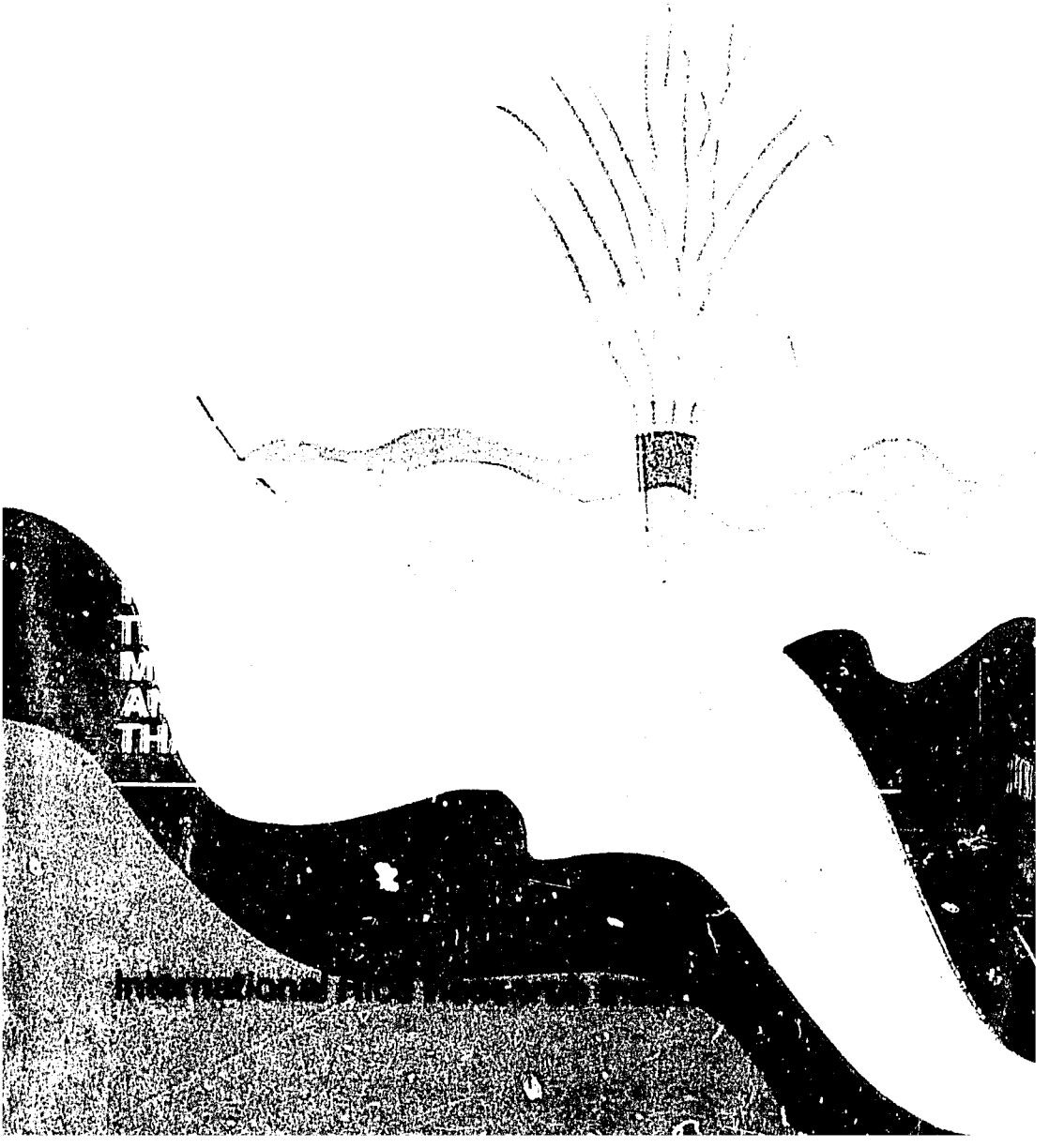
PROCEEDINGS OF THE 1981

International Deepwater Rice Workshop



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PROCEEDINGS OF THE 1981

International Deepwater Rice Workshop

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Foreword

These proceedings of the 1981 International Deepwater Rice Workshop, held at Bangkhen, Thailand, are concrete evidence of significant progress in deepwater rice research since the first group of deepwater rice researchers got together in Bangladesh in 1974. There is strong indication from the papers, the discussion, and the recommendations herein that accelerated research progress can be expected in the future. There is, therefore, greater confidence in our being able to help improve the lot of deepwater rice farmers.

The International Rice Research Institute (IRRI) was honored to cosponsor the workshop with the Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand.

This workshop was made possible by the diligent work of scores of people. We are most grateful to the participating scientists. We gratefully recognize the tremendous input of our Thai colleagues, particularly Chai Prechachat and Nopporn Supapoj, Siriporn Karin, Amara Wiengweera, and Samlee Boonyaviwatana. We recognize the generosity of Dr. Aphirat Arunin for making the National Research Council auditorium available for the workshop. Our IRRI colleagues in Thailand, Drs. H. D. Catling and D. W. Puckridge, worked hard with their Thai colleagues to make the workshop a success.

We thank the committee members who had the primary responsibility to develop the program: B. R. Jackson, D. V. Seshu, D. HilleRisLambers, B. S. Vergara, W. G. Rockwood, and S. K. De Datta, who served as chairman and technical editor.

IRRI Editor W. G. Rockwood and editorial assistant E. P. Cervantes spent long hours to see that all papers received were edited prior to the conference and many in the Office of Information Services spent long hours processing the papers for publication.

M. R. Vega
Acting Director General
International Rice Research Institute

Welcome of the Department of Agriculture

Phaderm Titatarn

It is a pleasure to meet with you this morning and participate in the opening ceremony of this International Deepwater Rice Workshop, which is jointly sponsored by the International Rice Research Institute (IRRI) and the government of Thailand.

Farmers in the irrigated areas have enjoyed good production using the new short-strawed, fertilizer-responsive rice varieties but the large number of rice growers who have not the fortune to have good irrigation have continued to suffer from low productivity because technology was not available for increasing their rice yields. It is especially significant that we have seen considerable progress in the research of this important but formerly neglected type of rice culture. I am not suggesting that the problems have all been solved but I believe that the reports and discussions that will take place among researchers this week will reveal that there is a good chance to make a breakthrough that will materially benefit millions of people.

I am pleased that IRRI chose to join our efforts here in my country because the expertise and facilities of this world-renowned organization can be brought to bear on the deepwater problem. This should help not only my country but many other countries of this region as well.

I welcome you and thank you for joining me and my colleagues at this workshop, and I wish you a successful meeting and stay in Thailand. We look forward to a rapid productive period of research as a result of this gathering.

Director general, Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand.

Welcome of IRRI

M. R. Vega

I consider the opportunity to participate in this International Deepwater Rice Workshop a most filling cap to a delightful and rewarding 10-day visit to Thailand. Some of you are aware that the IRRI Board of Trustees have been traveling and observing rice agriculture in Thailand. I must say that the members of the IRRI Board of Trustees did get a fairly good idea, and appreciated the range, of environmental conditions under which rice is cultivated by Thai farmers — all the way from the deepwater rice areas in the Central Plains to the rainfed areas of the Northeast and the northern part of Thailand, plus literally all of the shades of rice growing conditions in between. It was a most interesting and educational week for us.

I fully realize that many of the Thai scientists present here are responsible for some of the research work we saw and I take this opportunity to publicly acknowledge the fine work you are doing. We thank you for sharing your work with us, particularly with the IRRI Board of Trustees. I feel certain that the rice production technology you are generating will, as in the past, prove useful not only to your rice farmers but also to rice farmers of other countries with similar growing conditions.

Workshops such as we are holding this week are one of the most effective mechanisms we know of through which the knowledge gained and technology developed by a national program can be quickly shared with other national programs for evaluation, followed either by outright adoption, or eventual use after modification to suit the nuances of the local situation. Such sharing of knowledge, of experience, and of useful technology is a must if food production is to win the race against population growth. All of us must share a feeling of responsibility to help feed a hungry world, a hungry world that is likely to get hungrier if we do not move with dispatch and determination to produce more food on the rapidly dwindling arable land each country possesses.

Man has for centuries lived along river deltas where there is sufficient water to grow rice. However, in years when floods come early his rice crop is destroyed because the plants neither withstand submergence, nor elongate rapidly at an early growth stage. In essence this is the rice growing situation — the rice production problem that brings

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Acting director general, IRRI.

this international group of scientists together for this workshop on deepwater rice.

Although deepwater rice may have different meaning for different people there seems to be agreement on the requirement of a suitable variety: seedling vigor, elongation ability, submergence tolerance, and drought tolerance. There seems to be agreement likewise on the cultural management problems that the deepwater rice farmers face: the weed problem, problems associated with date and rate of seeding, fertilizer application, pest management, planting methods, and land preparation.

Over the last several years there has been a growing interest among national programs in research to improve deepwater rice production. Everyone recognizes that the new rice technology has not benefited the extensive regions where water depths range from 50 cm to more than 600 cm and cannot be controlled.

Many of you present here, and also at the first international seminar on deepwater rice held in Dacca 21-26 August 1974, will recall a statement made during the first meeting and which I believe reflected a major interest of the seminar: "to focus attention of the world's rice scientists on the problems of this important crop, which covers 10 million ha in South and Southeast Asia."

Four years later at the 1978 International Deepwater Rice Workshop in Calcutta, India, B. R. Jackson and B. S. Vergara summarized the "Progress in deepwater rice research." The years 1970-77 were referred to as "an era of increased research emphasis." Because scientists have accelerated their work, Jackson and Vergara concluded, we are now in a better position to answer questions concerning the production of deepwater rice. However, Jackson and Vergara raised a rather probing question: "Facilities have been constructed and work is in progress in several research areas: but how much more do we know than we did at the first meeting in Bangladesh 4 years ago?" You will recall that Jackson and Vergara, in concluding their review of progress in deepwater rice research, called attention to 10 questions for consideration. Let me, at this time, repeat 5 of the questions raised in 1978:

1. Is it possible to develop a semidwarf rice that will perform well at water depths of 2 or 3 m?
2. How much do we know of the inheritance of elongation?
3. Are pests of minor or major importance?
4. Can improved agronomic practices such as better weed control, sowing methods, and land preparation significantly improve yields?
5. Do the new deepwater-tolerant types respond to fertilizer better than the older varieties?

Judging from the titles of the papers to be presented and discussed this week I am confident that scientists are on track and that if they do not have the full answers to the questions, they either have the partial answers or now understand the problem a whole lot better. Accepting the reality that an immediate breakthrough, which will change the lives of deepwater rice farms as dramatically as the semidwarf varieties did for the farmers in the irrigated regions, cannot be expected, then I say the scientists have made considerable progress. However, although it is true that if we look at where we came from, we have come a long way, it is also true that if we look at where we are going we still have quite a distance to go!

