 wet season.

Parent/mutant/ check	Grain yield (t ha^{-1})			
	Sirsi (2)[a]	Mundgod (2)	Mugad (1)	% increase
AM3	6.3	6.5	5.0	
Abhilash	5.5	6.1	4.9	7.9
Intan	5.1	4.8	3.6	31.9

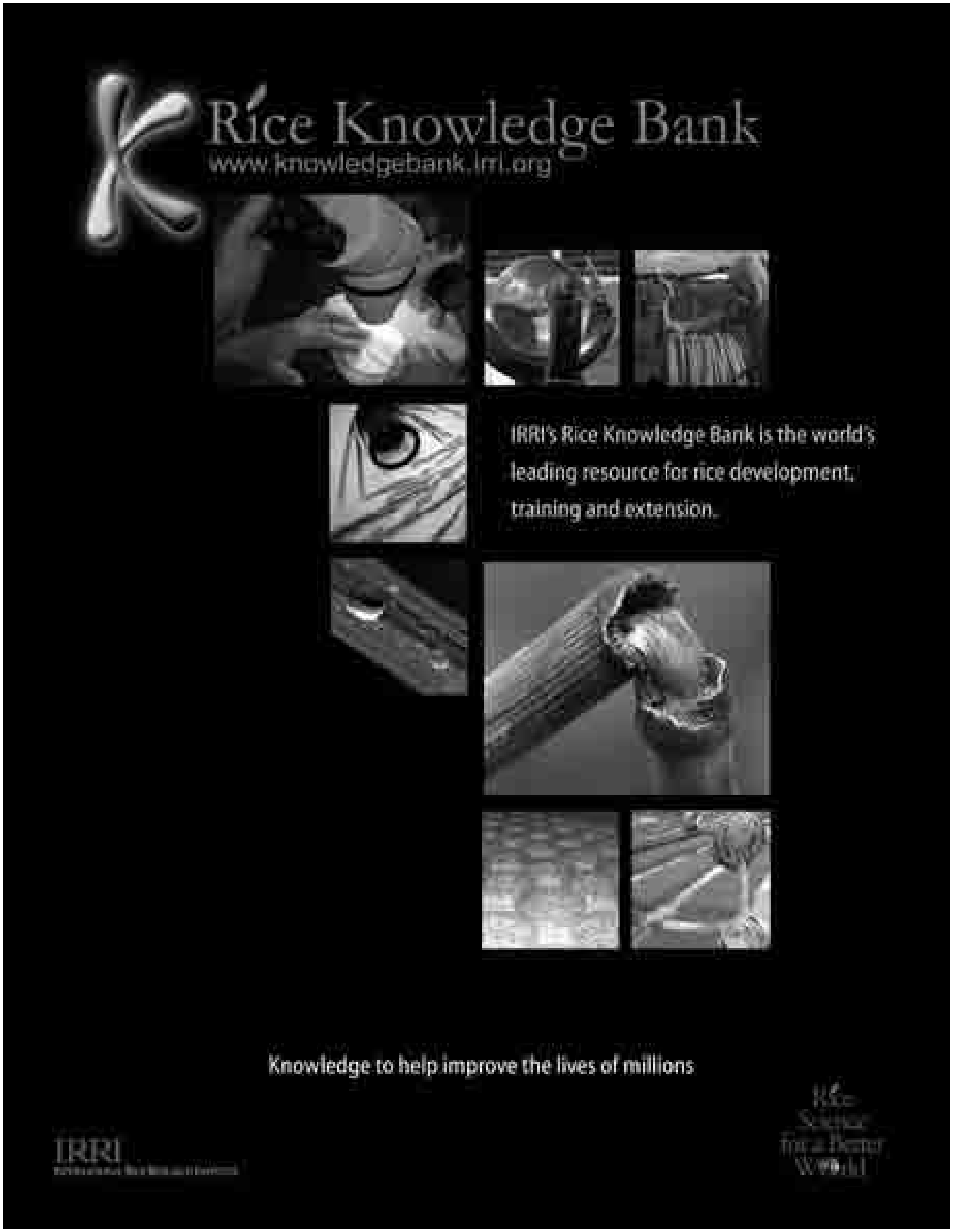
[a]Number of test locations.

during the 2006 Wet season. It recorded 7.9% and 31.9% higher yield than checks Abhilash and Intan, respectively (Table 2).

References

Joshua DC. 2000. Guidelines for success in mutation breeding. In: Proceedings of the DAE-BRNS Symposium. Mumbai (India): Bhabha Atomic Research Centre. p 21-25.

Kaul AK. 1970. Early generation testing for quality characteristics II. Rice. Indian J. Genet. Plant Breed. 30:237-243.



Survival of *Sarocladium oryzae* in rice seeds as affected by length of storage period

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Fungal sheath rot is caused by *Sarocladium oryzae* (Sawada) W. Gams & D. Hawksw., a seedborne pathogen present in rice-growing countries worldwide (Mew and Gonzalez 2002). Information on the survival of *S. oryzae* in rice seeds under various storage conditions is vital, especially when farmers use their own saved seeds. This study was undertaken to determine the survival of *S. oryzae* in rice seeds stored for various lengths of time.

The survival of *S. oryzae* was studied in seeds of eight popular varieties and two hybrids in Tamil Nadu—ASD16, ASD18, ASD19, Improved white ponni (IWP), ADT36, ADT43, IR50, ADT39, ADTRH1, and CORH2. For each variety, 200 seeds were used per replication; three replications were maintained. The seed samples were assessed for *S. oryzae* infection initially and stored in white cloth bags under laboratory conditions. The seeds were assessed for the presence of *S. oryzae* at monthly intervals (up to 7 mo under storage) using the standard blotter method.

The survival of *S. oryzae* in all rice seed samples declined with the increase in storage period (see table). The fungus survived up to 90 d in all seed samples, even if seed infection level was minimum. However, surviving *S. oryzae* were detected even after 120 d (in eight samples) and 210 d (in four samples) of storage. It was observed that the fungus survived for a longer period among seed samples with initial 30–40% *S. oryzae* seed infection. Maiti et al (1991) found *S. oryzae* surviving for 10 mo in infected rice seeds stored in Bihar, India, while Singh and Raju (1981) stated that the fungus can survive for as long as 4 mo in the seed and 7 mo in leaf sheaths kept at room conditions. It can last as long as 10 mo in leaf sheaths in the field in Pantnagar, India. In Taiwan, it survived for 75 d in rice stubbles (Hsieh et al 1980). The differences in survival time of the fungus as reported by various workers can be attributed to variations in environmental and storage conditions. This study confirms that *S. oryzae*-infected seeds stored for less than 7 mo, depending on initial seed infection, may give rise to seedling infection that could lead to sheath rot disease in the field.

Survival of *S. oryzae* in rice seeds in various storage periods.

Variety	*S. oryzae*-infected seeds (%)[a]							
	0 d	30 d	60 d	90 d	120 d	150 d	180 d	210 d
ASD16	9.00 ab	8.33 ab	3.67 ab	1.67 bc	0.66 ab	0.00 a	0.67 cd	0.0 c
ASD18	12.67 ab	8.00 ab	3.67 ab	1.00 ab	0.00 a	0.00 a	0.00 d	0.0 c
ASD19	5.00 a	4.67 a	2.00 ab	1.67 bc	0.66 a	0.00 a	0.67 d	0.0 c
Improved white ponni	11.67 ab	9.33 ab	6.33 bc	2.67 bc	1.00 ab	0.00 a	1.00 cd	0.0 c
ADT36	17.00 bc	11.67 abc	5.33 abc	3.33 c	1.67 ab	0.00 a	1.67 cd	0.0 c
ADT43	24.67 cd	17.67 bcd	9.33 cd	9.00 d	3.00 bc	0.66 ab	3.00 bc	0.67 bc
IR50	38.00 e	35.33 e	29.33 f	8.33 d	7.33 cd	1.33 b	1.33 ab	1.33 b
ADT39	8.33 ab	4.33 a	1.33 a	0.33 a	0.00 a	0.00 a	0.00 d	0.00 c
ADTRH1	33.33 de	27.00 de	13.33 de	12.67 d	7.33 cd	3.67 c	7.33 ab	3.67 a
CORH2	39.67 e	24.67 cde	20.00 ef	13.33 d	8.67 d	4.00 c	8.67 a	4.00 a

[a]Mean of three replications. Means followed by a common letter are not significantly different at the 5% level by DMRT. Arcsine-transformed values were used in the analysis.

References

Hsieh SPY, Shue MF, Liang WJ. 1980. Etiological studies on the sterility of the rice plant. II. Fungus associated with sterile rice plant. Plant Prot. Bull. Taiwan 22:41-46.

Maiti D, Variar M, Shukla VD. 1991. Off-season perpetuation of *Sarocladium oryzae* under monocropped rainfed ecosystem. Indian Phytopathol. 44(4):454-457.

Mew TW, Gonzales P. 2002. A handbook of rice seed-borne fungi. Manila (Philippines): International Rice Research Institute and Science Publishers. 83 p.

Singh RA, Raju CA. 1981. Studies on sheath rot of rice. Int. Rice Res. Newsl. 6(2):11-12.

Effects of planting arrangement on the occurrence of tungro virus infection in mixtures of resistant and susceptible varieties

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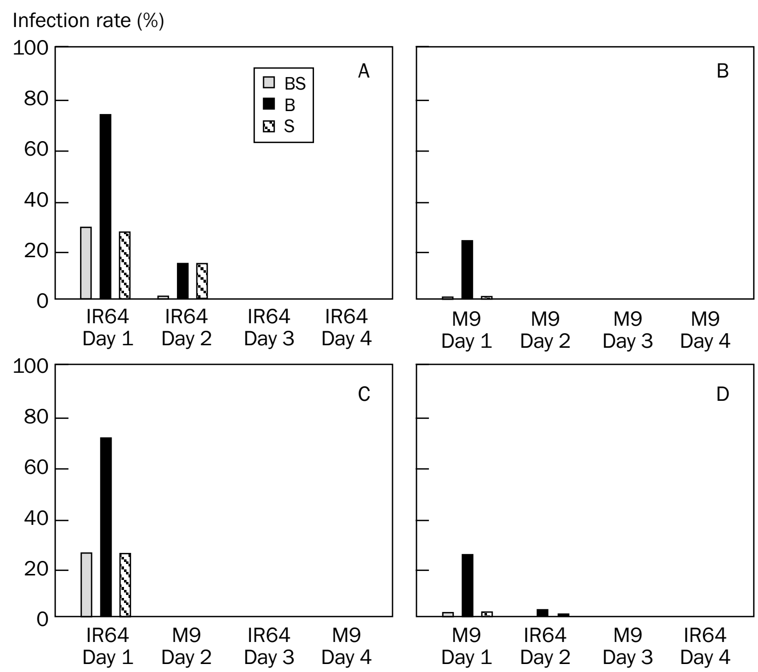
The application of variety mixtures has been shown to be an effective strategy to manage various fungal diseases of cereals (Mundt 2002). Nevertheless, few attempts have been made to examine the effects of variety mixtures on viral diseases in cereals. Rice tungro disease (RTD) is caused by the interaction between rice tungro spherical virus (RTSV) and rice tungro bacilliform virus (RTBV), both of which are transmitted by green leafhoppers (GLH) (Hibino et al 1990). To evaluate the efficacy of variety mixtures in the management of RTD, we examined the occurrence of tungro virus infection in confined settings simulating the mix-planting of RTD-susceptible IR64 and RTD-resistant Matatag 9 (IR73885-1-4-3-2-1-6) (Khush et al 2004).

To assess the virus transmission capability of GLH (*Nephotettix virescens*) for tungro viruses in the setting of a variety mixture, the incidence of tungro virus infection in IR64 and Matatag 9 serially inoculated with viruliferous GLH was examined (see figure). Single six-day-old seedlings of both varieties were infested with one viruliferous GLH for 24 h. The viruliferous GLH were then transferred daily to other seedlings for 3 d in the sequences shown in the figure. The rates of tungro virus infection were evaluated at 21 d after inoculation (DAI) by enzyme-linked immunosorbent assay. The consecutive transmission of RTBV to IR64 by GLH was observed for 4 d, although the infection rate was only about 1% on the fourth day (see figure, A). However, the transmission of RTSV to IR64 was observed for only 2 d. Meanwhile, both viruses were detected only in the first plants of the serial transmission through Matatag 9 (see figure, B). In serial transmissions alternating between IR64 and Matatag 9 (see figure, C and D), the transmission capability of GLH was retained only when they were transferred from Matatag 9 to IR64. These findings suggest that the transmission of tungro viruses by GLH was adversely affected when GLH were fed on Matatag 9.

To examine whether the proportion and distribution of Matatag 9 in the mixtures affect RTD occurrence, the rates of virus infection in variety mixtures established by seed mix and interplanting were compared. For the seed mix, seeds of Matatag 9 and IR64 were premixed in ratios specified in the table and sown in a plastic tray (49 cm × 37 cm × 12.5 cm) with 16 columns, 25 seeds per column. For the interplanting, the



Serial transmission of tungro viruses by GLH (*Nephotettix virescens*) on IR64 and Matatag 9. Single plants of IR64 and Matatag 9 (M9) were inoculated with one viruliferous GLH for 24 h. The viruliferous GLH were transferred daily to other plants in the sequences as depicted in A-D. The rates of infection with RTSV (S) and RTBV (B) and those of simultaneous infection with RTBV and RTSV (BS) were evaluated at 21 DAI. The rates of infection were based on results from 40 plants with three replications.

planting columns consisting of either of the two varieties were arranged in trays according to specified ratios. Ten-day-old seedlings were mass-inoculated with 3 or 10 viruliferous GLH per plant for 4 h. The rates of virus infection were evaluated at 21 DAI and normalized by the corresponding rates in the monoculture of IR64 for proper comparison. The experiment was set up using a split-plot design with three replications.

In general, the relative rates of tungro virus infection decreased significantly as the proportions of Matatag 9 in the mixtures increased, regardless of mixing method (see table). For the 75%:25% and the 25%:75% mixtures of IR64 and Matatag 9 inoculated with three viruliferous GLH per plant, the relative rates of infection with either tungro virus in the mixtures by seed mix were significantly lower than those in the corresponding mixtures by interplanting. Significant differences in the relative rate of simultaneous infection with RTBV and RTSV (RTBV+RTSV infection) were also observed between the mixtures by seed mix and the corresponding mixtures by interplanting inoculated with 10 GLH per plant. The relative rates of RTSV infection and those of RTBV+RTSV infection in the mixtures by seed mix inoculated with three GLH per plant were apparently lower than the actual ratios of IR64 in the mixtures, thus demonstrating the effectiveness of the seed mix in suppressing RTSV infection. The results presented here collectively indicate that the mixtures of a susceptible and a resistant variety, especially those by seed mix, could be applied to manage RTD in fields under moderate disease pressure.