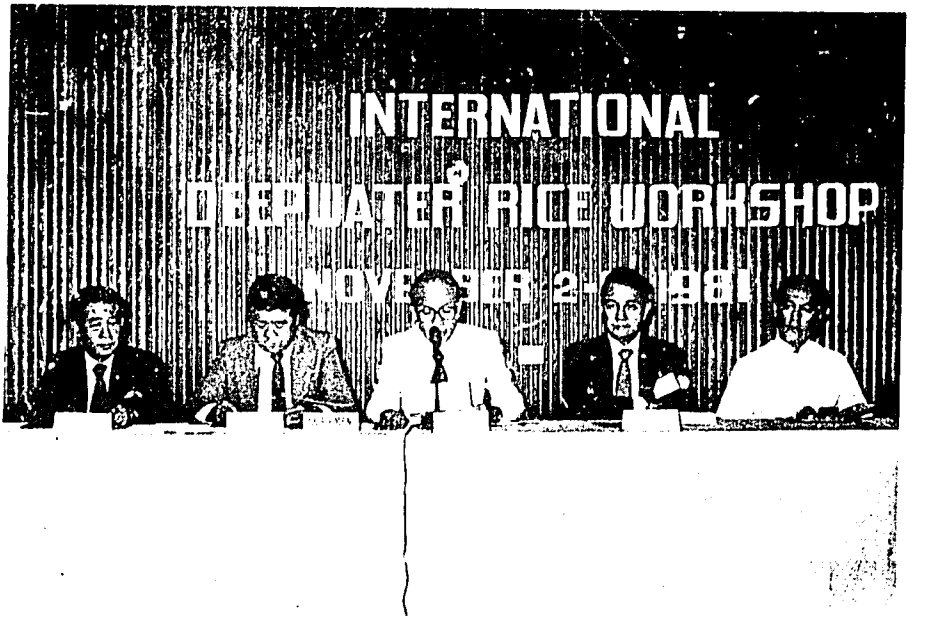
I am more than convinced that the quickest and most effective and efficient way of getting where we want to go is by pooling our talents, efforts, and resources together in

solving the problems of deepwater rice production. We must work together — it is important to let each other know what we are doing and the progress we are making. However, I cannot overemphasize that it is doubly important that we discuss and develop our work plans together. It is for this reason that I urge each of you to actively participate in the planning sessions that are scheduled.

We welcome you to this International Deepwater Rice Workshop, jointly sponsored by the Department of Agriculture, Ministry of Agriculture and Cooperatives, Thailand, and IRRI. Although this workshop is under a joint sponsorship I want to make sure we all recognize that our Thai colleagues did more than their share in preparing for this workshop. We want them to know this is sincerely appreciated. We hope the discussions will be lively and active. Finally we hope the planning sessions will be fruitful.

Workshop opening

Narong Wongwan



Deputy Minister Narong Wongwan, Ministry of Agriculture and Cooperatives, Thailand (center), officially opened the 5-day Deepwater Rice Workshop on 2 November 1981. From the left are Phaderm Titatarn, director general, Department of Agriculture, M. R. Vega, acting director general, IRRI, Mr. Wongwan, D. L. Umali, FAO regional representative, and Amphon Senanarong, deputy director general, Department of Agriculture.

It is stimulating to observe so many persons interested in deepwater rice and to know you are gathered here to share and exchange information. Rice has been, and will continue to be, the lifeblood of my country. In slightly more than 15 years the population of Thailand has increased by 50% — from 30 million to 45 million people — all of whom consume large amounts of rice. The average Thai is one of the world's greatest consumers of rice, averaging more than 150 kg milled rice/person per year.

The development of the new short-strawed, fertilizer-responsive rice varieties has helped us maintain sufficient rice for the Thai people to eat and provide some extra for export. However, the irrigated areas where the new varieties are grown are almost fully exploited and thus we must look at new ways to increase production, especially among rice farmers in the nonirrigated areas. I do not need to impress upon this

Deputy minister, Ministry of Agriculture and Cooperatives, Thailand.

learned group the high cost of construction of dams and irrigation projects, which, although very useful, are a drain on the government's budget and require many years to construct. In addition to gradually increasing the irrigated area, we must find other means for improving production on those broad expanses of rice growing land where water cannot be controlled.

I believe those at this workshop have the capacity to develop research results that can help solve the problem. On behalf of my government, I thank the International Rice Research Institute for its assistance to Thailand and for helping make this workshop possible. I wish you a pleasant, productive meeting and speedy success in your work.

I now declare this workshop formally open.

A second wind for the green revolution

D. L. Umali

"Your work will translate itself into farm-level practices in this troubled decade," D. L. Umali, FAO Regional Representative for the Asia and Pacific, said in his keynote address to deepwater rice scientists.

This Deepwater Rice Workshop convenes in the wake of an equally significant meeting: the North-South Summit in Mexico. Twenty-two heads of state, from both industrialized and developing nations, as you know, met in Cancun to consider ways of coping with the problems of poverty and hunger that fester in our world. What will ultimately result from the fragile consensus reached at that unique conference remains to be seen.

For us who gather here today, in this less glamorous but, in my view, equally significant workshop, it may be enough to note one fact — food constituted a major concern of the leaders at Cancun. We all share the hope that concerns expressed at the Summit will translate into practical programs where food is produced and that scientific research will constitute a critical input.

We live in a world divided more dangerously by hunger than by ideology. The

FAO regional representative for Asia and the Pacific, Bangkok, Thailand.

north-south division is strikingly illustrated in a few rough indicators.

One is the much maligned but still useful gross national product (GNP) yardstick. In low-income countries, per capita income between 1950 and 1980 rose by US$80/person. In stark contrast, the increase in advanced countries for the same period was US$6,500.

Poverty sentences many to premature deaths in the south. By 1979, life expectancy in low-income countries had risen to 51 years — no mean achievement. But better nutrition, health services, and education enable those of the advanced nations to live, on the average, a full 23 years longer.

Is our world, then, one where the affluent have acquired a near monopoly over one of God's most precious gifts — life? This injustice has a particularly dangerous edge. It is the poor's angry knowledge, spread by 20th century news media, that their truncated lives are not inevitable.

Cancun symbolized the search for solutions to these social grievances. This quest, as the Brand Commission noted,"is not an act of benevolence, but a condition of mutual survival" both for the affluent north and impoverished south.

IRRI, FAO, and similar institutions represent part of the international response in that search. Today, the high-yielding varieties of rice and wheat, introduced in the 1960s, are sown on 55 million ha. This covers one-third of the area under cultivation in developing countries. This achievement has led to the use, in newspaper headlines, of the term Green Revolution — a label that scientists, by temperament and training, tend to shun.

Yet, the fact remains that your work has launched the greatest transfer of agricultural technology in history. It has also bought us time in the race to provide food for a world that adds a million people every 5 days. In terms of the daily lives of people, it has meant more food on the table.

Thus, I am confident that history will take a kind view of the work you have done. "If you pour yourselves out for the hungry," the sacred writers tell us, "you shall raise up the foundation of many generations . . . . And you shall be called the repairer of the breach and restorer of paths to dwell in."

Despite this assured niche in agricultural history, this workshop indicates your awareness that the task of feeding the hungry is far from done. In fact, the situation today may be as worrisome as when the modern varieties were first sown.

FAO's *State of Food and Agriculture* (SOFA) report for 1981 notes that "the world, as a whole, experienced stagnation in food production in 2 successive years: 1979 and 1980. This has largely conditioned the agricultural situation and food security . . . and makes 1980-81 one of the most difficult periods of the postwar era . . . " World cereal production slipped below trend for the first time since 1971-80. By the end of this year, world carryover stocks could be only 14% of apparent world consumption. They provide thin protection against shortfalls.

Also, the "nutritional status of the developing world population does not yet indicate any major progress in reducing the incidence of undernourishment." The worst affected are those in urban slums or in rural areas where agricultural production fluctuates widely. Children and nursing mothers are the worst hit.

This short-term picture only reflects persistent unsatisfactory long-term trends. Despite the production spurt, partly due to the new varieties, cereal self-sufficiency in

Asia falls short — at 90%. Due to increased population and incomes, cereal demand grew by 2.9% yearly between 1970 and 1978, but production lagged at 2.3%. Inevitably, this has spilled over into ever-increasing imports for countries whose capacity to buy has eroded badly. In the last decade, food imports of developing countries under the impact of population, increased income, and changing diets, climbed by almost 7% yearly. This doubled the pace of the 1960s.

FAO's recent study *Agriculture towards 2000* cautions that these trends, if not reversed, could see net import of cereals in this Region spiral from 14 million tons in 1975 to 50 million tons by the year 2000. In such a setting, the already unsatisfactory self-sufficiency ratio would deteriorate from 93 in 1975 to only 86 within the same period.

This trend-scenario is loaded with far-reaching socioeconomic and political consequences. Obviously, the trend cannot continue indefinitely. In a world where limits of arable land are being reached, something will have to give. "A poor hungry people," the Overseas Development Council has said, "have nothing to lose by embracing strange causes."

Agriculture towards 2000's normative scenario is more optimistic. But there are a big number of if's. The report says if overall economic growth rate is higher and if agricultural inputs are increased, agricultural growth could accelerate to 3.9% yearly in 1980-90 and 3.5% the decade thereafter. The growth rate in 1965-75, as you know, was 2.6%. In 2000, total agricultural output could be 2.5 times as high as in 1975.

Obviously such a phenomenal acceleration calls for matching increases in inputs. Irrigated areas would have to expand by 638%. Fertilizer use must be stepped up by 700%; improved seeds — and this is where this workshop has a direct interest — by 55%. Pesticide use will also have to increase, in the same period, by 229%; energy by 350%. The arithmetic of these tasks, as well as the painful daily evidence of hunger, have dissipated much of the earlier uncritical expectations of the new seeds.

I suspect the rice scientists are pleased with this new realism because they lead to a more hard-nosed assessment of the constraints. You are familiar with most of them. They include:

- The fact that the modern varieties are underpinned by a capital-intensive technology. This priced them out of the reach of small producers. Furthermore, its almost exclusive technical focus tended to blur, especially in the early years, equally important social and cultural factors that impinge on production.
- The fact that the new technology was tailored to "congenial" production conditions, i.e. irrigated areas. But only 26% of the rice area is irrigated. Most fields are in arid zones, under deep water, or on rainfed uplands. They are tilled by subsistence farmers. As a result, the new technology unwittingly locked out the vast majority of farmers — ironically the people who needed the innovations most.

With the clarity of hindsight, we find these seeds are high-input varieties. The cheap oil-based inputs that helped make quantum leaps in yields genetically possible — thanks to dedicated scientific work — are now threatened by, among other things, the fourfold increase in energy prices since 1973. But in 1965 who could have foreseen a $38 barrel of oil?