References

Hibino H, Daquioag RD, Mesina EM, Aguiero VM. 1990. Resistance in rice to tungro-associated viruses. Plant Dis. 74:923-926.

Khush GS, Angeles E, Virk PS, Brar, DS. 2004. Breeding rice for resistance to tungro virus at IRRI. SABRAO J. Breed. Genet. 36:101-106.

Mundt CC. 2002. Use of multiline cultivars and cultivar mixtures for disease management. Annu. Rev. Phytopathol. 40:381-410.

Relative r

GLH per plant[a] (no.)	Variety ratio[b]	Rate of infection with RTBV + RTSV (%)[c]			Rate of infection with RTBV(%)			Rate of infection with RTSV (%)		
		Seed mix	Interplanting	Difference[d]	Seed mix	Interplanting	Difference	Seed mix	Interplanting	Difference
3	100% R	2.0 ae	2.0 a	0.0 ns	14.9 a	17.3 a	2.5 ns	5.9 a	4.8 a	1.1 ns
	75% R:25% S	17.3 b	34.3 b	17.1*	31.5 b	49.6 b	18.0**	19.5 b	36.0 b	16.5*
	50% R:50% S	39.4 c	51.0 c	11.6 ns	51.4 c	59.9 b	8.5 ns	42.0 c	52.2 c	10.1 ns
	25% R:75% S	66.4 d	82.8 d	16.4*	69.3 d	84.6 c	15.3*	67.5 d	82.8 d	15.3 *
	100% S	100.0 e	100.0 e	0.0 ns	100.0 e	100.0 d	0.0 ns	100.0 e	100.0 e	0.0 ns
10	100% R	15.7 a	14.7 a	0.9 ns	83.4 a	74.1 a	9.3 ns	16.8 a	15.2 a	1.6 ns
	75% R:25% S	29.8 ab	43.1 ab	13.3 *	88.8 a	94.7 a	5.9 ns	30.2 ab	41.2 b	11.0 ns
	50% R:50% S	49.0 b	60.2 b	11.2*	93.1 a	100.3 a	7.2 ns	47.6 b	57.1 b	9.5 ns
	25% R:75% S	89.8 c	101.2 c	11.5*	98.8 a	106.7 a	7.9 ns	86.7 c	93.6 c	6.8 ns
	100% S	100.0 c	100.0 c	0.0 ns	100.0 a	100.0 a	0.0 ns	100.0 c	100.0 c	0.0 ns

[a]Approximate number of RTBV/RTSV-viruliferous GLH per plant to mass-inoculate a variety mixture. [b]R: Matatag 9, S: IR64, [c]Rate of infection in each treatment was normalized by the corresponding rate in the monoculture of IR64 (100% S). [d]Difference in the relative rate of infection between a variety mixture established by seed mix and that by interplanting. ** = difference significant at 1% level, * = significant at 5% level, ns = not significant. [e]Means for infection rate in variety mixtures inoculated with the same number of GLH followed by a common letter in a column are not significantly different at the 5% level by LSD test.

Reaction of introgression lines of rice to a BPH population from India

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The brown planthopper (BPH) is an important insect pest of rice, having emerged as a serious threat to rice production in the major rice-growing countries during the green revolution in the 1970s. The application of insecticides to control BPH affects its natural enemies and results in planthopper resurgence. Host-plant resistance is considered an ideal option to manage BPH. Several wild species—*Oryza latifolia, O. minuta, O. nivara, O. officinalis, and O. punctata*—are thought to possess resistance to various biotypes of BPH (Wu et al 1986). The identification and transfer of novel resistance genes from these sources into popular varieties can significantly enhance the yield potential of these cultivars by increasing host-plant resistance to BPH (Brar and Khush 1997).

In this study, a set of 27 introgression lines developed at IRRI, using wild species *O. officinalis, O. australiensis, O. minuta, and O. rufipogon*, was screened against BPH populations from India. The insects were collected from rice fields at the experimental farm of the Barwale Foundation in Hyderabad, India, and reared on susceptible variety Taichung Native 1 (TN1), following the method of Heinrichs et al (1985). The standard seedbox screening test as described by Heinrichs et al (1985) was used to screen the introgression lines. Seeds were presoaked and sown in rows (3-cm intervals) in 60 × 45 × 10-cm seed boxes along with standard checks PTB33 (resistant) and TN1 (susceptible). A row of 20 seedlings was maintained per accession. Ten-day-old seedlings were infested with second- and third-instar nymphs (5–8 per seedling). The experiment was conducted at 28–30 °C and at 70–80% relative humidity in a greenhouse at the experimental farm of the Barwale Foundation. About a week after insect infestation, hopperburn was observed. Using the *Standard evaluation system for rice (SES)* (IRRI 1986), the plants were scored individually based on a 0–9 scale, when more than 90% of the TN1 plants were killed. The experiment had three replications. Accessions with a mean damage rating of 0–3.9, 4–6.9, and 7–9 were rated as resistant, moderately resistant, and susceptible, respectively.

Five introgression lines derived from the wild species exhibited strong resistance to BPH (see table). IR65482-7-216-1-2-B inherited its BPH resistance from *O. australiensis*; IR71033-62-15-8, IR71033-121-5-B, and IR71033-

Reaction of introgression lines of rice to BPH.

Introgression line	Wild species	Damage rating[a]	Reaction[b]
IR31917-45-3-2	Recurrent parent	9.0 ± 0.0	S
IR54571-1-2-44-15-2-3	*O. officinalis*	9.0 ± 0.0	S
IR54751-2-41-10-5-1	*O. officinalis*	4.8 ± 0.6	MR
IR65482-4-136-2-2-B	*O. australiensis*	9.0 ± 0.0	S
IR65482-7-216-1-2-B	*O. australiensis*	3.4 ± 0.8	R
IR65482-17-511-5-7-B	*O. australiensis*	8.3 ± 1.3	S
IR65482-18-539-2-2-B	*O. australiensis*	9.0 ± 0.0	S
IR71033-1-2-4-B	*O. minuta*	9.0 ± 0.0	S
IR71033-62-15-8	*O. minuta*	3.9 ± 1.8	R
IR71033-105-23-1-B	*O. minuta*	8.0 ± 1.0	S
IR71033-121-5-B	*O. minuta*	3.7 ± 1.3	R
IR71033-4-1-127-B	*O. minuta*	8.3 ± 1.4	S
IR71033-14-2-1	*O. minuta*	9.0 ± 0.0	S
IR71033-121-15	*O. minuta*	3.0 ± 0.0	R
IR71033-4-1-127	*O. minuta*	7.7 ± 1.4	S
IR73382-7-12-1-1-B	*O. rufipogon*	4.3 ± 2.5	MR
IR73382-7-12-1-9-1	*O. rufipogon*	8.9 ± 0.2	S
IR73382-7-12-3-B-B	*O. rufipogon*	8.3 ± 1.1	S
IR73382-85-9-1-2-1-1	*O. rufipogon*	7.0 ± 0.0	S
IR73382-85-9-1-2-2-B	*O. rufipogon*	7.6 ± 0.8	S
IR73384-3-6-10-4-6-2	*O. rufipogon*	8.5 ± 1.0	S
IR73680-9-24-8-1-2-2	*O. rufipogon*	8.3 ± 1.3	S
IR73680-9-4-3-2-3-2	*O. rufipogon*	9.0 ± 0.0	S
IR73680-4-5-10-2-1-2	*O. rufipogon*	3.5 ± 0.3	R
IR73681-1-1-8-6-2-2	*O. rufipogon*	8.5 ± 0.5	S
IR73681-1-1-8-6-3-3	*O. rufipogon*	8.8 ± 0.3	S
IR73885-1-4-3-2-1-10	*O. rufipogon*	6.3 ± 1.3	MR

[a]Mean ± SE of three replications. [b]Damage rating: 1–3.9 (resistant [R]), 4.0–6.9 (moderately resistant [MR]), and 7.0–9.0 (susceptible [S]).

121-15 got it from *O. minuta*; and IR73680-4-5-10-2-1-2, from *O. rufipogon*.

A similar study undertaken at IRRI also indicated that IR65482-7-216-1-2 and IR71033-121-15 were resistant and IR65482-18-539-2-2 was susceptible to BPH populations from Korea (IRRI 2002). Jena et al (2006) recently reported that IR65482-7-216-1-2 carries a dominant resistance gene, *Bph18(t)*. Results of this study suggest that it could be a potential donor of resistance to BPH populations in India as well. Further, in contrast to results obtained in Korea, the introgression line IR65482-4-136-2-2 was found susceptible to BPH in India, suggesting the possibility of a differential reaction of BPH populations from India and Korea to different genes from wild sources. The results of the present study can help breeders improve genetic resistance in rice cultivars as well as explore biotypic differences across BPH populations from different countries.

References

Brar DS, Khush GS. 1997. Alien introgression in rice. Plant Mol. Biol. 35:35-47.

Heinrichs EA, Medrano FG, Rapusas HR. 1985. Genetic evaluation for insect resistance in rice. Manila (Philippines): International Rice Research Institute.

IRRI (International Rice Research Institute). 1986. Standard evaluation system for rice. 4th ed. Manila (Philippines): IRRI. 52 p.

IRRI (International Rice Research Institute). 2002. Annual report: Plant Breeding, Genetics, and Biochemistry Division. Manila (Philippines): IRRI. 40 p.

Jena KK, Jeung JU, Lee JH, Choi HC, Brar DS. 2006. High-resolution mapping of a new brown planthopper (BPH) resistance gene, *Bph18(t)*, and marker-assisted selection for BPH resistance in rice (*Oryza sativa* L.). Theor. Appl. Genet. 112: 288-297.

Wu JT, Heinrichs EA, Medrano FG. 1986. Resistance of wild rice, *Oryza* spp., to the brown planthopper, *Nilaparvata lugens* (Homoptera: Delphacidae). Environ. Entomol. 15:648-653.

Validation of reported molecular markers for fertility restorer genes for WA cytoplasm of rice

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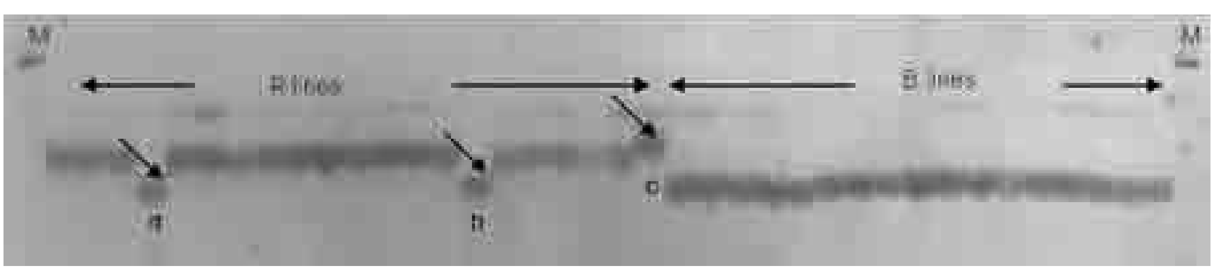
Hybrid rice, grown in more than 50% of the area in China, is becoming popular in other Asian countries as well, including India. Since rice is a self-pollinated crop, the cytoplasmic male sterility system is used to develop commercial rice hybrids. For this purpose, the use of restorers, which possess nuclear genes *(Rf)* that restore the fertility of CMS lines, is essential. Not all genotypes can be used as restorers. Conventionally, restorers are identified by test-crossing a large number of genotypes with CMS lines and then evaluating their progeny for pollen and spikelet fertility. This method is laborious, time-consuming, and less accurate. There is therefore a need to identify molecular markers that are tightly linked to *Rf* genes so that marker-aided selection (MAS) can be routinely done to identify restorers more quickly and more efficiently.

We used one F_2 population (IR58025A/KMR3) and one BC_1F_1 population (IR62829A//IR62829A/IR10198) for this study. To validate the linkage between *Rf* genes and molecular markers, we analyzed eight randomly amplified polymorphic DNA (RAPD) markers ($OPK05_{800}$, $OPN13_{600}$, $OPW01_{350}$, $OPU10_{1100}$, $OPAA12_{700}$, $OPY16_{550}$, $OPB07_{640}$, and $OPB18_{1000}$), nine simple sequence repeat (SSR) markers (RM258, RM228, RM244, RM171, RM216, RM6100, MRG4456, and pRf 1 and 2, and three cleaved amplified polymorphic sequence (CAPS) markers (RG140FL/RL, C1361*Mwo*I, and S12564*Tsp*5091) reportedly linked to *Rf* genes of different sources of cytoplasm.

Of the eight oligomers used in RAPD analysis, none were polymorphic between the parents of both populations studied. The primer OPK05800 did not show any amplification at all. Seven SSR primers—RM6100, RM228, RM216, RM171, MRG4456, and pRf 1 and 2—produced polymorphism in the F_2 population, whereas RM6100 showed polymorphism in both populations. Of the three CAPS markers analyzed, RG140FL/RL produced a polymorphic banding pattern between the parents of the F_2 population after digestion with *EcoR*1 enzyme, but none produced polymorphism between the parents of the BC_1F_1 population. Since RM6100 produced polymorphism in both populations studied, we checked the accuracy and efficiency of this marker for MAS using 18 B (maintainer) and 21 R (restorer) lines. The marker could distinguish all restorers from the maintainers, except for IR66 and C-20 R (see figure). It appears that these restorers have restoration genes different from the others. The selection accuracy of RM6100 marker was 94.87%. In view of its greater accuracy, this marker can be used for routine screening of genotypes to identify restorers. Using RM6100, MAS will save a lot of time and labor and also enhance the efficiency of hybrid rice breeding.



Validation of RM6100 on maintainer and restorer lines. a = IR66, b = C-20R, c = PRR78R; M = marker (100 bp); R = restorer; B = maintainer.

Performance of transgenic rice expressing C4 photosynthesis enzymes

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It has been demonstrated that transgenic rice with the *PEPC* gene has higher F_v/F_m and lower content of O_2 and malonyldialdehyde (MDA) (Zhang and Jiao 2002). Simultaneously, photosynthetic rate increased by 50% at 1,200 µmol m^{-2} s^{-1} and CO_2 compensation point decreased by 27% compared with those of untransformed rice. But the photosynthetic rate of NADP-malic enzyme (NADP-ME) and pyruvate Pi dikinase (PPDK) transgenic rice did not increase (Jiao et al 2002).

On the basis of previous research, a stable PPDK + PEPC + ME transgenic rice was obtained by crossing two transgenic lines with *PEPC* and *PPDK* genes and transgenic rice with the *NADP-ME* gene. The activities of PEPC, PPDK, NADP-ME, and malate dehydrogenase (MDH) in CKM transgenic rice, which were examined by a direct assay of enzyme activity, were 1,139, 83.47, and 102.60, and 98.05 µmol mg^{-1}chl h^{-1}, respectively (see table). Compared with untransformed rice plants, net photosynthetic rate of CKM transgenic rice increased by 46%. Supplying $NaHSO_3$, the ATP activator, the photosynthetic rate of CKM transgenic rice was 82% that of maize (see figure). Therefore, ATP is a key factor in developing C4-like rice. In addition, the table showed that MDA and O_2 content of CKM transgenic rice were lower than those of untransformed rice, which may be related to the increase in the photooxidation-tolerant enzymes superoxide dismutase and peroxidase.

References

Jiao DM, Hang XQ, Li X, Chi W, Kuang TY, Zhang QD. 2002. Photosynthetic characteristics and tolerance to photooxidation of transgenic rice expressing C_4 photosynthesis enzymes. Photosynth. Res.72:85-93.

Zhang YH, Jiao DM. 2002. Photosynthetic characteristics of PEPC transgenic rice. Int. Rice Res. Notes 27(2):14-15.

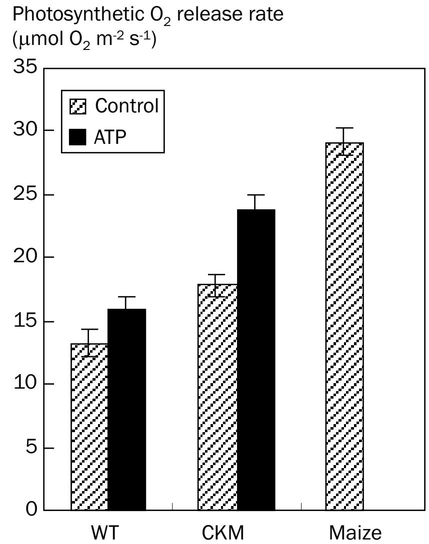
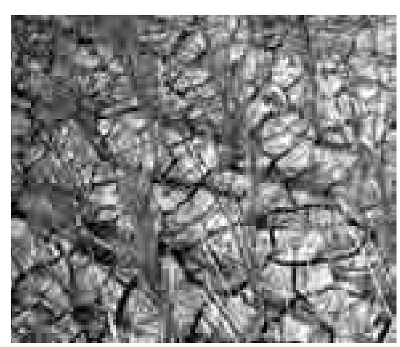


Fig.1 O_2 generation rate of WT and CKM and Maize. WT – untransformed rice (Kitaake); CKM – PEPC+PPDK+ ME transgenic rice. Values are means + SE (n = 4)

Activities of C4 photosynthesis enzymes and photooxidative indices in transgenic rice and untransformed rice.

	WTa	CKM	Enhancement
PEPC (µmol mg^{-1}ch .h^{-1})	62.10 ± 3.85	1139 ± 65.65	18.4 fold
PPDK (µmol mg^{-1}chl h^{-1})	23.52 ± 1.08	83.48 ± 6.80	3.5 fold
ME (µmol mg^{-1}chl h^{-1})	20.64 ± 1.76	102.60 ± 6.64	5.0 fold
MDH(µmol mg^{-1}chl h^{-1})	93.24 ± 4.91	98.05 ± 3.44	5.1%
SOD (units mg^{-1} protein min^{-1})	82.80 ± 2.49	128.07 ± 3.35	54.7%
POD (units mg^{-1} protein min^{-1})	53.04 ± 2.28	70.25 ± 3.02	32.5%
MDA (nmol g^{-1} FW)	17.36 ± 0.75	8.71 ± 0.37	–49.8%
O2 (nmol mg^{-1} protein min^{-1})	5.84 ± 0.23	3.33 ± 0.143	–43.0%

WT = untransformed rice (Kitaake); CKM = PEPC + PPDK + ME transgenic rice. Values are means + SE (n = 4).



Identification of marker loci associated with tungro and drought tolerance in near-isogenic rice lines derived from IR64/Aday Sel

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Drought and tungro disease are economically important constraints to rice production in Asia. Tungro is caused by rice tungro spherical virus (RTSV) and rice tungro bacilliform virus (RTBV), which are transmitted by the green leafhopper *Nephotettix virescens*. IR64, a popular rice variety, is highly susceptible to tungro and readily affected by drought. Here, we report on the performance of BC_3-derived lines from IR77298, which are nearly isogenic to IR64, but differ from it in their tolerance for tungro disease and drought. Such near-isogenic lines (NILs) are useful in physiological and genetic studies.

At IRRI, three tungro-tolerant BC_3F_2-derived lines (IR77298-14-1-2, IR77298-12-7, and IR77298-5-6) were developed by backcrossing Aday Sel to IR64 (Khush et al 2004). The coefficient of parentage of these lines with IR64 is 0.9. We confirmed the tolerance of these lines for tungro virus by enzyme-linked immunosorbent assay (ELISA) (Table 1). By screening these lines under drought conditions, it was observed that they also differed in yield under drought stress (Table 2); IR77298-14-1-2 was the highest yielding, IR77298-12-7 was intermediate, and IR77298-5-6 was the lowest. This difference was not evident under nonstress conditions. These lines have been evaluated for yield under a range of hydrological conditions and drought stress levels in 12 field trials conducted from 2003 to 2006 at IRRI. Results for IR77298-14-1-2 and IR77298-5-6 (extreme lines under drought stress) are presented in Table 2; the advantage of the former over the latter increased with decreasing mean yield resulting from water stress. Yield of IR77298-14-1-2 was 43 and 72% greater than that of IR77298-5-6 under severe lowland and upland stress conditions, respectively, but only 6% and 11% greater under nonstress lowland and upland conditions, respectively.

Since the three IR77298 lines are very closely related to each other and to IR64, if we scan the genome of these lines with DNA markers for loci that are polymorphic for the parents Aday Sel

Table 1. Rates of infection with tungro viruses based on ELISA.

Line designation	RTSV			RTBV + RTSV				
	Plants tested (no.)	RTSV-infected plants (no.)	RTSV-infected plants (%)	Plants tested (no.)	RTBV-infected plants(no.)	RTBV-infected plants (%)	RTSV-infected plants (no.)	RTSV infected (%)
Aday Sel	40	0	0	39	22	56	0	0
IR77298-5-6	40	2	5	40	32	80	0	0
IR77298-14-1-2	40	1	3	40	31	78	4	10
IR77298-12-7	40	5	13	40	35	88	1	3
Habiganj DW8 (T17905)	40	8	20	38	32	84	2	5
O. longistaminata (T11604)	40	10	25	39	36	92	14	36
Matatag 9 (IR73885-1-4-3-2-1-6)	39	14	36	39	19	49	2	5
IR72	33	13	39	35	30	86	4	11
IR62	38	26	68	32	30	94	14	44
Utri Rajapan	40	0	0	37	22	59	5	14
Utri Merah (16880)	40	0	0	37	12	32	0	0
Balimau Putih	34	11	32	31	16	52	6	19
ARC 11554	39	0	0	39	35	90	0	0
Utri Rah (16682)	35	0	0	32	22	69	0	0
IR64	38	24	63	40	38	95	19	48
Taichung Native 1	37	33	89	36	34	94	21	58
IR64 mutant M4D6 83-1	39	4	10	38	37	97	1	3

and IR64, it should be possible to answer two questions: 1) By comparing the three IR77298 lines with IR64, what genetic loci are responsible for tungro tolerance? 2) By comparing IR77298-14-1-2 and IR77298-5-6, what genetic loci cause yield differences under drought stress?

To identify the polymorphic loci, the three lines and the parents were genotyped with 157 SSR markers spaced at approximately 10 cM. All three IR77298 lines carried four common introgressions, one each on chromosomes 2 (RM154-RM279), 4 (RM335-RM518), 6 (RM136), and 9 (RM201) (see figure). Of these, the first two were larger introgressions, whereas the last two were smaller. RZ262, an RFLP marker located between RM335 and RM518, was previously reported to be linked to a dominant gene for green leafhopper and tungro virus resistance (Sebastian et al 1996). Testing it remains to be done to see whether there are any interactions of these loci with other loci affecting tungro tolerance.

Upon comparing IR77298-14-1-2 with IR77298-5-6, differences in introgression were found at six regions, one each on chromosomes 2 (RM555-RM262), 7 (RM11-RM248), 8 (RM152-RM404), 9 (RM464-RM566), 11 (RM552), and 12 (RM179-RM519). At all these loci, except on chromosome 9, IR77298-14-1-2 had introgressions that IR77298-5-6 lacked. Of all these loci, the region covering RM511 on chromosome 12 is particularly interesting. A large-effect QTL for yield under drought stress has been previously reported (Bernier et al 2007) to be linked to RM511 on chromosome 12. Thus, the region around RM511 seems to carry an important locus (or loci) for yield under drought stress. The same region has also been implicated in breeding for resistance to bacterial leaf blight and blast (Li et al 2006) and tolerance for phosphorus deficiency (Wissuwa et al 1998).

Further work using these NILs is ongoing to confirm these results and to test for interactions among all loci introgressed from Aday Sel to determine yield under drought stress. Additional backcrossing to IR64 has been done using these lines and large populations segregating at each of the loci (see figure) have been developed. With the new

Table 2. Grain yield (kg ha^{-1}) of lines during 2006 dry-season trials.

Line	Lowland, nonstress	Lowland, moderate drought stress	Lowland, severe drought stress	Upland, severe drought stress
Apo	4,710	1925	467	1564
IR64	3,972	692	320	296
IR77298-5-6	5042	881	257	77
IR77298-12-7	4002	1672	523	413
IR77298-14-1-2	5336	1573	1443	552
Mean	4945	1498	528	412
SED	946	375	206	323

Marker	Chromosome	Position (Mb)	IR77298-5-6	IR77298-12-7	IR77298-14-1-2
RM154	2	1055553	▨	▨	▨
RM236	2	1987397	▨	▨	▨
RM279	2	2763846	▨	▨	▨
RM555	2	4187025		▨	▨
RM452	2	9325914		▨	▨
RM262	2	20462030		▨	▨
RM335	4	679893	▨	▨	▨
RM518	4	2021511	▨	▨	▨
RM261	4	6396885		▨	
RM136	6	8812554	▨	▨	▨
RM11	7	19205425		▨	▨
RM248	7	29264592		▨	▨
RM152	8	676936		▨	▨
RM404	8	15285869		▨	▨
RM464	9	5460491	▨		
RM524	9	11597824	▨		
RM566	9	13303213	▨		
RM201	9	18408976	▨	▨	▨
RM552	11	4838207		▨	▨
RM179	12	14301400		▨	▨
RM511	12	17206059		▨	▨
RM519	12	19712608		▨	▨

Graphical genotype showing polymorphic loci (patterned cells) between lines IR64 and IR77298. Nonpatterned cells indicate monomorphic loci.

materials, it should be possible to fine-map and/or clone genes responsible for tungro tolerance and/or drought tolerance.

References

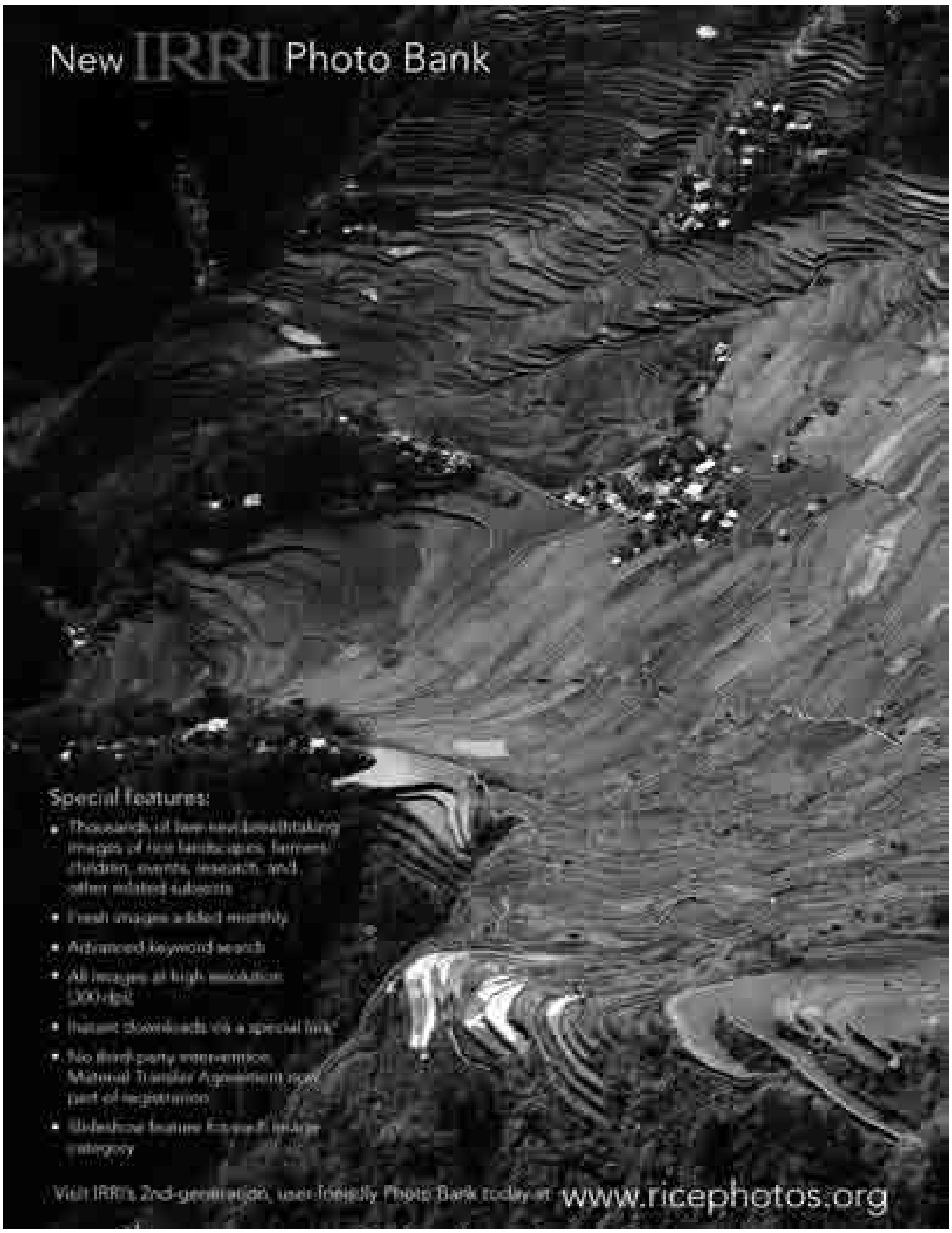
Bernier J, Kumar A, Venuprasad R, Spaner D, Atlin G. 2007. A large-effect QTL for grain yield under reproductive-stage drought stress in upland rice. Crop Sc.i 47:505-516.