Was it not George Santayana who once said: "Those who do not learn from the

mistakes of the past are often condemned to repeat them"? If we are to avoid this condemnatory situation, the logical question to ask is: What can we learn from the history of these seeds for our future work?

There are useful summaries on some of the socioeconomic experiences in the 1981 World Bank sector paper on agricultural research. It observes, for instance, that large-scale farmers reaped the largest gains from the new varieties. This is not due to inability of small farmers to adopt the new technology. In fact, the evidence is that those who till small farms ultimately adopt technologies nearly as well as the better-off farmers.

But the small farmers are cut off from the benefits of the new technology because of unequal access to production inputs, especially land. Hence, the income gap between small- and large-scale farmers has widened further — at least in the short run. SOFA 1981 rightly insists that "improved access to productive inputs, including land, by the rural poor, is an essential step in alleviating the continuing problem of rural poverty."

Research has also revealed that as modern varieties are adopted, the area under tenancy has shrunk. Tenants have been displaced in some cases; in others, rents levied on them have spiralled. Tenants, therefore, are likely to be adversely affected by the introduction of modern varieties, unless special provisions are taken to protect them.

The modern varieties also increase labor requirements. Estimates say increases could go as high as 15-30 days/ha per crop. Thus, some gains in income have obviously accrued to farm labor — of which developing countries have large under-utilized pools. But there is another side to this issue: Where introduction was accompanied by greater mechanization, labor has been displaced. Thus, the principal impact of the new seeds on employment may lie within off-the-farm jobs. These are created by increased demand for nonfarm products, due to higher rural incomes.

In a few areas, wage levels have increased, but they have lagged behind the spurt in land values. This has exacerbated the income gap between landowners and laborers. Researchers have also noticed that the disparities have been most marked for the resource-poor farmers who live in arid zones, flooded areas, or other marginal sectors.

Thus, it is clear that we can compartmentalize technical innovation and social changes only at the cost of failure. The new seeds are meaningless without the farmer's full access to land, water, tools, credit, storage, and market.

When one analyzes what farmers do and how agricultural support activities are conducted, it becomes obvious these are strongly influenced by the mold of national policies and its international linkages. These include agrarian reform, and price and tax policies, as well as research support. These set the rules for the game. They create the economic and political conditions within which farmers produce and agencies support — or undercut — them. Thus, the 154 governments that convened for the World Conference on Agrarian Reform and Rural Development (WCARRD) stated in their declaration of principles: "Agrarian reform is a critical component of rural development . . . and the sustained improvement of rural areas requires fuller and more equitable access to land, water, and other natural resources."

In research, far too few national systems have developed to the point where they absorb, adopt, and transfer to farmers — rapidly and effectively — the knowledge becoming available at centers like IRRI or at research institutions in advanced countries. We need to expand, at national levels, the capacity to generate, verify,

demonstrate, and adopt technology of direct benefit to farmers. The Chinese experience, for example, shows there is scope for closer integration of research with extension. More research must be conducted under conditions farmers face. On-farm testing contributes to the extension process without losing its research character.

On the technical aspect, there are dozens of lessons. But let me share one that currently worries us in the FAO Regional Office — the fact that outbreaks of insects and diseases can be spurred by the intensified cropping systems and other technologies required for high yields. If not properly managed, these outbreaks can — and do — lead to heavy losses, and worse, to rejection of badly needed innovations.

Recall the millions of hectares of rice in this Region devastated by tungro, brown hopper, and bacterial blight in the early 1970s. Tungro reached epidemic proportions in the Philippines destroying more than 187,500 ha of IR8 in 1971-72. Thereafter rice queues appeared and there were ugly fights that incurred political cost as well.

The brown planthopper epidemic followed in 1975 in Indonesia where 208,300 ha planted to modern rices were wiped out. And in 1979, another 187,500 ha of modern rice crops in South Korea were lost, also to disease. What followed was a tense standoff between a government that considered withdrawing crop insurance and farmers who refused to use the new varieties unless covered by insurance.

I raise this topic because today Burma is reporting initial success in sharply increasing rice yields with the use of modern varieties. Initiated in two townships covering an area of 98,300 ha in 1978-79, the program expanded in 1980-81 to 72 townships and more than 2.4 million ha. Average yield per hectare this year skyrocketed by 41.5% over 1977 levels.

We are, of course, pleased with Burma's success. But as the old proverb says, "Once burned, twice shy." Thus, cautionary flags are starting to rise as we become aware that the microenvironments of the crops are altered. So we must ask: What concrete steps are being taken so that Burma and other similarly inclined countries will not be condemned to repeat the costly mistakes of the past?

It is the same spirit of cautious realism that recognizes only a small fraction of our agricultural land is well endowed for most of current varieties to fulfill their potential. Is there scope then for a "Second Green Revolution" within the harsher rainfed environment where most of the world's farmers live and work? These areas, which include the upland and deeply flooded fields, are sometimes called, in slightly disparaging tones, the "secondary regions." Usually, these are areas where cultivation of basic cereals would not constitute the best use of land and large-scale irrigation is often not technically or economically feasible.

By some estimates, such areas could constitute as much as 70% of the available agricultural environment in South and Southeast Asia. Deepwater areas, for instance, cover 11% of the world's rice areas. It is here where the small-scale farmers grow, in addition to rice, what are called the "poor man's crops" — pulses, tubers, roots, and coarse grains. These areas are also called marginal. But this perhaps is a loaded adjective. In agroeconomic terms, marginal refers to land capability as well as varying levels of technology and management needed to compensate for soil deficiencies.

But what is marginal for rice may not be marginal for cassava. Inputs for one crop that turn in a profit could be a losing proposition for another crop.

Unfortunately, there is little research on the significant food crops grown in such

regions, much less on the social, economic, and political characteristics intertwined in farming practices that prevail here. This workshop has been convened precisely because we need improved varieties and technologies for deepwater areas.

The FAO Director General observed in his address to the 15th Regional Conference that "Our knowledge and technology on rainfed tropical agriculture is sketchy at best . . . we will have to concentrate more on the rainfed areas. And the program there must be so designed that small farmers can participate in, contribute to, and benefit from growth."

The stakes involved in developing new and appropriate technology for deepwater rice match the difficulties. Nature appears to have "loaded the dice" against us. As you know, the plants' ability to survive hostile environments, like deep water, is bought at the cost of high yields. The fickle monsoons do not help and often increase the instability factor. Thus, yields in deepwater areas are often held down to around 0.5-1.0 t/ha — and are often unpredictable.

But the lives and hopes of about 100 million subsistence farmers rise or sink with the fortunes of deepwater rice. In Bangladesh alone, 30 million farmers depend on deepwater rice. About 10% of the rice area in Asia is described as typical deepwater rice land and 30%-40% of this Region's land is subject to flooding. A breakthrough in technology from your work would enable millions to move on to more humane standards of living.

In this search for a breakthrough, the harsh and risk-prone environment is a fixed parameter, along with the US$38 barrel of oil and huge underutilized labor pools. We must seek a technology that gives high payoffs in stable production and high yields but is sparing of resources and amenable to low levels of management. The jargon for this is "appropriate technology." Among its essential elements will be

- intensive labor use,
- polyculture,
- conservation tillage,
- increased reliance on a broad germplasm base, organic fertilizers, and biological controls for pests, as chemical inputs price themselves out through, shall we say, "the magic of the market place," and
- emphasis on nonpolluting inputs derived from solar energy.

This is a tall order.

But the farmer for whom this technology is being designed is in no position to pay the bill for costly inputs. He was not able to do so in 1965 and he cannot do so today.

The workshop program indicates some of the major thrusts of your work. These will be discussed in detail at the workshop sessions. So, I shall not comment on them. May I, however, say that the tasks — given your dedication and competence — appear achievable. They are well worth the resources being applied.

Also, it would seem that deepwater rice research will provide unique opportunities for probing into gene action and productivity. The new knowledge could well unlock new doors in our effort to understand, not only deepwater rice but other types as well. I am fascinated, for example, at the potentials hinted in the possibility of using the elongation gene to increase biomass in commonly grown modern rices, coupled with high harvest index. This could open a novel way for increasing production.

The other interesting suggestions are in the fields of recombination breeding of

promising germplasm, increased photosynthesis, nutrient uptake efficiency, and enhanced yields. I welcome the stress on adaptive breeding where greater reliance is placed on traditionally well-adapted local strains that, over the years, have shown remarkable capacity to cope with environmental stresses.

Despite the sharp technical focus of the papers — which is necessary due to the nature of the subject — I am heartened by the greater awareness of the need to avoid fragmented single commodity approaches, that builds the general cropping system around one crop. A keener appreciation of the need for placing your work in the context of farming systems exists. This perspective hews closer to how farmers think, that is in terms of their combined crops, be they root crops, legumes, or coarse grains. It is this sensitivity to farmers' concerns that can reinforce our scientific efforts.

This workshop has come at the start of the Third Development Decade. It is a decade that has not — to borrow a phrase from President Reagan — "hit the ground running." Recession in the industrialized countries has persisted. Inflation, fluctuating prices for primary commodities, and high energy costs continue to erode capacity of developing countries to pay for their imports. Aid budgets are stagnating.

The 22 at Cancun, therefore, faced the likelihood that, in the 1980s, the income gap between North and South will not narrow. In fact, it will widen from its current 5-to-1 difference. What will this mean for the 700 million plus men, women, and children who live in "absolute poverty"?

If the world economy does not pick up, as the first year of this decade shows, then "at the end of a century of unprecedented economic and social advance in some parts of the world," — to quote from the IBRD's 1981 *World development report* — "850 million people may still be living in absolute poverty."

Your work will translate itself into farm-level practices in this troubled decade. It will, therefore, affect directly these men and women who are unable to articulate their hopes for a "Second Green Revolution." We know, from experience, that technology that improves productivity of the poorest and increases provision of food and other basic necessities does accelerate and sustain rapid growth. This underscores the significance of this workshop.

In life, there is no such thing as final success. There will be food problems in this decade. They will not be limited to production but will include processing, storage, delivery, markets and prices, and, above all, purchasing power. In a food-short world, only the poor go hungry; the rich can afford and merely rearrange their menus. The issue in the 1980s is not technology, important as it is. The issue is inequality in the control of productive resources and its benefits which, in the final analysis, is a question of social justice.

Justice and development require that the weakest and the poorest should not pay the costs for all of us.

VARIETAL DEVELOPMENT

DEVELOPMENT OF DEEPWATER RICE VARIETIES AND BREEDING MATERIALS FOR SOUTH AND SOUTHEAST ASIAN COUNTRIES

B.R. Jackson, D. HilleRisLambers, and C. Prechachat

SUMMARY

Several significant developments have occurred since the third deepwater rice workshop in 1978. Six new varieties have been released in Asia and good tolerance for submergence has been identified and successfully transferred to semidwarf types. Yield trial data support the concept that deepwater-tolerant semidwarf rices can outperform the traditional tall and floating varieties, especially if fertilizer is judiciously applied.