Khush GS, Angeles E, Virk PS, Brar DS. 2004. Breeding rice for resistance to tungro virus at IRRI. SABRAO J. Breed. Genet. 36:101-106.

Li ZK, Arif M, Zhong DB, Fu BY, Xu JL, Domingo-Rey J, Ali J, Vijayakumar CHM, Yu SB, Khush GS. 2006. Complex genetic networks underlying the defensive system of rice (*Oryza sativa* L.) to *Xanthomonas oryzae* pv. *oryzae*. Proc. Natl. Acad. Sci. USA 103:7997-7999.

Sebastian LS, Ikeda R, Huang N, Imbe T, Coffman WR, McCouch SR. 1996. Molecular mapping of resistance to rice tungro spherical virus and green leafhopper. Phytopathology 86:25-30.

Wissuwa M, Yano M, Ae N. 1998. Mapping of QTLs for phosphorus-deficiency tolerance in rice (*Oryza sativa* L.). Theor. Appl. Genet. 97:777-783.



Effect of silicon carriers and time of application on rice productivity in a rice-wheat cropping sequence

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Scientists report declining trends in productivity of the irrigated rice-wheat cropping system and this growth stagnation has been observed not only in India but in most Asian countries as well. Experiments conducted so far have failed to establish a positive correlation between declining rice-wheat yield under the irrigated system and properties of available nutrients under long-term fertility experiments in intensive cropping systems. Scientists are therefore looking at another possibility. Plant-available silicon (Si) in the soil could be a possible soil-related cause of declining rice yields due to continuous higher mining by rice (Singh et al 2005). The present study aimed to find out the effect of recycling Si carriers through rice straw compost at different times of Si application on rice productivity in rice-wheat cropping systems.

A field experiment was conducted at the IAS Research Farm during the rainy seasons of 1999-2000, 2000-01, 2001-02, and 2002-03. Soil was sandy clay loam (Ustocrepts), slightly alkaline, with a pH of 7.2, with 0.34% organic carbon, 223 kg available N ha^{-1}(alkaline permaganate method; Subbiah and Asija 1973), 11.3 kg available P ha^{-1} (0.5 M $NaHCO_3$ extractable, colorimetric method; Olsen et al 1954), 232.4 kg available K ha^{-1}(ammonium acetate method; Jackson 1958), and 301.2 kg available Si ha^{-1}(acetic acid method; Barbosa Filho 1996). The trials tested eight Si carriers—control (0%), calcium silicate (100%), basic slag (100%), rice straw compost (100%), rice straw compost (50%) + calcium silicate (50%), rice straw compost (50%) + basic slag (50%), basic slag (50%) + calcium silicate (50%), and rice straw compost (33%) + calcium silicate (33%) + basic slag (33%)—and three time intervals of Si application—every year, alternate years, and every third year. The experiment was laid out in a split-plot design with three replications with Si carriers as the main plot and times of application as the subplot. Si was applied at 150 kg ha^{-1}, representing a 100% rate. A common dose of nutrients (120-60-60 kg NPK ha^{-1}) was applied through urea, diammonium phosphate, and muriate of potash, respectively. Nitrogen was applied in three splits: half as basal and the remaining half in two equal splits—at tillering and at panicle initiation. Total P and K were applied as basal. Rice variety Swarana (MTU 7029) was used as the test crop.

Application of Si carriers significantly increased effective tillers $hill^{-1}$, grains $panicle^{-1}$, and 1,000-grain weight. The highest effective tiller number $hill^{-1}$ was recorded with rice straw compost + calcium silicate, followed by rice straw compost + basic slag. Panicle weight also increased and maximum weight was noted with the application of rice straw compost + calcium silicate. This was significantly superior to the control and calcium silicate treatments. In general, the longest panicles were noted with rice straw compost + calcium silicate, although this was statistically on a par with the other Si carrier treatments, except the control. Application of rice straw compost + calcium silicate recorded a higher grain yield than the control but remained on a par with the rest of the Si carrier treatments. Similarly, straw yield was also higher with rice straw compost + calcium silicate, followed by rice straw compost + basic slag. The increase in straw and grain yield with the application of different Si sources could be attributed to the sum of the increases in growth and yield attributes. The favorable effect of rice straw compost + calcium silicate was probably brought about by the stable supply of Si during the rice crop cycle (Rani et al 1997).

The different times of Si application failed to show any significant effect on yield and yield attributes. However, the highest grain yield was recorded with the annual application of Si, followed by the alternate-year treatment. This could indicate that yearly application maintained Si availability throughout the growth and development of the rice crop. None of the interactions during the study period were significant.

Effect of Si carriers and time of application on yield and yield attributes of rice (pooled data over 3 y).[a]

Treatment	Effective tillers $hill^{-1}$ (no.)	Grains $panicle^{-1}$ (no.)	Panicle weight (g)	Panicle length (cm)	1,000-grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Silicon carrier							
Control	9.43	93.8	2.10	19.77	17.85	5.7	8.8
Calcium silicate (100%)	9.70	119.9	2.20	20.16	18.34	6.0	9.3
Basic slag (100%)	10.14	119.8	2.37	20.26	18.40	6.1	9.8
Rice straw compost (100%)	9.94	120.1	2.27	20.06	18.35	6.1	9.5
Rice straw compost (50%) + calcium silicate (50%)	10.65	124.5	2.44	20.57	18.56	6.4	10.0
Rice straw compost (50%) + basic slag (50%)	10.45	123.0	2.38	20.31	18.41	6.3	9.9
Basic slag (50%) + calcium silicate (50%)	9.92	119.2	2.36	20.24	18.32	6.1	9.7
Rice straw compost (33%) + calcium silicate (33%) + basic slag (33%)	10.05	119.9	2.33	20.17	18.33	6.1	9.6
SE±	0.30	3.6	0.06	0.27	0.12	0.1	0.2
CD ($P = 0.05$)	0.75	10.8	0.19	0.81	0.35	0.4	0.6
Application interval							
Every year	10.23	120.0	2.38	20.39	18.51	6.1	9.7
Alternate years	10.21	116.8	2.29	20.23	18.32	6.1	9.5
Every third year	9.67	115.8	2.26	19.98	18.17	6.0	9.4
SE±	0.10	2.2	0.03	0.15	0.06	0.1	0.1
CD ($P = 0.05$)	ns	ns	ns	ns	ns	ns	ns

[a]Interactions between Si carriers and time of application are not significant.

References

Barbosa Filho MP. 1996. Assessing Si available in soils and Si source for rice available Si in greenhouse studies. Research Report, EREC/IFAS. Belle Glade, Fla.(USA): University of Florida

Jackson ML. 1958. Soil chemical analysis. Englewood Cliffs, N. J. (USA): Prentice-Hall Inc. 498 p.

Olsen SR, Cole CW, Watanabe FS, Dean LA. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular 939. Washington, D.C.: United States Department of Agriculture.

Rani AY, Narayanan A, Saraswathi DV, Subbaramamma P. 1997. The effect of silicon application on growth and yield of rice plants. Ann. Plant Physiol. 11(2):123-128.

Singh K, Singh Y, Singh CS, Singh R, Singh KK, Singh AK. 2005. Silicon nutrition in rice. Fert. News 50(2):41-48.

Subbiah BV, Asija GL. 1973. A rapid procedure for estimation of available nitrogen in soils. Curr. Sci. 28(8):259-260.

Effect of polyolefin resin-coated controlled-release iron fertilizer on yield of transplanted rice

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Rice can suffer from iron (Fe) deficiency during the seedling stage because of aerobic conditions that favor the oxidation of Fe^{2+} to Fe^{3+} (Brown 1961). The ferric forms precipitate and get deposited on the root surface as ferric oxides and hydroxides, preventing the entry of soluble ferrous ions into the root system. As a result, the rice plant suffers from Fe deficiency and exhibits chlorosis in young leaves (Reddy and Prassad 1986). The correction of Fe chlorosis by soil application is difficult because of conversion into unavailable di- and trivalent Fe-hydrated oxides (Lindsay 1972). Similarly, foliar sprays often give erratic results because of limited penetration of Fe into the leaves. Therefore, there is a need to develop a method for supplying Fe continuously at the early crop growth stages. Polyolefin resin-coated slow-release Fe fertilizer is a potential alternative because the release of Fe from resin-coated materials is controlled by the quality of the resin coating. The greater solubility and stability result from the slow release of nutrients, which is in harmony with crop need. Therefore, our investigation was carried out to study the effect of rate and depth of placement of polyolefin resin-coated controlled-release Fe fertilizer on the yield of transplanted rice.

The field experiment was conducted during the rainy seasons of 2003-04 at the Agricultural Research Farm of IAS in Varanasi, India. The experimental soil (Inceptisol) has a pH of 7.2, 0.45% organic carbon, and an EC of 0.33 dS m^{-1} at 25 °C. The experiment was carried out in a split-plot design with three replications using scented rice variety Pusa Sugandha 3 (IET16313/Pusa 2504-1-31). The four Fe levels—0, 3, 6, and 9 kg ha^{-1}—were assigned to the main plot and the three placement depths—surface, 5 cm deep, and 10 cm deep—to the subplot. Fertilizers were applied just before transplanting. Half of N (60 kg ha^{-1}) and all of P (60 kg ha^{-1}) and K (60 kg ha^{-1}) were applied as basal. The remaining N (60 kg ha^{-1}) was applied in two equal splits at tillering and panicle initiation. Fe was applied basal according to the treatment. (The material was acquired from a Japanese company through Prof. Mori.) NPK was supplied as urea, single superphosphate, and muriate of potash, whereas Fe was supplied as polyolefin resin-coated controlled-release fertilizer. The usual water and crop management practices were followed.

The different Fe application rates induced a statistically significant improvement in dry matter accumulation. A maximum dry matter accumulation of 3 kg ha^{-1} was recorded. Yield attributes such as effective tillers $hill^{-1}$, grains $panicle^{-1}$, and test weight also increased markedly with 3 kg Fe ha^{-1} applied (see table). The values decreased with increas-

Effect of rate of polyolefin resin-coated controlled-release Fe fertilizer on rice yield and yield attributes, 2003 and 2004 rainy seasons.

Treatment	Effective tillers $hill^{-1}$ (no.)		Grains $panicle^{-1}$ (no.)		1,000-grain weight (g)		Grain yield (t ha^{-1})		Straw yield (t ha^{-1})	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
Fe application rate (kg ha^{-1})										
0	5.8	6.9	110	115	24.2	25.7	5.7	5.9	7.5	7.9
3	6.2	7.3	119	124	25.7	26.9	6.5	6.7	8.0	8.5
6	6.1	7.1	120	124	25.5	26.8	6.4	6.6	7.9	8.4
9	5.9	6.9	112	115	25.6	26.6	6.1	6.2	7.8	8.2
SE±	0.1	0.1	0.8	1.9	0.3	0.3	0.13	0.14	0.06	0.11
CD (P = 0.05)	0.2	0.2	1.8	4.7	0.8	0.7	0.32	0.34	0.14	0.27
Iron placement										
Surface	5.9	6.9	114	118	24.9	25.9	6.1	6.2	7.7	8.1
5 cm deep	6.1	7.2	116	120	25.3	26.7	6.2	6.3	7.8	8.2
10 cm deep	6.1	7.2	117	121	25.5	26.8	6.4	6.6	8.0	8.4
SE±	0.1	0.1	0.9	1.4	0.4	0.4	0.10	0.15	0.17	0.26
CD (P = 0.05)	ns[a]	ns	ns	ns	ns	ns	ns	ns	ns	ns

[a]ns = not significant.

ing rates. Grain and straw yields depended on yield attributes, which were favorably affected by Fe application. Maximum yields were recorded for the 3 kg Fe ha^{-1} treatment and decreased slightly thereafter. The different Fe placement depths failed to show any significant effect on yield and yield components, but the 10-cm-deep placement recorded the highest grain and straw yields. Interactions were not significant during both years of experimentation.

References

Brown JC. 1961. Iron chlorosis in plants. Adv. Agron. 13:329-369.

Lindsay WL. 1972. Zinc in soils and plant salinity, alkalinity and iron sources on availability of iron. Plant Soil 24:147-186.

Reddy CK, Prassad GVSS. 1986. Varietal response to iron chlorosis in upland rice. Plant Soil 94:289-292.

Effect of sea water intrusion on yield and grain quality of rice in coastal regions of Korea

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Soil salinity and intrusion of sea water are major problems in the coastal areas of several rice-growing regions in Korea. An example is the southwestern part of the country, where the inland area is usually inundated by sea water every rice cropping season in August.

In developing rice ecotypes that could withstand sea water, it is important to determine the growth stage of rice at which damage by sea water is critical. In this study, we identified the critical growth stages in terms of yield, yield components, and grain appearance on a reclaimed coastal saline soil in Korea. The experiment was conducted at the Kyehwa Substation of the Honam Agricultural Research Institute in 2002-03.

The experiment involved growing rice at four growth stages (panicle initiation, booting, heading, and milky stage) and a control (no treatment) in a randomized complete block design with three replicates. Sea water without dilution (about 2.7%) was applied once at each stage for 5 d. Seoganbyeo, a newly developed japonica rice variety for the reclaimed area, was used.

The number of spikelets per panicle decreased in all treatments compared with the control, but there were no significant differences among the growth stages (Table 1). In terms of 1,000-grain weight, no significant difference was observed between the control and the salt treatment. However, the percentage of ripened grain decreased sharply when salt stress was applied at booting stage. Sea water did affect yield, especially when salt stress was applied at panicle initiation and booting stages.

Milled rice yield decreased significantly in the treatments in the following order: booting, panicle initiation, heading, and milky stage.

Grain appearance of brown rice was affected by sea water (Choi et al 2003). A lower percentage of head rice was observed in the stress treatments at all growth stages compared with the control. The low percentage of head rice is attributed to the high percentage of immature and damaged rice in the stress treatments (Table 2).

The results demonstrated that the critical growth stage for flooding by sea water was the booting

Table 1. Yield and yield components of rice grown after 5 d of flooding with sea water at critical growth stages on reclaimed medium (0.3%) saline soil, Kyehwa, Korea, 2002-03.[a]

Treatment/growth stage	Spikelets $panicle^{-1}$ (no.)	Ripened grains (%)	1,000-grain weight (g)	Milled rice yield (t ha^{-1})
No treatment (control)	73 a	80 a	21.5 a	3.9 a
Panicle initiation	65 b	69 b	21.3 a	3.4c
Booting	68 b	64 c	21.1 a	3.3 d
Heading	67 b	72 b	21.3 a	3.7 b
Milky	66 b	77 a	20.9 a	3.7 b

[a]Means in a column followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

Table 2. Grain appearance of brown rice grown after 5 d of flooding with sea water at critical growth stages on reclaimed medium (0.3%) saline soil, Kyehwa, Korea, 2002-03.[a]

Treatment/ growth stage	Head rice (%)	Incomplete rice (%)			
		Broken	Immature	Damaged	Dead
No treatment (control)	59.7 a	7.2 a	21.1 d	5.7 c	3.7 a
Panicle initiation	55.0 b	7.5 a	23.8 b	9.5 b	3.2 a
Booting	52.8 c	7.1 a	25.0 a	11.7 a	3.7 a
Heading	53.9 bc	7.6 a	23.9 b	10.1 b	3.6 a
Milky	54.7 b	7.2 a	22.4 c	11.1 ab	3.7 a

[a]Means in a column followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

stage, which affected both grain yield and grain appearance of brown rice. To avoid severe stress by sea water, early-maturing varieties such as Unkwangbyeo should be cultivated in low-lying areas habitually inundated by the August floods.

Reference

Choi WY, Lee KS, Ko JC, Choi SY, Choi DH. 2003. Critical concentration of saline water for rice cultivation on a reclaimed coastal soil in Korea. Korean J. Crop Sci. 48(3):238-242.

Rice hull ash as a source of silicon and phosphatic fertilizers: effect on growth and yield of rice in coastal Karnataka, India

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Although silicon (Si) is not considered essential for growth and development, the addition of this element can enhance growth and increase the yield of rice (Savant et al 1997a, Takahashi 1995). Depletion of plant-available Si in the soil where rice is grown may contribute to declining or stagnating yield (Savant et al 1997a). An adequate supply of Si to the rice crop can decrease disease incidence and inhibit iron, aluminum, and manganese toxicities, besides improving the availability and use of P by the plant (Savant et al 1997b). However, many Indian farmers are not aware of these benefits and Si fertilizers are too expensive for them.

An important by-product of rice production is rice hull. A big amount is generated every year in all rice-growing countries. On average, 50% of the rice hull obtained is used as fuel in rice mills, hotels, and brick-making industries in south India. The rice hull ash (RHA) thus obtained has Si as a major constituent. It is already being used in rice nurseries and main fields in different parts of southern India. Application of black to gray RHA at 0.5–1.0 kg m^{-2} to the seedbed resulted in healthy and strong rice seedlings (Sistani et al 1997). Although it is not possible to replenish all the Si used up by the rice crop, a proper way of recycling plant Si will help solve the problem of soil Si depletion. Hence, there is a need to evaluate the effect of continuous application of RHA on growth and yield of paddy.

Though P management is not a problem under submerged conditions, studies on the role of RHA as a source of Si and the effect of RHA application on P availability in rice farming are limited. Our investigation aimed to know the effect of continuous recycling of RHA with and without phosphorus (diammonium phosphate [DAP] and rock phosphate [RP]) on growth and yield of paddy.

Field experiments were conducted at the agricultural research station (coastal zone) in Mangalore, Karnataka. The experimental soil was sandy loam, with a pH of 5.06 and 12.1 kg Si ha^{-1} (ammonium acetate extractable). The experiment was laid out in a randomized complete block design with nine treatments (T1: recommended N and K without P; T_2: T_1 + RHA at 2 Mg ha^{-1}; T_3: T_1 + RHA at 4 Mg ha^{-1}; T_4: recommended NPK (P as DAP); T_5: T_4 + RHA at 2 Mg ha^{-1}; T_6: T_4 + RHA at 4 Mg ha^{-1}; T_7: recommended NPK (P as RP); T_8: T_7 + RHA at 2 Mg ha^{-1}; and T_9: T_7 + RHA at 4 Mg ha^{-1}) with three replications. Three-week-old seedlings were planted at 20 × 10-cm spacing in a 16.25-m^2 treatment plot. The fertilizers recommended for the coastal zone of Karnataka are 60-30-45 kg NPK ha^{-1}. The recommended P (DAP) and K (muriate of potash) were applied during planting, whereas RHA and P as RP were applied 1 wk before planting. The recommended N (urea) was given in three splits (50%, basal; 25%, 20 d after transplanting; 25%, 45 d after transplanting). The field experiment had the same layout for four continuous seasons; the bunds were not disturbed and standard management practices were followed.

The application of RHA with and without P significantly increased grain and straw yield in both seasons (Tables 1 and 2). Compared with the control, RHA alone at 2 Mg ha^{-1} without P resulted in higher grain and straw yield of paddy. The results confirmed other findings that silicate materials increase rice yield and other yield components (Talashilkar and Chavan 1995, Savant et al 1997b). A field experiment in Sri Lanka showed that application of 740 kg RHA ha^{-1} gave an additional rice yield of 1.0–1.4 t ha^{-1} (Amarasiri 1978).

Addition of P either as DAP or RP without RHA also increased grain and straw yield (Tables 1 and 2). However, addition of RHA, along with either DAP or RP, further increased grain and straw yields in both 2001-02 seasons. This may be attributed to the Si-supplying power of the RHA. The yield increase was largely brought about by the advantage gained in grain filling and increasing grain weight because of better translocation of photosynthates (Savant et al 1997a, Rai et al 1997).

These results have shown that application of Si through RHA, along with P as RP or DAP, increases grain and straw yield, indicating better performance of RP or DAP as a source of P in Mangalore's acid soils. Thus, recycling of plant Si materials such as RHA helps mobilize soil P and achieve sustainable rice yield.

Table 1. Effect of RHA along with P sources on grain yield (t ha^{-1}) of paddy in coastal soils of Karnataka, India.

Treatment[a]	2001		Av	% of increase over control	2002		Av	% of increase over control	Pooled (2001+2002)	% increase over control
	Kharif	Summer			Kharif	Summer				
T1	2.43	4.30	3.37	–	4.84	4.42	4.63	–	4.00	–
T2	2.74	5.19	3.97	17.8	5.31	5.79	5.55	19.9	4.76	17.5
T3	3.10	5.19	4.15	23.1	5.78	6.07	5.93	28.1	5.04	26.0
T4	3.34	5.31	4.33	28.5	5.94	6.05	6.00	29.6	5.17	29.3
T5	3.50	5.38	4.44	31.8	5.53	5.98	5.76	24.4	5.10	27.5
T6	3.44	5.53	4.49	33.2	6.19	6.24	6.22	34.3	5.36	34.0
T7	3.23	4.85	4.04	19.9	6.24	5.08	5.66	22.2	4.85	21.3
T8	3.74	5.52	4.63	37.4	6.11	6.09	6.10	31.7	5.37	34.3
T9	3.47	5.47	4.47	32.6	6.34	5.69	6.02	30.0	5.25	31.3
SE	0.173	0.047			0.143	0.21			0.097	
LSD (0.05%)	0.84	0.102			0.428	0.63			0.273	

[a]See text for description of treatments.

Table 2. Effect of RHA along with P sources on straw yield (t ha^{-1}) of paddy in coastal soils of Karnataka, India.

Treatment[a]	2001		Av	% of increase over control	2002		Av	% of increase over control	Pooled (2001+2002)	% increase over control
	Kharif	Summer			Kharif	Summer				
T1	4.59	5.48	5.04	–	7.62	4.82	6.22	–	5.63	–
T2	5.53	5.74	5.64	11.9	8.01	5.86	6.94	11.6	6.29	11.7
T3	6.20	5.78	5.99	18.9	7.96	6.06	7.01	12.7	6.50	15.5
T4	6.56	5.91	6.24	23.8	7.90	5.50	6.70	7.7	6.47	14.9
T5	6.25	5.98	6.12	21.4	8.06	5.03	6.55	5.0	6.33	12.4
T6	6.61	6.17	6.39	26.8	7.61	5.08	6.35	2.1	6.37	13.1
T7	4.91	5.57	5.24	4.0	8.07	4.83	6.45	3.7	5.85	3.9
T8	6.44	6.03	6.24	23.8	8.04	4.70	6.37	2.4	6.30	11.9
T9	6.45	6.04	6.25	24.0	7.99	5.08	6.54	5.1	6.39	13.5
SE	281	0.11			0.081	0.30			0.087	
LSD (0.05%)	81	0.29			0.242	0.67			0.167	

[a]See text for description of treatments.

References

Amarasiri SL. 1978. FAO Soils Bull. 36:119-133.

Rai YA, Narayanan A, Devi VS, Subbaramma P. 1997. Effect of silicon application on growth and yield of rice plant. Ann. Plant Physiol. 11(2):125-128.

Savant NK, Datnoff LE, Snyder GH. 1997a. Depletion of plant available silicon in soils: a possible cause of declining rice yields. Commun. Soil Sci. Plant Anal. 28:1245-1252.

Savant NK, Snyder GH, Datnoff LE. 1997b. Silicon management and sustainable rice production. Adv. Agron. 58:151-199.

Sistani KR, Sawan NK, Reddy KC. 1997. Effect of rice hull ash on rice seedling growth. J. Plant Nutr. 20:195-201.

Takahashi E. 1995. Uptake mode and physiological functions of silica. Sci. Rice Plant 2:58-71.

Talashilkar SE, Chavan AS. 1995. Effect of rice hull ash on yield and uptake of silicon and phosphorus by rice cultivars at different growth stages. J. Indian Soc. Soil Sci. 44 (2):340-342.

Effect of leaf color chart on N fertilizer and insecticide use in rice: a case study in West Bengal, India

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During the green revolution in Asia, a common practice was to recommend a standard package of fertilizer rates for the cultivation of modern rice varieties. Later, it became clear that these blanket recommendations were not efficient because the soil's indigenous nutrient supply capacity varies widely among rice fields (Dobermann and White 1999, Olk et al 1999). The current scenario is that farmers apply more N than other nutrients because N fertilizers are relatively cheap and are often sold at subsidized prices (CREMNET 1998a) and farmers can observe impact on plant growth. Overuse and improper timing of fertilizers are common, which is inefficient and sometimes damaging to the crop. Studies show that N recovery by rice is low, ranging from 20% to 40%, because of losses through ammonium volatilization, denitrification, runoff, and leaching (De Datta and Buresh 1989, Win 2003) and that proper timing of N application is critical to minimizing N loss and increasing recovery (Becker at al 1994, Peng et al 1996, Cassman et al 1998). Unbalanced use and excessive use of N fertilizers also lead to overgrowth, making plants succumb to lodging as well as to opportunist pests such as certain diseases and planthoppers. The consequence is increased use of pesticides.

The leaf color intensity of rice is directly related to leaf chlorophyll content and leaf N status (CREMNET 1998b). Therefore, use of a chlorophyll meter (SPAD) in determining the timing of N application can minimize excessive use of N fertilizer without sacrificing yield and can increase N-use efficiency (Peng et al 1996, Balasubramanian et al 1999). But the high cost of acquisition restricts the adoption of the SPAD by most Asian rice farmers with tiny landholdings (Win 2003). However, the development and improvement of a cheap leaf color chart (LCC), which costs less than US$1 per unit, removed this barrier and resulted in wide-scale adoption for real-time N management in rice (Balasubramanian et al 2000).

IRRI made an effort to validate the effectiveness of the LCC with farmer participatory experiments in India under an IFAD-funded special project. The LCC was first introduced in the boro (dry) rice season of 2002-03 to 10 farmers per village, one village per district, in six districts of West Bengal. From the following prekharif (premonsoon) rice season, the LCC introduction was mainly concentrated in selected villages in Nadia District. In total, the LCC was introduced to 163 farmers in 2003-04, 53 in 2004-05, and 43 in 2005-06. In all cases, farmers were allowed to keep the LCC for use in other plots of their farms as well as for sharing with other farmers.

In 2006, a survey was conducted to assess the impact of real-time N fertilizer management with the LCC using a prestructured questionnaire. A random sampling method was used to select samples from villages under the LCC validation experiment (intervention village) and adjoining villages not covered by the project (control village). The survey covered 210 farmers in eight intervention villages and 178 farmers in seven control villages. This note reports the findings of the survey on the impact of real-time N management on the use of N fertilizer and insecticides.

In all three rice seasons, LCC adopter farmers used significantly less N fertilizer than nonadopters (Table 1). Reduced N use by LCC adopters did not affect grain yield in any of the seasons (Table 2). Rather, the adopters produced slightly higher yields than did nonadopters—about 19, 43, and 95 kg ha^{-1} higher in the prekharif, kharif, and boro season, respectively. N fertilizer savings by LCC adopters were on average 25 kg N ha^{-1} (54 kg urea ha^{-1}), a 19% savings over the current practice. The rates of N savings in the different rice seasons were similar—this was highest at 31 kg N ha^{-1} (67 kg urea ha^{-1}) in the boro season, followed by 23 kg N ha^{-1} (50 kg urea ha^{-1}) in the prekharif season, and 20 kg N ha^{-1} (44 kg urea ha^{-1}) during kharif.

Adopter farmers also reported low insect pest incidence in fields where N fertilizers were used according to LCC readings. Farmers reduced the number of insecticide sprays from an average of 2.55 per season to 1.28 (n=148) (see figure). The LCC adopters reduced insecticide sprays by 50%, which was significantly lower than what they used to apply before LCC adoption (t value for the difference in means = 30.3). The average number of sprays made by nonadopter farmers was similar to that by adopter farmers before the introduction of the LCC (2.56 sprays per season).

The findings show that LCC use contributes to a reduction in the use of N fertilizer and insecticides without any effect on grain yield, thereby increasing farmers' income. Adoption of the LCC for real-time N fertilizer management over a large area will have a positive role in environmental protection.

Table 1. Effect of LCC adoption on N use, by season.

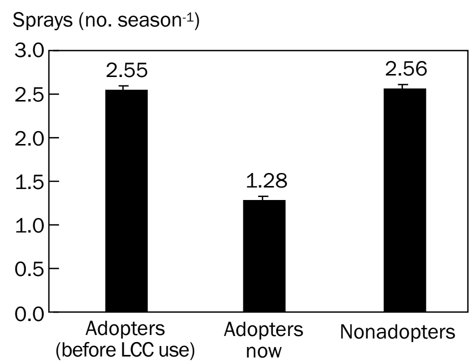
Season	N used (kg ha^{-1})		N saved		t value of the difference in means
	Farmers' practice (control plot)	LCC-monitored plot	Kg ha^{-1}	% over farmers' practice	
Prekharif (premonsoon)	115.7	93.2	225	19.5	5.81**
Kharif (monsoon)	121.2	100.4	20.8	17.2	13.63**
Boro (winter/dry)	151.4	119.6	31.8	21.0	4.42**
Av[a]	129.4	104.4	25.0	19.4	

[a]There were 148 LCC adopters and 240 nonadopters in the sample.