Photoperiod sensitivity, characteristics of promising new breeding lines, and general breeding procedures are discussed.

Estimates of the Asian area planted to high yielding varieties range from 30 to 40%. The logical question to follow such a statement is, "Why not 80% or more?" Because most of the Asian rice is grown during the monsoon season, the answer usually is that water is at times too deep for the modern varieties. Other limiting factors are problem soils, drought, diseases, insects, and maturities not suitable for the environment. Water depth and maturity are factors of prime importance because water control is not possible and harvesting must come after the departure of excess water.

How deep is deep water? This is a question we have confronted since the beginning of IRRI's collaboration in deepwater rice programs. As with pests or salinity, deepwater situations vary from area to area and year to year. Ikehashi (1981) pointed out similar problems with salinity. Considering the normal or average water depths over years, there are probably hundreds of different ecological niches where deep water is a rice production constraint. Because they have limited financial and human resources plant breeders working on this type of rice culture should keep priorities in mind. Otherwise the work will become so thinly spread that it will be ineffective. Breeders must clearly define the *major* problem areas, including size and present constraints. And then they need to ask the question, "Is the problem amenable to genetic manipulation through breeding? If so, at what cost?"

Plant breeder, the Rockefeller Foundation, and IRRI representative; plant breeder, IRRI, assigned to Thailand; and head, Deep Water Rice Branch, Rice Division, Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand.

TYPES OF DEEPWATER TOLERANCE

Broadly speaking, there are two types of deepwater tolerance — *elongation ability* and *tolerance for submergence* for up to 10 days. These are genetically controlled and, therefore, amenable to plant breeding. Within these two types is a great deal of variation. Some floating varieties can elongate rapidly as water depths increase up to 5 m for prolonged periods; others can withstand a depth of about 1 m. Some types withstand submergence for only 3 to 4 days but others survive 10 days or more.

Elongation ability appears to be mostly confined to the so-called floating varieties. Tests at the Huntra Station in Thailand have revealed that most of the traditional tall varieties do not contain genes for this character. Fortunately, there are many floating varieties available. Several of these are listed in the 1975 IRRI annual report (IRRI 1976).

Submergence tolerance has not been studied as extensively as elongation ability; however, several sources of submergence tolerance have been identified, such as FR13A and FR43B from India, BKN6986-108 and Nam Sagui 19 from Thailand, Kurkarrupan and Thavalu from Sri Lanka, and IR82340T-9-2 from IRRI. Generally, Indian varieties are the richest source of submergence tolerance and many Bangladesh varieties have the best elongation ability. Unfortunately, most of the varieties mentioned above have major undesirable characteristics such as long awns, red pericarp, weak straw, and short chalky grain, which calls for breeding to concentrate the deepwater-tolerant genes into desirable genetic backgrounds.

KIND OF VARIETIES NEEDED

The answer to the question of what kind of varieties should be developed will depend on the needs of the various countries. For example, at the 1978 International Deepwater Rice Workshop Swaminathan (1979) emphasized the need for improved varieties for the intermediate-deep (about 1 m), stagnant water areas whereas Bangladesh gave considerable emphasis to the need for improved varieties for areas where water is extremely deep (2-4 m). In Thailand, we are primarily concentrating on rices for the intermediate deepwater regions, as are Vietnam and Burma.

We believe that to improve varieties in the intermediate deepwater areas, plant types more nearly like those of the present high yielding varieties are needed. This includes high tillering capacity, erect leaves, and semidwarf-to-intermediate height in addition to the desired tolerance for flooding, either as tolerance for temporary submergence, or elongation ability, or both. These must be combined with the proper maturity (in most cases photoperiod sensitivity), grain characteristics, and disease and insect resistance.

In the case of very deep water (2-5 m maximum depth) there is the problem of high yield being compromised by the ability to survive the extreme deepwater stress. Our present thinking is that the extreme deepwater culture may be best improved through agronomic practices, such as better stand establishment, control of weeds, and proper timing of judicious fertilizer application. Through breeding it should be possible to create better plant type, improved grain quality, and disease and insect resistance.

The Thailand-IRRI Cooperative deepwater breeding program began with elongat-

ing parents that had several undesirable traits. Considerable time and work were spent to transfer their desired traits into satisfactory genetic backgrounds. We are hopeful that those more desirable backgrounds (such as good elongation ability, or submergence tolerance, or both, in semidwarf forms; varying photoperiod sensitivity; and improved grain quality) will provide good basic breeding materials for breeders' use. A few countries have used material of Thai origin for direct release through additional selection. Examples are Yenet-1 and Yenet-2 in Burma and CN540 and CN643 in West Bengal, India.

We believe forms like RD19, which can elongate in up to [illegible] cm of water, is semidwarf, and is photoperiod sensitive and drought tolerant, represents the prototype of future deepwater rice varieties. Such types should fit well into the intermediate deepwater areas of Thailand and replace traditional tall varieties (Table 1). A similar plant type with submergence tolerance is envisaged for those areas where water does not remain deep for prolonged periods but present varieties are unable to withstand sudden flooding. Hopefully, such types can cover wide areas of the rainfed rice regions of Asia and provide greater yield stability than now exists. Table 2 presents [illegible] two varieties and an experimental line tested for submergence 5-21 days at different plant ages. FR13A was clearly the most tolerant, older seedlings had a higher survival rate, and the longer period of submergence decreased survival of all. The greater tolerance of FR13A is obvious.

Breeders at this meeting represent a diverse deepwater background. However, we believe the following points are common to all deepwater situations:

- First, a scientist just starting work should define the major problems in his region, set priorities, and from these formulate a list of attainable breeding objectives.
- Second, he should obtain from IRRI, or from countries advanced in their

Table 1. Performance of RD19 and Leb Mue Nahng (LMN) 111 in tests at 14 sites, including 4 in farmer fields in Thailand, 1980.

Site	Yield (t/ha)		Plant length (cm)[a]	
	RD19	LMN 111	RD 19	LMN 111
Suphanburi	4.3	4.0	115	182
Kilometer 67[b]	3.9	2.5	-	230
Chainat	3.8	3.2	147	230
Klong Luang	3.6	3.3	123	178
Huntra	3.4	2.4	142	214
Pisanuloke	3.4	2.0	143	213
Prajinburi	2.8	2.2	-	-
Klong Luang	2.8	2.0	131	227
Prajinburi	2.7	2.0	163	196
Kok Samrong	2.7	1.5	112	178
Huntra	2.3	2.5	148	220
Wangnoi	2.3	2.4	173	247
Ayutthaya	2.2	2.3	158	164
Nakorn Nayok	2.1	1.6	-	-
Av	3.02	2.42	141	204

[a]A dash (-) indicates data not recorded. [b]Farmer field tests.

Table 2. Survival percentages for three genotypes after submergence of different durations and at different seedling ages (from Boonwite et al 1981).

Submergence duration days	Survival (%)								
	FR 13A			IR234-OT9-2			Khao Dawk Mali 105		
	35	28	21	35	28	21	21	28	21
21	78	62	65	0	0	0	0	0	0
14	98	78	48	0	0	30	0	0	0
5	100	100	75	42	20	25	10	8	5

research, a set of germplasm that most closely approaches his needs.

- Third, the appropriate germplasm can be incorporated into the breeding program.
- Fourth, breeders who are making good progress must share information and material.

EVALUATION OF DEEPWATER MATERIALS IN THAILAND

The Thailand-IRRI program seeks useful materials for distribution to various countries, and development of specific varieties for Thailand. Selection procedures reflect this.

Early-generation selection

In the breeding program elongation ability is tested following the method outlined by Sophonsakulkaew et al (1977). Procedures for testing submergence tolerance are described by Setabutara and Karin (1982, this vol.). Second-generation crosses are subjected to appropriate tests. In the case of elongation ability, stems of surviving plants are cut and transplanted into a field for seed increase. For submergence tolerance, 1 or 2 weeks is allowed for recovery after submergence. Surviving plants are then transferred to a field for seed increase and further selection.

F_3s are planted in shallow water in 4-row plots at the Klong Luang Rice Experiment Station and judged for plant type and bacterial leaf blight (BLB) resistance in the field. Evaluation includes such other natural pressures as present themselves. Plant selections are observed for plant height, flowering date, grain type, and chalkiness.

Advance-generation selection

Lines with clear grains at least 7 mm long are used for the Thai breeding program. Segregates that are promising regardless of Thai grain quality requirements are also saved for countries where quality standards are different.

Materials from the various observation nurseries are grouped into 3 height classes (less than 134 cm, 134-166 cm, and more than 166 cm). Those planted early enough, i.e. before July, are also separated into semimonthly flowering classes, to allow

Table 3. A selection and classification cycle for deepwater breeding materials in Thailand.

Character	Generation				
	F_2	F_3	F_4	F_5	F_6
Elongation	x		x		x
Submergence	x		x		x
Bacterial leaf blight		x		x	x
Plant height		x		x	x
Flowering		x		x	x
Grain appearance		x		x	x
Brown planthopper				x	x
Observational trial					x
Yield trial					x
Cooking quality					x
Drought tolerance					x

placement in degree of photoperiod sensitivity. Table 3 summarizes a typical selection cycle for breeding materials in the program.

Evaluation of advanced lines for their flowering behavior

An important basis for assigning lines to areas inside Thailand, or to meet requests from abroad, is the degree of photoperiod sensitivity expressed by flowering dates in the wet season. Photoperiod sensitivity is essential for most excess-water areas to ensure flowering after peak water stress (Pushpavesa and Jackson 1979). Translation of flowering behavior of materials at Huntra into approximate predictions of their behavior in other deepwater areas is possible (HilleRisLambers 1977). Table 4 gives flowering dates at Huntra of the International Rice Deep Water Observational Nursery (IRDWON) entries and popular photoperiod-sensitive varieties of interest. It is evident that floating rices from Bangladesh have some of the earliest flowering habits, and those from Thailand some of the latest. Thus, it is possible for breeders in Thailand to save promising breeding lines that flower at Huntra in September and be reasonably certain their flowering date will be comparable to that of adapted types such as Madhukar and Habiganj I, grown in Bangladesh and India.

VARIETAL MATERIALS WITH DEEPWATER TOLERANCE AND GOOD PLANT TYPE

We have used the IRDWON nurseries (1976-1980) not only to respond to numerous individual seed requests but also to make lines available to interested breeders. Currently there are 81 lines in the four deepwater rice screening sets, into which the IRDWON was evolved in 1981.

Some breeding materials, which combine deepwater tolerance with plant type of interest to breeders, are listed below. These are not recommended for release, but can serve as progenitors in breeding programs. (See HilleRisLambers and Seshu 1982, this vol., for other breeding materials of potential use.)

- RD19 (BKN6986-147-2) (IR262/Pin Gaew 56) — short stature, good tillering,

Table 4. Flowering dates of photoperiod-sensitive floating and rainfed rices when grown at Huntra Experiment Station, Thailand (14°22' latitude), 1980.