Table 2. Effect of LCC adoption on grain yield, by season.

Season	Grain yield (t ha^{-1})		Yield increase (kg ha^{-1})	t value of the difference in means
	Farmers' practice (control plot)	LCC adopted plot		
Pre-kharif (pre-monsoon)	3.35	3.37	20	0.72 ns
Kharif (monsoon)	3.43	3.47	40	1.71 ns
Boro (winter/dry)	4.82	4.91	90	2.73**
Av[a]	3.87	3.92	50	

[a]There were 148 LCC adopters and 240 nonadopters in the sample.



Effect of leaf color chart (LCC) adoption on the use of insecticide in rice.

References

Balasubramanian V, Morales AC, Cruz RT, Abdulrachman S. 1999. On-farm adoption of knowledge-intensive nitrogen management technologies for rice systems. Nutr. Cycl. Agroecosyst. 53:59-69.

Balasubramanian V, Morales AC, Cruz RT, Thiyagarajan TM, Babu M., Abdulrachman S, Hai LH. 2000. Adoption of the chlorophyll meter (SPAD) technology for real-time N management in rice: a review. Int. Rice Res. Notes 25(1):4-8.

Becker M, Ladha JK, Ottow JCG. 1994. Nitrogen losses and lowland rice yield as affected by residue nitrogen release. Soil Sci. Soc. Am. J. 58:1660-1665.

Cassman KG, Peng S, Olk DC, Ladha JK, Reichardt W, Dobermann A, Singh U. 1998. Opportunities for increased nitrogen use efficiency from improved resource management in irrigated rice systems. Field Crops Res. 56:7-39.

CREMNET (Crop and Resources Management Network). 1998a. Farmer participatory approach to nitrogen management in rice production using leaf color chart. CREMNET Technology Evaluation Protocol No. 1. Manila (Philippines): International Rice Research Institute. 15 p.
CREMNET (Crop and Resources Management Network). 1998b. Use of leaf color chart (LCC) for N management in rice. CREMNET Technology Brief No. 2. Manila (Philippines): International Rice Research Institute. 4 p.
De Datta SK, Buresh RJ. 1989. Integrated nitrogen management in irrigated rice. Adv. Soil Sci. 10:143-169.
Dobermann A, White PF. 1999. Strategies for nutrient management in irrigated and rainfed lowland rice systems. Nutr. Cycl. Agroecosyst. 53:1-18.
Olk DC, Cassman KG, Simbahan G, Sta Cruz PC, Abdulrachman S, Nagarajan R, Tan PS, Satawathananont S. 1999. Interpreting fertilizer-use efficiency in relation to soil nutrient-supplying capacity, factor productivity, and agronomic efficiency. Nutr. Cycl. Agroecosyst. 53:35-41.
Peng S, Garcia FV, Laza RC, Samico AL, Visperas RM, Cassman KG. 1996. Increased N-use efficiency using a chlorophyll meter on high-yielding irrigated rice. Field Crops Res. 47:243-252.
Win KK. 2003. Plot-specific N fertilizer management for improved N-use efficiency in rice-based systems of Bangladesh. Ecology and Development Series No. 12. University of Bonn. 168 p.

Simulating greenhouse gas emissions from Indian rice fields using the InfoCrop model

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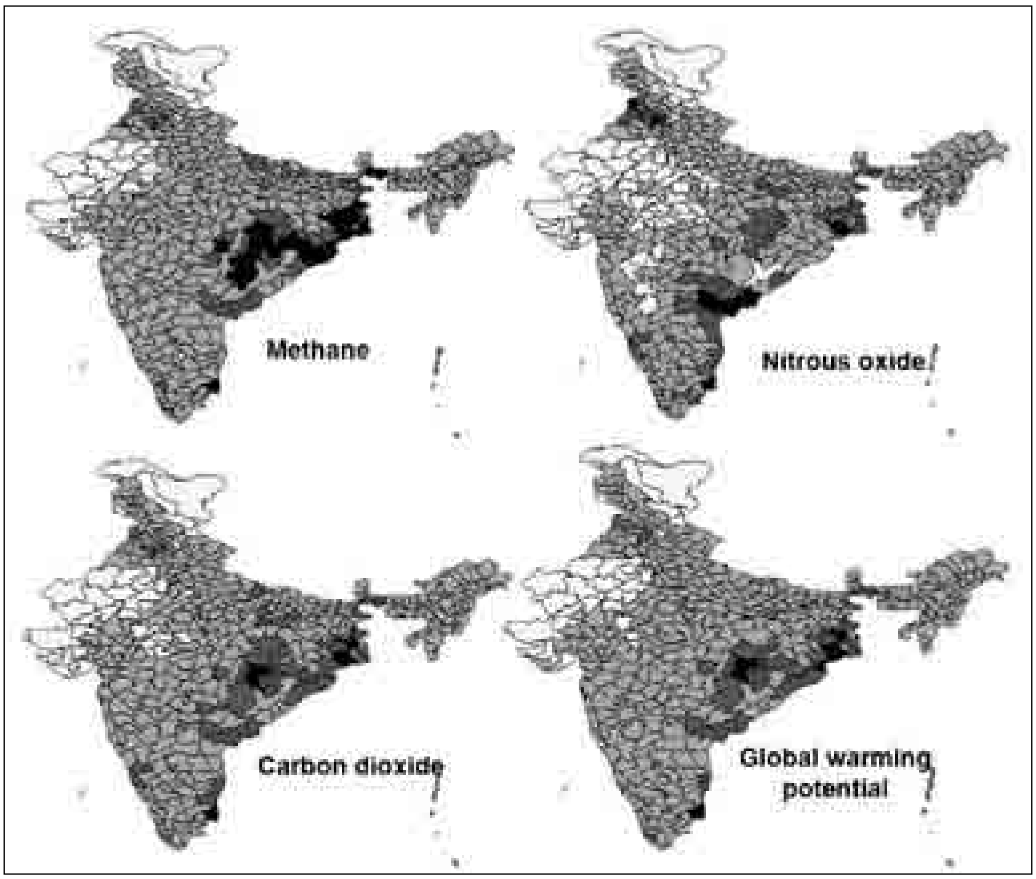
Rice production in South Asia has increased markedly with the widespread adoption of modern crop production technologies. In India, the production of rice, the country's most important staple food crop, increased from 53.6 million t in 1980 to about 90 million t in 2005. Crop management practices have also undergone drastic changes in recent decades, with the heavy use of irrigation, fertilizers, and pesticides, making the crop more energy-intensive. These changes have a direct impact on the emission of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from Indian rice fields.

As a signatory to the United Nations Framework Convention on Climate Change, India has agreed to assess GHG emissions from all development sectors, including agriculture. This quantification of GHG emissions from agriculture is needed in the context of ecosystem modification and climate change. There are, however, uncertainties in the estimation of GHG emissions from Indian agriculture because of diverse soil and climatic conditions and limited on-farm measurements. Simulation models can be helpful in minimizing these uncertainties and determining the impact of input use on global warming. Simulation modeling also provides a baseline from which future emission trajectories may be developed to identify and evaluate GHG mitigation strategies. The objective of our study was to simulate GHG emissions from rice fields under different management practices in different regions of India.

The InfoCrop model, a generic dynamic crop model used in the study, simulates soil nitrogen and organic carbon dynamics and GHG emissions. It has been validated in a variety of agro environments in India (Aggarwal et al 2006). Upscaling of GHG emissions from rice fields in India was done using the validated model and geographic information system. The required input parameters of the model consisted of daily meteorological data (maximum and minimum temperatures, precipitation, and solar radiation); soil characteristics (sand, pH, and thickness of different soil layers); agronomic management practices (date and method of sowing, N fertilizer, and irrigation); and area under different rice ecosystems (irrigated lowland, rainfed lowland, rainfed upland, and deepwater). These were compiled in a database. Simulations were carried out for the 94 agroecological zones (as drawn by India's Planning Commission) in different states during crop growth to obtain total GHG emissions from the rice-growing areas of the country. Global warming potential (GWP), an index defined as the cumulative radiative forcing between the present and some chosen later time 'horizon' caused by a unit mass of gas emitted now, was calculated using the following equation:

GWP = CO_2 emission + CH_4 emission * 21 + N_2O emission * 310

Simulated annual emissions from 42.21 million ha of rice fields in India were 2.07, 0.19, and 72.90 Tg (1 Tg = 10^{12} g) of CH_4-C, N_2O-N, and CO_2-C, respectively, with a GWP of 316.65 Tg CO_2 equivalent. The spatial distribution of GHG emissions and GWP from the rice-growing areas of the country is presented at the district scale in the figure. CH_4 emissions ranged from <1 Gg to 80 Gg (1 Gg = 10^9 g) CH_4-C per district. High emission values, observed in some of the districts of West Bengal in eastern India, were due to higher soil organic C content, continuous submergence of fields, and the larger area devoted to rice. Emissions of N_2O from various districts of India ranged from <1 Mg to 500 Mg (1 Mg = 10^6 g) N_2O-N, whereas CO_2 emissions varied between <1 and 2,000 Gg CO_2-C (see figure). Emissions of N_2O-N were higher from the southeastern (Andhra Pradesh) and northern (Punjab) states of the country because of larger rice area and the use of more N fertil-



Annual emissions of methane, nitrous oxide, and carbon dioxide, and global warming potential from Indian rice fields.

Legend	Emission per district			
	Methane (Mg C)	Nitrous oxide (Mg N)	Carbon dioxide (Gg C)	GWP (Tg CO_2 equiv.)
	<1	<1	<1	<0.001
	1–10	1–100	1–500	0.001–2.0
	10–20	100–300	500–1,000	2.0–4.0
	20–80	300–500	1,000–2,000	4.0–10.0

izers. Moreover, in northern India, rice is generally grown under intermittent drying conditions and considerable amounts of N_2O could be emitted. This alternate wetting and drying of rice fields result in the repetition of nitrification and denitrification processes. Some districts of West Bengal and Andhra Pradesh showed higher CO_2 emissions because of high soil organic C content and larger rice area. The eastern and southern parts of the country showed higher GWP mainly because of higher CH_4 and CO_2 emissions with larger rice area per district.

Several attempts were earlier made to estimate CH_4 emissions from Indian rice fields (Pathak et al 2005). However, only a few studies (Matthews et al 2000, Pathak et al 2005) tried to calculate in detail regional CH_4 emissions using simulation modeling. With the methodology adopted and assumptions made on the importance of different factors affecting CH_4 emissions, the estimates varied greatly (from 1.2 to 37.8 Tg CH_4 y^{-1}). The present estimate of 2.07 Tg is much lower than previous estimates but is comparable with those of Pathak et al (2005) and Matthews et al (2000), who estimated 1.5 and 2.1 Tg CH_4 emissions, respectively. Studies on regional N_2O emissions from Indian rice fields are limited. Bhatia et al (2004) estimated emissions of 0.08 Tg N_2O-N y^{-1}, while India's Initial National Communication (IINC 2004) estimated them to be 0.15 Tg from a net cultivated area of 149 million ha. Pathak et al (2005) calculated total GWP of rice-growing areas to be 130–272 Tg CO_2 equivalent y^{-1}. The preparation of this spatial inventory will be helpful in removing the uncertainties, identifying hot spots of GHG emissions, and implementing management practices to mitigate emissions.

References

Aggarwal PK, Kalra N, Chander S, Pathak H. 2006. InfoCrop: a dynamic simulation model for the assessment of crop yields, losses due to pests, and environmental impact of agro-ecosystems in tropical environments. I. Model description. Agric. Syst. 89(1):1-25.

Bhatia A, Pathak H, Aggarwal PK. 2004. Inventory of methane and nitrous oxide emissions from agricultural soils of India and their global warming potential. Curr. Sci. 87(3): 317-324.

IINC (India's Initial National Communication to the United Nations Framework Convention on Climate Change). 2004. Ministry of Environment and Forests, Government of India. 392 p.

Matthews RB, Wassmann R, Knox J, Buendia LV. 2000. Using a crop/soil simulation model and GIS techniques to assess methane emissions from rice fields in Asia. IV. Upscaling to national levels. Nutr. Cyc. Agroecosyst. 58:201-217.

Pathak H, Li CS, Wassmann R. 2005. Greenhouse gas emissions from Indian rice fields: calibration and upscaling using the DNDC model. Biogeosciences 2:113-123.

Effects of zinc fertilization on physical grain quality of basmati rice

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Physical grain quality in aromatic basmati rice has achieved great attention in recent years due to heavy foreign demand and increased exports. During 2003-04, 771,000 t of Basmati rice was exported from India (GOI 2004). No information on the effect of nutrient management on the physical grain quality of basmati rice before and after cooking is currently available. This study aims to bridge that gap. This information is also needed amid the rising demand for organic food (Prasad 2005) and the widespread concern that fertilizers have a harmful effect on food quality.

To study the effects of zinc fertilization on some aspects of physical quality, grain samples were obtained from the fields at IARI. The experiment aimed to assess the relative efficiency of zinc oxide- and zinc sulfate-coated (at 0.5%, 1.0%, 1.5%, and 2.0%) urea, uncoated urea, and a no-zinc (only N through urea) control. The experiment was conducted in a randomized block design with three replications. All plots received 120 kg N ha^{-1} as urea. Zinc sulfate- and zinc-oxide-coated urea were obtained from Indo-Gulf Fertilizers Ltd., Jagdishpur, India. Soil in the experimental field was a sandy clay loam with pH 8.2, 0.54% organic C, and medium fertility with respect to P and K. DTPA-extractable (Lindsay and Norvell 1978) zinc in soil was 0.68 mg kg^{-1} weight of soil. Rice quality parameters were studied following the methods described by Dela Cruz and Khush (2000). The basmati rice variety used in this study was Pusa Sugandh 5 (Pusa 3A/Haryana Basmati), which was recently developed at IARI and has been cultivated in the northwestern rice-wheat cropping system of the country.

Pusa Sugandh 5 has extra long and slender grains (Jennings et al 1979). Zinc fertilization with 2.0% zinc oxide- or zinc sulfate-coated urea significantly increased hulling percentage in rice compared with that treated with uncoated urea. Zinc coating of urea had no significant effect on grain length before cooking, but, after cooking, grains treated with 1.0%, 1.5%, and 2.0% ZnSO4 coating were significantly longer than those ob-

Grain quality parameters of Pusa Sugandh 5 as influenced by zinc fertilization.