Date	Variety	Origin[a]			
		Bangladesh	India	Thailand	Others
11-15 Sept	Sarsari	GAN			
	Laksmi Digha	GAN			
16-20	Chota Bawalia	JAM			
	Madhukar		UP		
21-25	FRG 7		UP		
	BKN6986-38-1			O	
	FRG 10		UP		
	Chamara	JAM			
26-30	FRG 2		UP		
1-5 Oct	Habiganj Aman I	MEG			
	Habiganj Aman II	MEG			
	Nam Sagui 19			NE	
	CNL 319		WB		
6-10	Chenab 64-117		BHR		
	Habiganj Aman IV	MEG			
	Habiganj Aman VIII	MEG			
11-15	GMS 13		UP		
	GMS 12		UP		
	CN 540		WB		
16-20	BIET 820		BHR		
	GEB 24	O	WB		
	CNL 31		WB		
	Baisbish	MEG			
	Jalamagna		UP		
21-25	FRRS 43/3				NIG
	Tau Binh C				VN
	CNL 241		WB		
	Khao Dawk Mali 105			NE	
26-31	Niaw San Patong			NE	
	CNL 319		WB		
	CR 1009		OR		
	BR118-3B-17				
	Sitpwa				BUR
1-5 Nov	SPR7233-1-24-2-2-2-3			O	
	Kalar Harsall	O			
6-10	Saran Kraham				CAM
	BKN6986-173-5			O	

Continued on opposite page

Table 4 continued

Date	Variety	Origin[a]			
		Bang-ladesh	India	Thai-land	Others
11-15	RD19			CP	
16-20	Leb Mue Nahng 111			CP	
	BKN6986-167			O	
21-25	-				
26-30	Pin Gaew 56			CP	

[a]GAN = Ganges floodplain; JAM = Jamuna floodplain; MEG = Meghna floodplain; WB = West Bengal; NE = Northeast Thailand; CP = Central Plain Thailand; UP = Uttar Pradesh; BHR = Bihar; CAM = Cambodia; VN = Vietnam; NIG = Nigeria; BUR = Burma; OR = Orissa; O = Thai hybrid.

photoperiod sensitive, elongating + 5 cm/day (in 1981 floating and medium deepwater IRDWON screening sets).

- BKNFR76045-35-1 (BKN6987-92-2/Rayada 7) — very short stature, good tillering, photoperiod sensitive, elongating 5 cm/day. Some submergence survival at peak flood enabled it to survive 176 cm flooding. Awned (available only in Thailand).
- DWCT 156-1-B-B (Deepwater composite Thailand and sister lines) — short stature, photoperiod insensitive, elongating 5 cm/day, resistant to BLB. Good plant type (in 1981 medium deepwater IRDWON screening set).
- SPR7282-2-0-7 (HTA1645/NSR6517-27) — tall floating rice type, elongating 5-10 cm/day, photoperiod sensitive, tested to 180 cm depth, resistant to ragged stunt (available in Thailand).
- BKNFR76035-106-1 (IR4427-70-6/RD19/BKN6987-52-1) — early photoperiod sensitive, short stature, elongating 5 cm/day, resistant to BPH-1, glutinous (available in Thailand).
- IR8234-OT-9-2 (Nam Sagui 19/IR1721-11-6-3/IR2061-213-2-16) — semidwarf-intermediate stature, tolerates several days of complete submergence, resistant to BLB, BPH-1. Photoperiod insensitive with long BVP (in 1981 flood-tolerant and tidal swamp IRDWON screening sets).
- BKNFR76106-16-0-1 (IR1529/FR13A) — semidwarf, photoperiod insensitive, awned, inherited submergence tolerance from FR13A (1981 flood-tolerant IRDWON screening set).
- IR6402-OT-7 (FR43B/IR2035-290-2-3) — high yielding type without awns and with good submergence tolerance from FR43B (1981 flood-tolerant IRDWON screening set).

These materials can allow plant breeders to bypass the cumbersome process of recombining elongation ability (or submergence tolerance) with improved plant types. Instead they can use the available deepwater rices with improved plant type as a source of both moderate elongation ability (or submergence tolerance) and short stature, thus allowing more locally adapted rainfed rices to be included as parents in future crosses.

THE FUTURE

The Thailand-IRRI collaborative deepwater rice research program has been under way for about 6 years, with the Huntra Station as a research base. During this period we have intensified studies on elongation and submergence tolerance, identified submergence-tolerant donor parents such as FR13A, and expanded studies on the yield potential of RD19, which was released in 1980. We remain convinced that varieties similar to RD19 — short stature and tillering ability with the proper degree of sensitivity to photoperiod and elongation equal to or better than RD19 — can replace the traditional tall varieties for areas where maximum water depths are about 1 m.

Submergence tolerance research intensified about 3 years ago when FR13A was identified. Prior to that, experiments had shown that varietal differences were clearly expressed when plants were covered with 120 cm of water for 10 days. As with elongation ability, breeders are transferring the submergence trait from the FR13A donor parent to semidwarf forms. Our aim is to produce genotypes sensitive to photoperiod and tolerant of submergence but with the other characteristics of ordinary high yielding varieties. For areas with very deep water, we believe improvements can be made in plant type, grain quality, and disease and insect resistance.

Because of the large variation in deepwater situations in Asia, breeders may find it necessary to modify the breeding objectives to suit the needs of their region but can have access to elite materials rather than starting with the traditional donor parents.

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DISCUSSION

HOQUE: Deepwater rice is grown in a variety of diverse production complexes. In developing deepwater rice varieties for the future, breeders should bear in mind the agroecological situations for which these varieties are developed.

VEGA: Dr. Hoque, I believe cropping systems scientists should give rice breeders the varietal requirements for different production situations. Then the breeders can develop appropriate deepwater rice varieties.

HOQUE: Compared with local traditional varieties RD19 gives about 1 t/ha higher grain yield without fertilizer, and about 2 t/ha higher with fertilizer. Do you find variation in fertilizer responsiveness among the improved materials in deep water? Should these materials be screened with or without fertilizer?

JACKSON: We find a wide variation in fertilizer responsiveness among experimental lines. I suspect the variation among lines is greater than for ordinary wetland-rice breeding programs. This is because most of the deepwater-tolerant parents originated from floating rice, which is notorious for weak straw and poor fertilizer responsiveness. All our breeding materials are screened with moderate fertilizer levels. Those are higher than used by the farmer. It is applied at a uniform rate at time of planting. Our philosophy is that all future varieties must show good response to fertilizer. Otherwise, production cannot be increased significantly.

GOMOSTA: I believe the FR13A type of submergence tolerance is not desirable for deep water where plants have to elongate in a true floating rice environment. FR13A type of submergence tolerance is desirable in intermittent flooding. Should we screen for submergence tolerance for floating rice and varieties suitable for intermittent flooding using FR13A as a tolerant check in the same experiment?

JACKSON: I agree with your comment in general. FR13A submergence tolerance is for flash-flooded fields in the rainfed areas. However, floating rice is occasionally subjected to a flash flood that comes so quickly that elongation is not fast enough to keep its head above water. I believe there is a need for a type that can elongate rapidly such as a few varieties found in Bangladesh.

PETPISIT: Is there any difference between testing in still water and in flowing water?

JACKSON: Water movement may influence root establishment. I would expect differences. We have not tested rices in rapid water movement but are attempting to find a site where it occurs naturally.

GRIFFIN: Have the traits seed germination vigor and seedling establishment under broadcast seeding been considered in the development of improved deepwater rice varieties?

JACKSON: Perhaps not as much as it should. We know that floating rice seedlings grow fast during their first 30 days of age. We have observed some dwarf segregates of crosses between floating and dwarf materials that have faster seedling growth than others. This is partly an agronomic problem, but breeders should also be concerned with identifying fast-growing lines in the seedbed.

TUNEY: Are you assuming that the main development of the crop will be with direct seeding and not with transplanting?

JACKSON: We have large areas of transplanted tall traditional varieties. High yielding varieties are not grown in those areas, primarily because sometime during the season the water may get as deep as 1 m. If we can come up with a new type of variety — and we believe we have — which can appreciably affect the yields in those areas we can make real progress in the areas

not growing high yielding varieties. But there are areas where the farmers, due to either large size of farms and lack of labor to transplant or the necessity to get the crop started early to be broadcast, have to go for broadcast. My answer is both.

GRIFFIN: I feel that perhaps there is danger in screening on a large scale with only one method. Performance is not likely to be the same between the two planting methods.

JACKSON: This is a question we have faced for several years. If you develop a variety for broadcast seeding is it going to be of any use in transplanting, or vice versa? We have some data and the most outstanding study I have seen is one from the Suphanburi station where they broadcast-seeded and transplanted and got little yield difference. As a matter of fact many farmers in this part of the country broadcast-seed high yielding varieties on mud. We have compared the yield of those with that of transplanted crops and as long as weeds are controlled, there is no yield difference. So we don't believe a variety selected in transplanted plots will do poorer in broadcast-seeded plots.

TAYLOR: What is the time scale involved in breeding? In Bangladesh, for example, population increases 2 million per year — that is 10 million more people to feed in 5 years.

JACKSON: It required more than 10 years from making the cross to releasing RD19. This was partly due to lack of information on the approach to use because there was no background research. With the development of methodology and establishment of a series of elite breeding lines, I expect the time required to develop new varieties to be less.

SOME IDEAS ON BREEDING PROCEDURES AND REQUIREMENTS FOR DEEPWATER RICE IMPROVEMENT

D. HilleRisLambers and D. V. Seshu

SUMMARY

Recent results of international tests on deepwater rice are interpreted and their implications for deepwater rice breeding are discussed. Short-stature materials had a range of water depth adaptation equivalent to, sometimes surpassing, that of tall traditional rice varieties. Water depth alone did not completely explain the pattern of survival and destruction of lines tested. The effect of time as seen in first onset of water, rise in water level per day, and date of peak water level in relation to date of flowering gave good additional explanation. Moderate levels of submergence tolerance appear to be behind the high acceptability ratings of some entries in the IRDWONs. This trait deserves more emphasis in breeding programs. Test results for disease and insect resistance on floating rices from various areas suggest differences in local requirements for resistance. Several entries had wide acceptability in the various sites. These are highlighted and their adaptation range given. Correspondence between deepwater test sites, both in type of flooding and in varieties with good survival, did not necessarily correspond with geographical proximity.

DEEPWATER STRESS CHARACTERIZED

In South and Southeast Asia about 61 million ha are subject to drought or floods, or both. Seven million ha are classified as deepwater (maximum depth more than 1 m), and 13 million ha are medium-deep rainfed, with maximum water depths to 100 cm. In this paper, based on experience from international screening tests, we focus on breeding strategies for these excess-water areas.

Excess water is traditionally defined in terms relevant to the local situation. When scientists from various countries come to international meetings on deepwater rice, this gives rise to widely divergent terminologies and concepts (Sen 1975, Ismail 1979).

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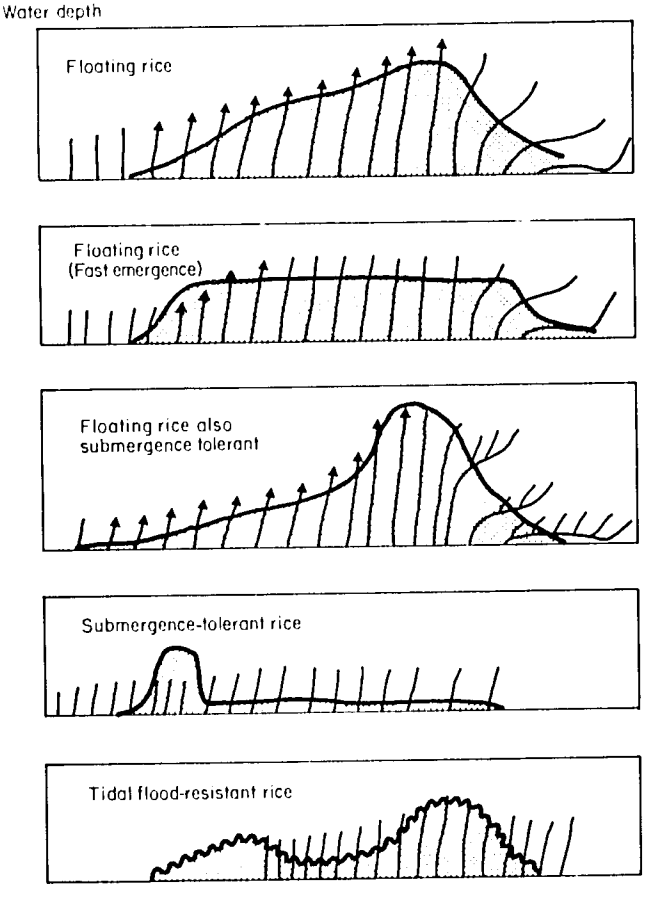
Most often deepwater stresses are defined in terms of maximum flood level. Such definitions do not take into account the time factor. As a working concept we propose thinking of excess-water situations with the growth curves of improved varieties in mind. It is where the water-level curve approaches, or actually overtakes, the modern variety growth curve that we consider water excessive. In those terms, a 30-cm flood at transplanting may be excessive yet 60 cm of floodwater later on may not cause crop damage.

Figure 1 has schematic representations of key water depth curves and the varietal types best suited to them. The following traits can contribute to survival of rice in excess water:

- *Tall stature* enables tall rainfed rices to survive floodings of 50-100 cm (depending on the growth stage). Tallness allows floating rices to absorb fast onset of water and temporary fluctuations of about 50 cm. Tallness expressed as seedling vigor is also important when growth conditions are poor, such as in the case of drought and problem soils.
- *Elongation ability* should allow 10 cm/day increases in water depth with tall varieties. Combined with short stature, 5 cm/day increases in water level can be tolerated as long as plants are in the vegetative stage.
- *Fast emergence,* with fast elongation ability, allows some floating rice varieties to



1. Schematic representation of different types of excess and deep water and the appropriate varietal tolerance mechanisms.

emerge within a week after a sudden surge of water 1 m deep. It also allows elongation of stems at the relatively early age of 14 days.

- *Submergence tolerance* allows varieties to stay completely submerged for 10 days in water 1 m deep without much damage.

OTHER VARIETAL REQUIREMENTS FOR DEEPWATER RICES

In addition to specific deepwater stresses, rice in excess-water situations needs to meet other site-specific criteria:

- *Flowering behavior.* When flood hazards span a long time period or when optimum harvest date is more predictable than possible planting date, or both, photoperiod sensitivity may be essential.
- *Tolerance for local stresses.* Many areas are drought prone during the rice-growing season. Other areas have acid sulfate soils. Some areas have salinity problems or, the weather may get too cold at the end of the growing season.
- *Resistance to local insects and diseases.* Resistance to stem borers, bacterial leaf blight, tungro virus, brown planthoppers, ufra nematodes, etc., is needed.
- *Adaptation to local agronomic practices and cropping systems.* In areas where farmers want to grow a crop after deepwater rice, early flowering dates are desired. In Thailand, however, farmers grow no crop immediately following deepwater rice and here late-maturing varieties are sought to allow harvest on dry soil. Good kneeing ability is important then. Weeding practices in Bangladesh call for varieties that can survive treatment with a tooth harrow (Catling, BRRI, pers. comm.).
- *Quality requirements and other market demands.* Countries differ in consumer preferences and in price incentives for meeting them. In Thailand long, slender, nonchalky, and slightly soft-cooking rices are required; in Bangladesh, where parboiling is common, rices of shorter grains, harder cooking quality, and more chalkiness are preferred.

FORMULATING DEEPWATER RICE BREEDING OBJECTIVES

The number of traits available from deepwater rices is considerable. Incorporation of all conceivable useful traits into a single variety is impractical. Breeding programs for deepwater rice use different methods to determine their needs:

- *Empirical approach.* An empirical approach is indispensable, at one stage or another, in every program. Programs operating in traditional deepwater rice areas have made progress in making line selections from farmer varieties and testing and releasing the best yielding lines.
- *Analytical approach.* Whenever crosses involving exotic parents are made, or when introductions of deepwater rice from other countries are sought for possible release, some analysis of environmental requirements is necessary. However, this should be followed by empirical testing of the selected varieties. A special case arises when one aims at changing the ideotype, as in recent work to replace tall, traditional rainfed rice with modern rices that compensate for their lack of tallness by their elongation ability (Beachell 1975, Jackson et al 1972). Breeding

approaches that use exotic materials in this and other ways can easily produce irrelevant materials if the validity of the plant-type concept is not verified by frequent testing in farmer fields.

SCREENING RESULTS ON VARIETAL ADAPTATION

The International Rice Deep Water Observational Nursery (IRDWON) results of 1976-80 (IRRI 1977, 1978, 1979, 1981) provide an important source for comparison of deepwater rices and their performance in a wide range of environments. Seshu (1982, this volume) provides comprehensive information on the IRDWON. Here we examine some data from these nurseries in more depth, using traditional data provided by nursery cooperators.

Figure 2 reproduces 14 water depth graphs from 1978 to 1980 IRDWON sites, ranked for maximum water depth. Some of the graphs correspond with one of the examples of Figure 1, others are more complex. There is little benefit to be expected in comparing the average performances of varieties over environments as diverse as these as one would likely come up with a variety not really good for any specific place.

Table 1 gives average survival percentages of key entries at a number of IRDWON sites. To calculate these percentages, entries were selected to represent 4 key types separately:

- short-stature (average plant height less than 130 cm) modern varieties.
- short-stature deepwater varieties with elongation ability.
- tall stature (no dwarfing genes).
- tall stature, with good elongation ability (floating rice).

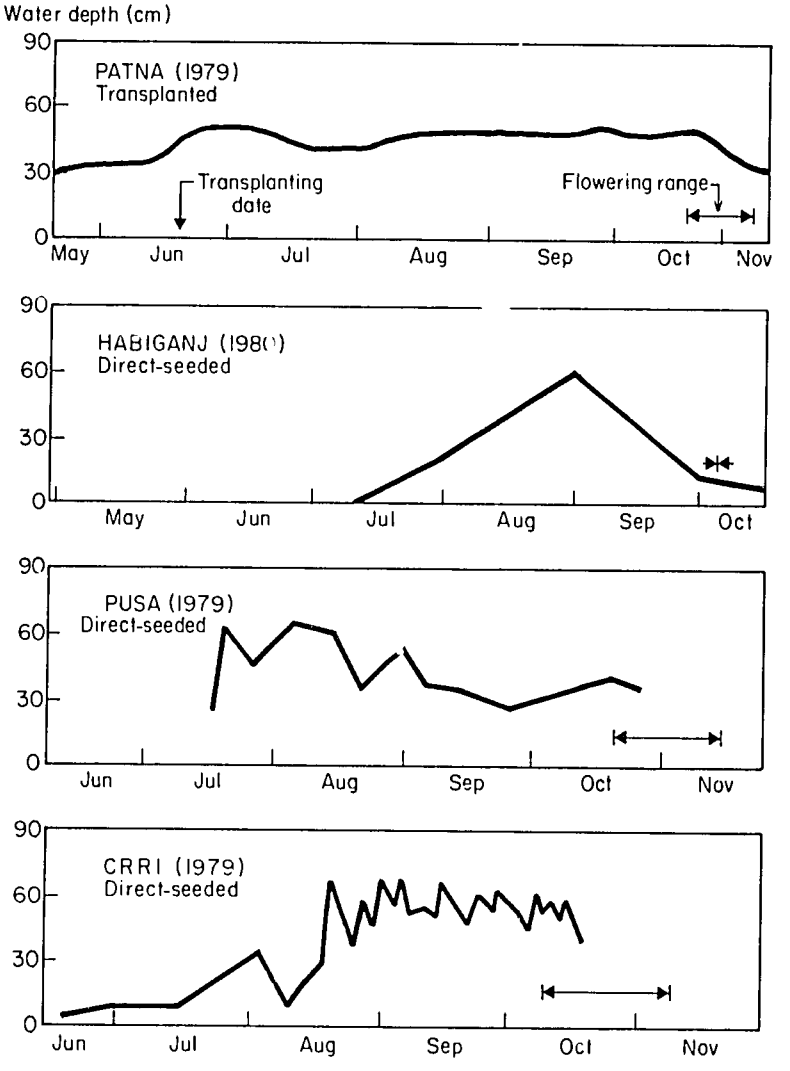
For each nursery, entries occurring in more than one nursery were grouped according to the above classification.