Treatment	Hulling (%)	Grain length before cooking (mm)	Grain breadth before cooking (mm)	L/B[a] before cooking	Grain length after cooking (mm)	Grain breadth after cooking (mm)	L/B[a] after cooking	L_1:L_2[b]	B_1:B_2[c]
Prilled urea	64.7	7.6	1.4	5.5	12.8	2.0	6.4	1.69	1.47
0.5% ZnO-coated urea	68.1	7.8	1.5	5.2	13.5	2.1	6.4	1.72	1.44
0.5% $ZnSO_4$-coated urea	68.2	7.9	1.6	4.9	13.6	2.2	6.2	1.72	1.39
1.0% ZnO-coated urea	68.9	7.8	1.6	4.9	13.7	2.2	6.2	1.74	1.39
1.0% $ZnSO_4$-coated urea	69.5	8.0	1.7	4.7	13.9	2.3	6.0	1.74	1.36
1.5% ZnO-coated urea	69.9	7.8	1.6	4.9	13.6	2.3	6.0	1.74	1.43
1.5% $ZnSO_4$-coated urea	70.8	8.0	1.7	4.7	13.9	2.3	5.9	1.74	1.38
2.0% ZnO-coated urea	73.0	7.9	1.6	4.9	13.6	2.3	5.9	1.73	1.43
2.0% $ZnSO_4$-coated urea	74.5	8.1	1.8	4.5	14.3	2.4	6.0	1.76	1.33
CD (P=0.05)	6.4	ns	0.2	0.9	1.0	0.2	ns	ns	0.12

[a]L/B: length-breadth ratio. [b]L_1:L_2 = ratio of grain length before (L_1) to that after cooking (L_2). [c]B_1:B_2 = ratio of grain breadth before cooking (B_1) to that after (B_2) cooking.

tained with urea alone. For grain breadth, treatments with 1.0%, 1.5%, and 2.0% $ZnSO_4$-coated urea had bolder grains before and after cooking. Coating prilled urea with ZnO at 1.5% and 2.0% gave significantly bolder grains than prilled urea only after cooking. Upon cooking, grain length increased by 1.69 to 1.76 times that of the grain before cooking, but the effect of coating prilled urea with zinc was not significant. Similarly, grain breadth increased by 1.33 to 1.47 times (see table). The grains obtained with 2.0% $ZnSO_4$-coated urea were significantly thinner (considered a good quality trait) than those obtained with prilled urea. It is therefore concluded that zinc fertilization had no deleterious effects on the quality of basmati rice; it even increased hulling percentage and produced longer and better grains.

References

Dela Cruz N, Khush GS. 2000. Rice grain quality evaluation procedures. In: Singh RK, Singh US, Khush GS, editors. Aromatic rices. New Delhi (India): Oxford & IBH Publishing Co. Pvt. Ltd. p 15-28.

GOI (Government of India). 2004. Agricultural statistics at a glance. New Delhi (India): Directorate of Economics and Statistics, Ministry of Agriculture and Cooperation.

Jennings CR, Coffman WR, Kauffman HE. 1979. Rice development. Los Baños (Philippines): International Rice Research Institute. 186 p.

Lindsay WL, Norvell WA. 1978. Development of DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Am. J. 42:421-428.

Prasad R. 2005. Organic farming vis-à-vis modern agriculture. Curr. Sci. 89:252-254.

BRRI dhan 47: a salt-tolerant variety for the boro season

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The demand for a salt-tolerant rice variety for the salinity-prone areas of Bangladesh during the boro season has long been felt. Three environmental constraints—saline soil, saline irrigation water, and cold temperature—have made this environment very complex. On-station replication of such an environment is thus very difficult. An alternative approach used participatory variety selection (PVS) under a mother-and-baby trial in 200 farmers' fields in salinity-prone areas of Bangladesh. The farmers had chosen four genotypes—PVS-B3, PVS-B8, PVS-B9, and PVS-B1—from 385 BR and IR lines with different degrees of salt tolerance.

Salt stress screening of the four PVS-B genotypes was done under controlled conditions. Of these genotypes, PVS-B3, PVS-B9, and PVS-B19 showed a very high degree of seedling-stage tolerance at 12–14 dS m^{-1} (Fig. 1). It should be noted that popular boro variety BRRI dhan 28 could tolerate salt stress at 4.0 dS m^{-1} only. The same set of four PVS-B lines was screened for adult plant resistance to salt stress at 6.0 dS m^{-1}. Salinity was applied at transplanting and was continued throughout the crop growth period. BRRI dhan 28 died 30 d after transplanting; PVS-B8 and PVS-B9 soon followed. PVS-B3 and PVS-B19 survived and flowered at 6.0 dS m^{-1} (Fig. 2).

Fig. 1. Salt stress tolerance of BRRI dhan 47 at 12 dS m^{-1} at the seedling stage. V1 = PVS-B3 (BRRI dhan 47), V2 = PVS-B8, IR29 = susceptible check, BRRI dhan 28 = standard check, V3 = PVS-B9, and V4 = PVS-B19.

Fig. 2. Salt stress (EC 6 dS m^{-1}) tolerance of PVS-B3 (BRRI dhan 47) and PVS-B19 at the reproductive phase. BRRI dhan 28 = standard check, PVS-B3 (BRRI dhan 47), PVS-B19, and IR29 = susceptible check.

Table 1. Grain yield potential of BRRI dhan 47 in salinity-prone coastal areas[a] in 2005 boro.

Genotype	Yield (t ha^{-1})						Mean
	L1	L2	L3	L4	L5	L6	
BRRI dhan 47 (PVS-B3)	5.4	7.0	7.4	5.6	5.3	5.7	6.1
BRRI dhan 28 (check)	3.2	5.9	5.8	5.0	4.7	5.4	5.0

[a]L1=Botiaghata; L2 = BRRI farm, Satkhira; L3 = Satkhira Sadar; L4 = Ashashuni; L5 = Kaliganj; L6= Tala.

Knowing the high-temperature sensitivity of PVS-B19, PVS-B3 was finally chosen for the variety trials conducted at six salt-affected locations—Botiaghata, Kaliganj, Tala, Ashasuni, Satkhira Sadar, and the BRRI farm in Satkhira. The initial soil salinity of these fields (before irrigation) ranged from 8 to 12 dS m^{-1}. The salinity of the irrigation water ranged from 0.2 to 2.0 dS m^{-1}. The field evaluation team of the National Seed Board (NSB) compared the performance of PVS-B3 with that of BRRI dhan 28 under these conditions. PVS-B3 had a 1.0 t ha^{-1} yield advantage (mean) over BRRI dhan 28 (Table 1). The other agronomic and grain characteristics of the two lines are shown in Table 2.

PVS-B3 is an IR line with pedigree IR63307-4B-4-3. The NSB has approved the release of PVS-B3 as BRRI dhan 47 for cultivation in salt-affected boro areas of Bangladesh.

Table 2. Agronomic and grain quality characteristics of BRRI dhan 47 in salinity-prone areas in 2005 boro.

Genotype	Plant height (cm)	Growth duration (d)	1,000-grain weight (g)	Whole-grain length (mm)	Decorticated grain				Amylose content (%)
					Length (mm)	Width (mm)	Length-width ratio	Size and shape	
BRRI dhan 47 (PVS-B3)	101	152	27.1	8.0	5.6	2.7	2.1	Bold	28.3
BRRI dhan 28 (check)	105	147	22.1	9.0	6.5	2.0	3.3	Slender	28.5

Rice Research in China*

Transgenic expression of the recombinant phytase in rice (*Oryza sativa*)

Liu Qiao-quan, Li Qian-feng, Jiang Li, Zhang Da-jiang, Wang Hong-mei, Gu Ming-hong, and Yao Quan-hong

In most cereal crops, phytic acid is the main storage form of phosphorus, which can decrease the bioavailability of phosphate. Transgenic expression of phytase is regarded as an efficient way to release phosphate from phytate in transgenic plants. In this study, a plant expression vector, containing the recombinant phytase gene driven by the maize ubiquitin (Ubi) promoter was constructed and introduced into an elite rice variety via *Agrobacterium*-mediated transformation. During the experiment, a total of 15 independent transgenic rice lines were regenerated. The results of PCR and Southern blot indicated that the target gene was integrated into the genome of transgenic rice plants. Moreover, the RT-PCR analysis of total RNAs extracted from the immature seeds of several transgenic lines showed that the recombinant phytase gene could be normally expressed. The inorganic phosphorus content, both in mature seeds and the leaf, was significantly higher in transgenic plants than in the untransformed wild type.

Rice Science. 2006. 13(2): 79-84
Full paper: www.ricesci.cn/pdfile/2006/E060201.pdf

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* *IRRN* and the Chinese journal *Rice Science* are collaborating to disseminate results of rice research to as wide an audience as possible. These abstracts are from recently published papers in *Rice Science*. URL links to the full papers on the *Rice Science* Web site are provided.

QTL mapping of low temperature on germination rate of rice

Chen Liang, Lou Qiao-jun, Sun Zong-xiu, Xing Yong-zhong, Yu Xin-qiao, and Luo Li-jun

To investigate the effect of low temperature on germination capacity (LTG), a double haploid rice (DH) population with 198 lines derived from anther culture of F_1 hybrid with indica line Zhenshan 97B and a perennial japonica line AAV002863 was used to construct a linkage map with 140 SSR markers. The germination rate in Zhenshan 97B and AAV002863 was 79.7% and 30.1%, respectively, while it ranged from 0 to 100% in DH population at 15 ºC after 6 d. Quantitative trait loci (QTLs) controlling low temperature germinability were identified on chromosomes 3 and 10. The percentage of observed phenotypic variance attributed to qLTG-3 and qLTG-10 was 12.6% and 12.9%, respectively. The allele from Zhenshan 97B increased the LTG at qLTG-3 region, while the allele from AAV002863 increased the LTG at qLTG-10 region. One pair of epistatic interaction was detected between loci on chromosomes 3 and 10. The main-effect of QTL on chromosome 10 was also involved in epistatic interaction.

Rice Science. 2006. 13(2): 93-98
Full paper: www.ricesci.cn/pdfile/2006/E060203.PDF

Development and substance accumulation of caryopsis in transgenic rice with antisense Wx gene

Chen Gang, Wang Zhong, Liu Qiao-quan, Xiong Fei, Gu Yun-jie, and Gu Guo-jun

The development and substance accumulation of rice caryopsis were studied by using transgenic japonica and indica rice with antisense *Wx* gene. The weight of caryopses in transgenic rice was lower than that in a nontransgenic one, and the reduction in weight was significantly correlated to the reduction in amylose content. In caryopsis of transgenic rice, the number of endosperm cells was smaller than that in the caryopsis of the nontransgenic one, but proliferation speed was considerably higher during the first 6 d after flowering (DAF). During the first 9 DAF, soluble sugar content of transgenic rice caryopsis was less than that of the nontransgenic one, but the situation was reversed after 9 DAF. Moreover, total starch content also declined with the decrease in amylose content of transgenic rice caryopsis, while amylopectin content increased accordingly. Therefore, the composition of starch in caryopsis also changed, but it did not affect protein accumulation in transgenic rice caryopsis.

Rice Science. 2006. 13(2): 106-112
Full paper: www.ricesci.cn/pdfile/2006/E060205.pdf

Variations in concentration and distribution of health-related elements affected by environmental and genotypic differences in rice grains

Ren Xue-liang, Liu Qing-long, Wu Dian-xing, and Shu Qing-yao

Research was conducted to investigate the variations in concentration and distribution of health-related elements as affected by environmental and genotypic differences in rice grains. The grains of Xieqingzao B (indica rice variety) and Xiushui 110 (japonica rice variety) were divided into hull, bran, and milled rice, based on conventional rice consumption and processing. Xieqingzao B was grown at four different locations; at one location, it was planted in the same field and season as Xiushui 110. In addition, another four indica and four japonica varieties were cultivated in the same field and time to analyze the elements in milled rice. The average concentrations of total P and phytic acid P were highest in the bran, followed by milled rice and hull; Zn, K, Mg, and As concentrations were highest in bran, followed by hull and milled rice; whereas Fe, Ca, and Cu concentrations were highest in the hull, but similar in bran and milled rice. The results indicated that genotype and environment significantly affected the concentrations of all the tested elements, while the distribution of the above elements in grains was not in the same order as concentration. Moreover, all the elements, except 97.7% of Cu and 93.2% of Fe, were deposited in the hull on average, and mostly distributed either in the bran (37.3% and 57.7% for K and phytic acid P) or in milled rice (41.7%, 42.6%, 40.3%, and 49.8% for Zn, Mg, As, and total P, respectively).

Rice Science. 2006. 13(3): 170-178
Full paper: www.ricesci.cn/pdfile/2006/E060304.pdf

Photosynthetic characteristics and heterosis in transgenic hybrid rice with maize phosphoenolpyruvate carboxylase (*pepc*) gene

Li Ji-hang, Xiang Xun-chao, Zhou Hua-qiang, He Li-bin, Zhang Kai-zheng, and Li Ping

Three F_1 hybrids derived from sterile rice lines Gang 46A, 776A, and 2480A and improved restorer line Shuhui 881 containing maize phosphoenolpyruvate carboxylase (*pepc*) gene were used to analyze the effect of the gene on heterosis and photosynthetic characteristics. The F_1 obtained by crossing Shuhui 881 with the abovementioned sterile lines served as control. The dynamics of photosynthetic characteristics in the leaves of three F_1 with the *pepc* gene and their control were determined at the initial-tillering, maximum-tillering, elongation, initial-heading, heading, and maturity stages; and at different times after the flag leaf has been fully expanded. The PEPCase activities of the three F_1 with *pepc* gene increased significantly as compared with control plants during the whole development process. Moreover, the net photosynthesis rate (Pn) also increased to a certain extent. The data showed that PEPCase activity was significantly correlated to Pn (correlation coefficient of 0.6081**). The photosynthetic indexes of the three F_1 with *pepc* gene were obviously superior to respective controls in apparent quantum efficiency, light compensation point, and carboxylation efficiency, while the CO_2 compensation point was lower than that of the corresponding control. The Pn of the three F_1 with *pepc* gene at light saturation point and CO_2 saturation point was also higher than that of control plants. In addition, the three F_1 with *pepc* gene had an average increase of 37.10% in grain yield per plant in comparison with control plants. The results indicated that photosynthetic characteristics of hybrid rice containing the *pepc* gene had been improved to some extent because of the introduction of this gene.

Rice Science. 2006, 13(3): 185-192
Full paper: www.ricesci.cn/pdfile/2006/E060306.pdf

Breeding rice restorer lines with high resistance to bacterial blight by using molecular marker-assisted selection

Deng Qi-ming, Wang Shi-quan, Zheng Ai-ping, Zhang Hong-yu, and Li Ping

Two bacterial blight (BB) resistance genes, *Xa21* and *Xa4*, from IRBB24 were introduced into hybrid rice restorer line Mianhui 725, which is highly susceptible to BB, using hybridization and molecular marker-assisted selection techniques. Four homologous restorer lines were obtained through testing the R target genes with molecular markers and analyzing parental genetic background. Inoculation of the four lines and their hybrids with specific strains of *Xanthomonas oryzae* pv. *oryzae*, P1, P6 and seven representative strains of Chinese pathotype CI-CVII showed that all four lines and their hybrids were highly resistant, presenting broad resistance-spectrum to BB. The hybrids of G46A/R207-2 had good agronomic characters and high yield potential. R207-2 was named Shuhui 207.