Flooding pattern and survival of varietal groups

The average survival of the selected key type groups in each site (Table 1) leads to the following conclusions:

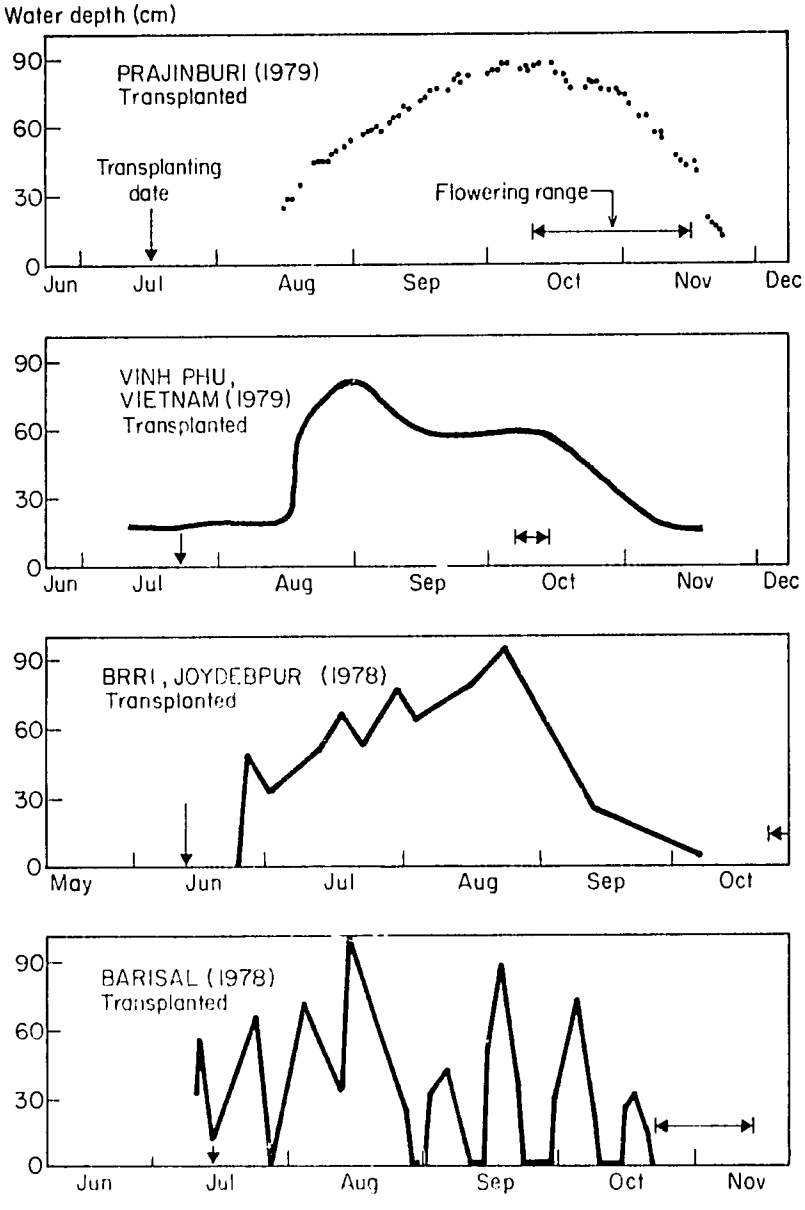
- Maximum water depths below 1 m gave survival of modern varieties anywhere between 5 and 100%. The association between maximum water depth and survival of modern varieties showed wide fluctuations. Compare, for example, Chinsurah (1977) and Cuttack (1979). This suggests the importance of factors such as time and duration of flooding.
- The difference between the average survival of elongating varieties and that of regular modern varieties at the same site (type 1 and 2) is an indication of the potential benefit of shorter-stature elongating deepwater types. Differences in survival of at least 25 percentage points were seen in Huntra (Thailand, 1976), Mudon (Burma, 1979), Habiganj (Bangladesh, 1980), Pusa (India, 1979), Prajinburi (Thailand, 1980), and Mopti (Mali, 1977).
- The differences between groups 2 and 3 (elongating modern varieties and tall traditional rices) were negligible when taken across all environments of Table 1, supporting the premise (Jackson et al 1972) that elongating modern varieties can survive minor flooding as well as the tall varieties they are meant to replace, and much better than the short plant types without such elongation ability.

- The difference between the survival of tall traditional rices and that of floating rices was small or negative in sites with maximum water depths below 1 m but substantial (at least 25 percentage points) in many sites with water deeper than 1 m.
- At various sites damage occurred selectively on modern varieties, deepwater improved plant types, tall traditional entries, or floating rices. Where floating rices were favored water level graphs suggest that there was a steady increase in water depth. When floating rices survived relatively poorly, water levels rose and



2. Water level graphs for 14 1978-80 IRDWON sites, ranked for increasing peak water depths. Date of seeding is the intersect of Y axis with the horizontal. An arrow (↓) indicates the transplanting date; ↔ indicates range of flowering dates of best adapted entries.

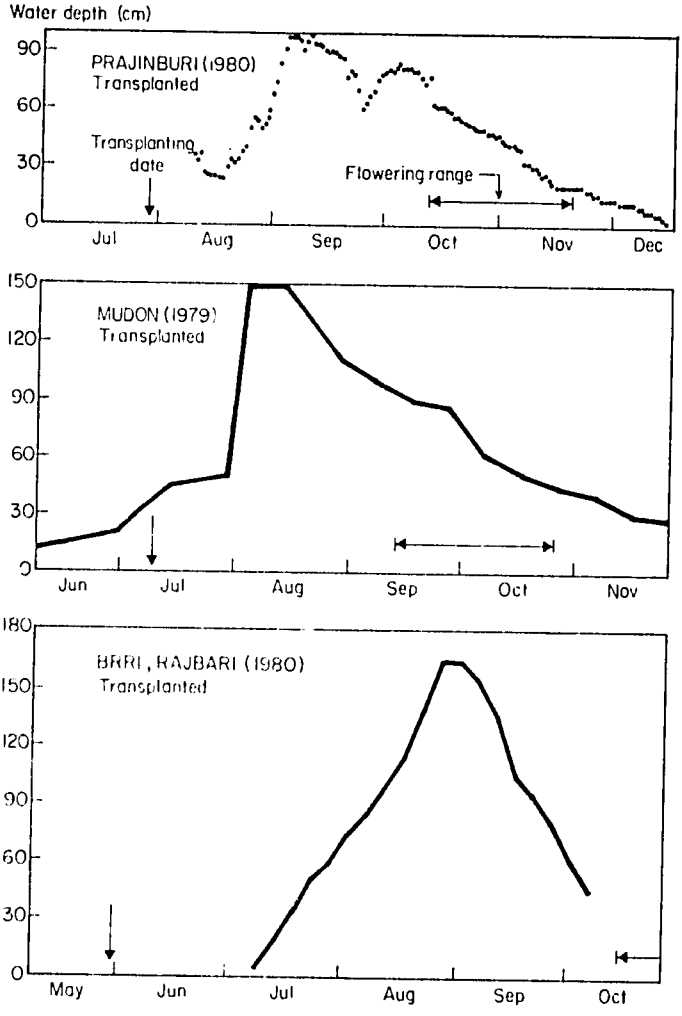
Fig. 2 continued



fell quickly, conforming with the need for submergence tolerance rather than elongation ability. Here, too, maximum water levels exceeding mature-plant heights still gave good survival (Fig. 2 for Habiganj, 1980; CRRI, 1979; Vinh Phu, 1979).

- Characterization of the best performing entries with independent knowledge of their elongating ability or submergence tolerance suggests that environments

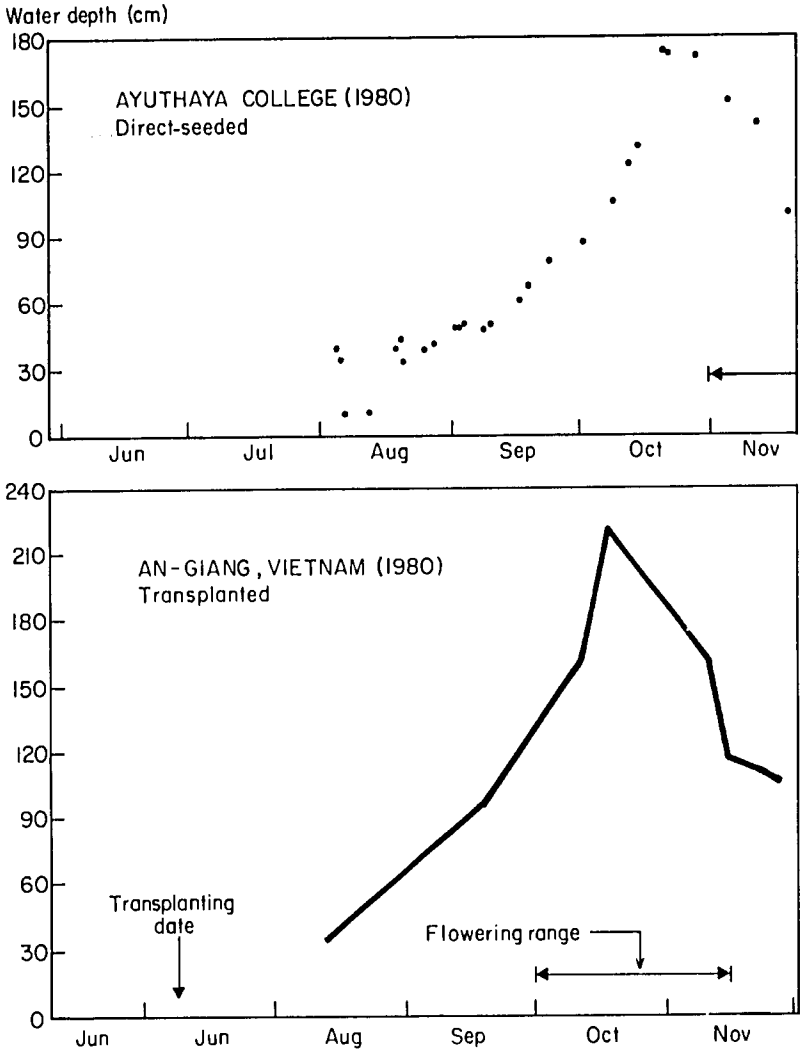
Fig. 2 (continued)



such as Mudon (1979), Mopti (1977), and Pusa (1979) allowed some varieties to survive through submergence tolerance and others through elongation ability.

- Some results illustrate the limitations of characterization of floods by their maximum level. Not everyone would characterize a 70-cm flood as one to favor

Fig. 2 continued



only floating rices, as it did in Chinsurah (1977).

- At several sites (Chinsurah, 1977; Joydebpur, 1980) the high best single entry survival, compared to that of any average varietal group survival (Table 1), reflects adaptability to site-specific flooding.
- Survival of modern varieties that do not have elongation ability per se (Table 1) reached zero at water depths about 100 cm unless the water started to increase late (97 days) in the growing period as in Habiganj (1979).

Fig. 2 continued

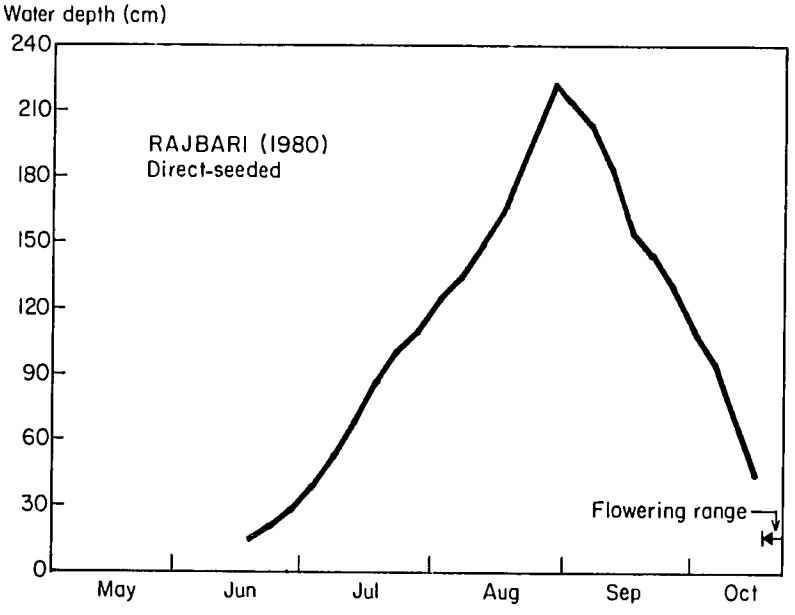


Table 1. Average survival of selected reference varietal types and of the best single entries in 28 sites collaborating in IRDWON 1976-80.