Rice Science. 2006, 13(1): 22-28
Full paper: www.ricesci.cn/pdfile/2006/E060104.pdf

Effects of weak light on starch accumulation and starch synthesis enzyme activities in rice at the grain-filling stage

Li Tian, R. Ohsugi, T. Yamagishi, and H. Sasaki

Dynamic changes in starch, amylose, sucrose contents and the activities of starch synthesis enzymes under shading treatments after flowering were studied using two rice varieties IR72 (indica) and Nipponbare (japonica). Under shading treatments, the starch, amylose, and sucrose contents decreased, while ADP-glucose pyrophosphorylase (ADPGPPase) activity only changed a little, soluble starch synthase activity and granule bound starch synthase activity decreased, soluble starch branching enzyme (SSBE, Q-enzyme) activity and granule-bound starch-branching enzyme (GBSBE, Q-enzyme) activity increased, and starch debranching enzyme (DBE, R-enzyme) activity varied with varieties. Correlation analyses showed that changes in starch content were positively and significantly correlated with changes in sucrose content under weak light. Both ADPGPPase activity and SSBE activity were positively and significantly correlated with starch accumulation rate. It was implied that the decline of starch synthase activities was related to the decrease in starch content and that the increase in the activity of the starch-branching enzyme played an important role in reducing the ratio of amylose to total starch under weak light.

Rice Science. 2006, 13(1): 51-58
Full paper: www.ricesci.cn/pdfile/2006/E060108.pdf

Relationship between variation in activities of key enzymes related to starch synthesis during grain-filling period and eating and cooking quality in rice

Shen Peng, Qian Chun-rong, Jin Zheng-xun, Luo Qiu-xiang, and Jin Xue-yong

Four japonica rice varieties with significant differences in eating and cooking quality were used in the experiment. The varieties showed differences in amylose and amylopectin contents at different grain-filling stages, which were attributed to the accumulative speed of starch at these different stages. During the grain-filling period, the varieties did not differ when the activities of ADP glucose pyrophosphorylase (AGPP) and soluble starch synthesis (SSS) reached maximum; they had differences when the activity of starch branching enzyme (SBE) reached a maximum—the inferior-quality varieties were earlier than the high-quality ones, and the high-quality varieties maintained high enzyme activities at the late stage of grain filling. The correlation and correlative degree between AGPP, SSS, SBE, amylose content, amylopectin content, taste meter value, and RVA properties varied with the stage of grain filling. The correlation between SSS activity and taste meter value was not significant during the whole grain-filling period, but the activities of AGPP and SBE had significant or highly significant correlation with taste meter value. The data will help improve eating and cooking quality of japonica rice for use as materials with low enzyme activity at the early stage of grain filling or with high enzyme activity at the late stage as parents.

Rice Science. 2006, 13(1): 43-50
Full paper: www.ricesci.cn/pdfile/2006/E060107.pdf

Cloning and expression analysis of *OsNADPH1* gene from rice in drought stress response

Chen Jing, Wan Jia, Jiang Hua, Gao Xiao-ling, Wang Ping-rong Xi Jiang, and Xu Zheng-jun

An experiment was conducted to compare the mRNA expression differences in rice leaves and roots under drought stress and normal conditions using fluorescent differential display (FDD) method. One positive fragment was isolated by combination of the H. A. Yellow-PAGE (contained 0.1% H. A. Yellow) separation and macroarray screening methods. Compared with *Arabidopsis thaliana NADPH oxidoreductase gene*, it has 96% identity. The cDNA was 1423 bp and contained a complete open reading frame of 1048 bp, encoding a protein with 345 amino acid residues. Moreover, the gene expression level was higher under drought stress than that under normal conditions. The possible role of *NADPH oxidoreductase* gene under drought response was also discussed.

Rice Science. 2006, 13(3): 149-154
Full paper: www.ricesci.cn/pdfile/2006/E060301.pdf

Effect of high temperature on sucrose content and sucrose-cleaving enzyme activity in rice grain during the filling stage

Li Tian, Liu Qi-hua, R. Ohsugi, T. Yamagishi, and H. Sasaki

Dynamic changes in sucrose, fructose, and glucose contents and differences in activities of sucrose synthase, vacuolar invertase, and cell wall-bound invertase in rice grain after flowering stage were studied under natural and high temperatures using japonica rice varieties Koshihikari and Sasanishiki. In rice grains, sucrose synthase activity was higher than that of invertase, which was significantly correlated with starch accumulation rate. This indicates that sucrose synthase played an important role in sucrose degradation and starch synthesis. Under high temperature, the significant increase in grain sucrose content without any increase in fructose and glucose contents suggested that the high temperature treatment enhanced sucrose accumulation, while diminishing sucrose degradation in rice grains. Compared with the control plants, the decrease in activities of sucrose synthase, vacuolar invertase, and cell wall-bound invertase with high temperature-treated plants indicated that the deceleration of sucrose degradation was related to the decrease in activities of sucrose synthase and invertase.

Rice Science. 2006, 13(3): 205-210
Full paper: www.ricesci.cn/pdfile/2006/E060309.pdf

Source-sink and grain-filling characteristics of two-line hybrid rice Yangliangyou 6

Zhao Bu-hong, Wang Peng, Zhang Hong-xi, Zhu Qing-sen, Yang Jian-chang

With two-line hybrid rices Yangliangyou 6 (YLY6) and Liangyoupeijiu (LYPJ) and three-line hybrid rice Shanyou 63 (SY63) as materials, source, sink, and flow characteristics in association with grain filling were investigated. Seed-setting rate, grain-filling degree, and grain yield of YLY6 and SY63 were significantly higher than those of LYPJ. The export and transformation percentages of matter in culms and sheaths of YLY6 and SY63 were significantly higher than those of LYPJ. Activities of sucrose synthase, adenosine diphosphoglucose pyrophosphorylase, starch synthase, and starch-branching enzyme in grains were higher for YLY6 and SY63 than for LYPJ and were very significantly correlated with maximum grain-filling rate, mean grain-filling rate, grain-filling degree, and grain weight. Spikelet number, grain yield, and total sink load per area of vascular bundle and phloem of YLY6 and SY63 were significantly smaller than those of LYPJ, and the greater the load, the lower the seed-setting rate and the poorer the grain filling. The transportation rate per phloem area of YLY6 was greater than that of LYPJ or SY63. The results suggest that YLY6 possesses strong source, great sink activity, and efficient flow, which gave the a physiological basis for its high seed-setting rate and good grain filling.

Rice Science. 2006, 13(1): 34-42
Full paper: www.ricesci.cn/pdfile/2006/E060106.pdf

Effects of nonflooded cultivation with straw mulching on rice agronomic traits and water use efficiency

Qin Jiang-tao, Hu Feng, Li Hui-xin, Wang Yi-ping, Huang Fa-quan, and Huang Hua-xiang

A field experiment was conducted to study water use efficiency and agronomic traits in rice cultivated in flooded soil and nonflooded soils with and without straw mulching. The total amount of water used by rice under flooded cultivation (FC) was 2.42 and 3.31 times as much as that by rice under nonflooded cultivation with and without straw mulching, respectively. The average water seepage was 13,560 m^3 ha^{-1} under flooded cultivation, 4,750 m^3 ha^{-1} under the nonflooded cultivation without straw mulching (ZM), and 4, 680 m^3 ha^{-1} under nonflooded cultivation with straw mulching (SM). The evapotranspiration in the SM treatment was only 38.2% and 63.6% of the FC treatment and ZM treatment, respectively. Compared with the ZM treatment, straw mulching significantly increased leaf area per plant, main root length, gross root length, and root dry weight per plant of rice. The highest grain yield under the SM treatment (6,747 kg ha^{-1}) was close to that of rice cultivated in flooded soil (6,811.5 kg ha^{-1}). However, yield with the ZM treatment (4 716 kg ha^{-1}) was much lower than those with FS and SM treatments. The order of both water use efficiency and irrigation water use efficiency were as follows: SM> ZM> FC.

Rice Science. 2006, 13(1): 59-66
Full paper: www.ricesci.cn/pdfile/2006/E060109.pdf

Simulation and validation of rice potential growth process in Zhejiang Province of China by utilizing the WOFOST model

Xie Wen-xia, Yan Li-jiao, and Wang Guang-huo

A crop growth model, WOFOST, was calibrated and validated through rice field experiments from 2001 to 2004 in Jinhua and Hangzhou, Zhejiang Province. For late rice variety Xiushui 11 and hybrid Xieyou 46, the model was calibrated to obtain parameter values using experimental data from 2001 and 2002; the parameters were then validated by the data obtained during 2003. For single hybrid rice Liangyoupeijiu, the data recorded in 2004 and 2003 were used for calibration and validation, respectively. The study aimed to show that the WOFOST model is good in simulating rice potential growth in Zhejiang and can be used to analyze the process of rice growth and yield potential. The potential yield obtained from the WOFOST model was about 8,100 kg ha^{-1} for late rice and 9,300 kg ha^{-1} for single rice. The current average yield in Jinhua is only about 78% (late rice) and 70% (single rice) of their potential yield. The results of the simulation also showed that the current practice of management at the middle and late growth stages of rice should be reexamined and improved to achieve optimal rice growth.

Rice Science. 2006, 13(2): 125-130
Full paper: www.ricesci.cn/pdfile/2006/E060208.pdf

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- report pertinent, adequate data
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- reach supportable conclusions.

Routine research. Reports of screening trials of varieties, fertilizer, cropping methods, and other routine observations using standard methodologies to establish local recommendations are not ordinarily accepted.

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Each note may include up to two tables and/or figures (graphs, illustrations, or photos). Refer to all tables and figures in the text. Group tables and figures at the end of the note, each on a separate page. Tables and figures must have clear titles that adequately explain contents.

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).

Terminology

- 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.
- Provide scientific names for diseases, insects, weeds, and crop plants. Do not use local names alone.
- Do not use local monetary units. Express all economic data in terms of the US$, and include the exchange rate used.
- Use generic names, not trade names, for all chemicals.
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- Define any nonstandard abbreviation or symbol used in tables or figures in a footnote, caption, or legend.

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Mini reviews should address topics of current interest to a broad selection of rice researchers, and highlight new developments that are shaping current work in the field. Authors should contact the appropriate editorial board member before submitting a mini review to verify that the subject is appropriate and that no similar reviews are already in preparation. (A list of the editors and their areas of responsibility appears on the inside front cover of each IRRN issue.) Because only 1-2 mini reviews can be published per issue, IRRN will require high quality standards for manuscripts accepted for publication. The reviews should be 2000-3000 words long, including references. Refer to the guidelines for research notes for other aspects of writing and content.

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Notes from the field should address important new observations or trends in rice-growing areas, such as pest outbreaks or new pest introductions, or the adoption or spread of new crop management practices. These observations, while not the result of experiments, must be carefully described and documented. Notes should be approximately 250 words in length. Refer to the guidelines for research notes for other aspects of writing and content.

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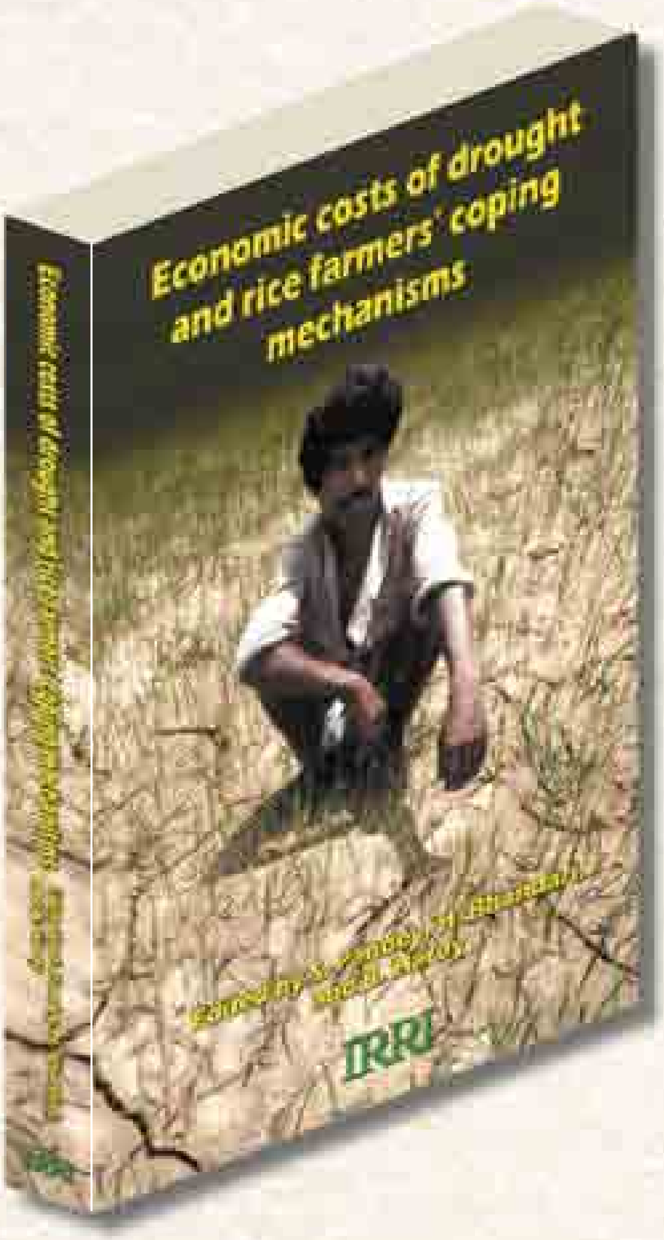

Drought is a major constraint affecting rice production, especially in rainfed areas across Asia and sub-Saharan Africa. At least 23 million hectares of rainfed rice area in Asia (20% of total rice area) are estimated to be drought-prone. This situation has been historically associated with food shortages and imposes a serious economic burden on society.

This book reports on research conducted in drought-prone rice-growing areas in China, India, and Thailand. The study aimed to estimate the economic costs of drought; document farmers' risk-coping mechanisms; and recommend suitable interventions, both technical and policy, for effective drought management.

According to the authors, research on drought and developments in biotechnology may help alleviate the problem. However, there are serious concerns about lack of investment in agricultural research in developing countries in Asia, which impacts not only drought mitigation but overall agricultural development.

Edited by S. Pandey, H. Bhandari, and B. Hardy

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