Year[a]	Site	Maximum water depth (cm)	% Survival by varietal group[b] Short NE	Short E	Tall NE	Tall E	Best surviving entries	Other attributes of best performers
1977	Bombuwela	30	100	100	100	100	100	
1979	Joydebpur	40	100	100	100	100	100	
1978	Joydebpur	45	100	100	100	100	100	
1978	Habiganj	58	100	100	100	100	100	
1977	Gograghat	60	100	100	100	100	100	
1979	Huntra	60	100	100	100	100	100	Submergence tolerance
1978	Prajinburi	70	100	100	100	100	100	
1979	Habiganj	100	100	100	100	100	100	Submergence tolerance
1977	Pusa	60	96	98	92	92	100	
1977	Pulla	71	91	93	98	90	100	
1979*	Cuttack	69	85	100	100	100	100	Submergence tolerance
1979*	Patna	50	72	77	74	-	90	Submergence tolerance
1976	Huntra	58	60	81	80	80	100	
1979*	Prajinburi	88	54	70	64	60	100	
1980*	Habiganj	60	34	66	72	65	90	
1979*	Vinh Phu	86	25	25	30	45	100	Submergence tolerance
1977	Habiganj	97	20	21	31	41	80	
1977	Mopti	210	16	32	31	75	100	
1979*	Pusa	66	11	56	62	51	90	
1977	Chinsurah	70	9	12	22	23	55	
1979*	Mudon	149	9	36	22	21	64	Submergence tolerance
1980*	Joydebpur	165	4	7	24	78	100	
1978*	Barisal	100	1	8	13	26	55	
1980*	Prajinburi	100	1	69	49	61	85	
1978*	Joydebpur	96	0	1	7	2	19	Submergence tolerance
1980*	Huntra	176	0	6	0	80	100	
1980*	An Giang	220	0	0	0	64	95	
1980*	Joydebpur	220	0	1	0	62	100	

[a]Asterisks indicated water level graphs in Figure 2. [b]Varietal groups contributing best performers are underlined. NE = nonelongating; E = elongating. -Not planted.

Table 2. Entries in IRDWON 1976-80 with frequently high survival of phenotypic acceptability, or both.

Group and entries[a]	Sites (no.) tested	Sites (no.) where entry excelled	Plant height (cm)	Range of water depth (cm) where entry excelled (40 60 80 100 120 140 160 180 200 220)
Group 1				
IR5825-41-2P1	12	3	106	
CN539	21	2	120	
Group 2				
BKN6986-147-2 (RD19)	28	8	123	
BKN7022-6-4*	21	6	122	
IR7732-B-A96-3	15	3	141	
Group 3				
Sitpwa*	14	4	142	
Chenab 64-117*	21	3	132	
Madhukar*	15	3	116	
BR118-3B-37*	14	5	141	
Group 4				
BKN[illegible]6-81-5	13	3	150	
SPR7[illegible]2-2-2-3	15	7	138	
FRRS43/3*	27	8	145	
Sarah Kranam	21	6	156	
Gula	12	4	147	
CNL31	12	3	148	
CNL241	12	5	151	
BR229-B-88	14	3	134	
Khama	6	3	201	
Chamara	6	3	186	

[a]Group 1 - short stature, Group 2 - short stature, elongating, Group 3 - tall stature, Group 4 - tall stature, elongating. Photoperiod-sensitive entries are underlined. Asterisks mark entries with submergence tolerance in one or more controlled tests.

Best varieties in the four groups

Table 2 lists some entries among four varietal groups that were frequently among the best at a given site. The best varieties for each site were determined usually as those with acceptability at maturity scored 3 or better by the cooperator. In several cases this was modified to restrict the number of best judged entries to 12 at most, except Gograghat (1977) which had 16 best entries, all with an acceptability score of 1. For each entry in Table 2 the dots representing the water depths at which they were judged acceptable are connected. We conclude the following:

- The range of (water depth) environments at which modern varieties are adapted has been considerably extended by adding elongation ability to those types (compare groups 2 and 1).
- The best judged varieties in group 3 (tall traditional rices) are *borderline cases* —varieties judged submergence tolerant in at least 1 controlled test, and also capable of survival in slowly rising water if water depths stay lower than about 150 cm. At lower water depths those entries often appear similar to floating rice.
- The floating rices group is not homogeneous in range of adaptation, with the Bangladesh varieties Khama and Chamara favored only in deep water, other entries such as BKN6986-81-5 and BR229-B-88 gaining best acceptance only at low water levels, and some varieties showing wide adaptation.

Table 3. Insects and diseases encountered by IRDWON cooperators in various countries, 1976-80.[1]

	SB	BLB	BS	RTV	ShB	ShR	FSm	LF	RRS, BPH	BST	BLS	NBLS	H	Others
Philippines	•			•					•					Grassy stunt virus
Vietnam			•											Fish, ufra, spider
Thailand	•		•		•			•	•		•	•	•	Cricket, seed discoloration, fish, crab
Burma	•	•						•					•	Crab
Bangladesh	•	•		•	•	•				•	•			Root knot nematode
India														
West Bengal	•	•												
Bihar	•	•	•											
Uttar Pradesh	•		•											
Andhra Pradesh	•	•												
Sri Lanka	•	•						•						Bronzing

[1]Abbreviations: SB = stem borer, BLB = bacterial leaf blight, BS = brown spot, RTV = rice tungro virus, ShB = sheath blight, ShR = sheath rot, FSm = false smut, LF = leaffolder, RRS = rice ragged stunt, BPH = brown planthopper, BST = blast, BLS = bacterial leaf streak, NBLS = narrow, brown leaf spot, H = hispa.

SCREENING RESULTS ON TRAITS OTHER THAN DEEPWATER ADAPTATION

Flowering behavior

The ranges in flowering date of the best entries are indicated in Figure 2, with horizontal bidirectional arrows connecting the flowering dates of the earliest and latest favored lines.

- The flowering date ranges of the best performing lines started about 1 month after the water had reached its highest peak. This is logical in more than one way because not only would a flowering date before the maximum-water stage be damaging, but deepwater stress may also delay floral initiation by as much as 20 days (see IRRI 1978, Habiganj data). Relief from such stress (after the peak water level) results in flowering about 35 days later.
- A site such as Prajinburi (Fig. 2, 1979, 1980) had a considerable range of flowering dates compatible with good phenotypic acceptability. Farming practice is decisive in such cases: if farmers wish to grow another crop on residual moisture, an early harvesting date will be desirable, but if not, farmers will likely prefer a crop that can be harvested on dry soil, as they do in Thailand's Central Plain.

Disease and insect resistance

Table 3 lists insects and diseases encountered by IRDWON cooperators. The tabulation expresses the prime importance of stem borers in almost every site. Bacterial leaf blight, brown spot, and leaffolders were also often mentioned. A different, more objective aid to focus on disease and insect resistance needs in a region is, of course, on-site sampling (Catling and Islam 1979). As a supplemental effort we emphasize the idea of taking a representative sample of farmer varieties from the region and testing them for resistance to various insects and diseases, and other stresses. Assuming that those problems to which resistance is most frequently found in the local varieties are indeed problems worthy of attention in breeding programs, one can then establish priorities.

Table 4. Diseases and insect resistance of some deepwater and rainfed varieties from Bangladesh, India, and Thailand.[a]

	Sal	BLB	BST	GLH	BPH biotypes 1,2,3	ShB	Zinc deficiency
Bangladesh							
Bawalia		3	6		9 9 9		
Beguamon 202		7	5	5	9 9		3
Beguamon 343		7	5	5	9 9		3
Beguamon 349		7	6	3	9 9 9		
Chota Bawalia		1	6	3	9 9 9		
Dholamon 39-3	4	4	4	4	9 9		4
Dholamon 64-3		4	6	7	9 9 9		
Dholamon 65		4	6	6	9 9 9		
Digha		3	6	5	9 9 9		
Dudamonor		3	1	9	9 9		3
Dudhsar		5		7	9 9		3
Gilamite			6	3	9 9 9		
Gowai 38-13		4	5	8	7 9 9	5	
Habiganj Aman VIII		7	6	8	8 9		5
Kalamon 21-7		6	4	8	9 9		3
Kalamon 55-22		5	5	9	9 9		3
Kalamon 113		4	2	4	8 9 9		
Kalamon 243		1	7	5	9 9 9		
Kalimekri 77		7	5	3	9 9 9		3
Kalimekri 77-5		6	6	4	9 9 9		3
Karkati 87		6	6	8	9 9 9	5	3
Kartik Sail		5	2		9 9 9		
Khama		1	6	3	9 9 9		
Khama 49-2		4	6	5	9 9 9		3
Khama 380		7	6	5	9 9		
Kahamai 55/27		7	7	9	7		
Laki 724		7	7	3	7 9 9		
Laki 550		7	4	6	9 9 9	4	
Lakshmi Digha		1	4		9 9 9		
Lalamon 593		7	9	7	7		
Matiamon 73-23	4	4	2	3	9 9 9	5	
Pankaish		7	8		9 9 9		
Sarsari		3	1	3	9 9 9		
BR223-B-37		7	7	9	7 9 7	5	3
BR226-B-216		1	9	3	9 9 9		
BR229-B-88		1	6	9	5 9		
India							
Chakia 59		7	5	9	9 9		
CNL241	4	6	5	6	8 9 9	5	
CNL319	4	4	4	5	9 9 9	5	
DW6172A		1	5	4	9 9		
DW6255		4	5	3	7 7 9		
FRC 1		5	6	9	9 9 9		
FRC 2		4	4	9	9 9		
FRC 7	5	6	4	9	9 9		
FRC 10		6	6	8	9 9		
FR13A	3	4	5	6	8 9 9	5	3

Continued on opposite page

Table 4 continued

	Sal	BLB	BST	GLH	BPH biotypes 1,2,3	ShB	Zinc deficiency
Kekowa Bao		7	6	3	7 9 9		
Madhukar	5	3	5	6	9 8 9		
NPS 270		7		9	9 7		
CN540		3	8	6	7 9 9	5	
CR1009		5	7	7		5	
GEB24		6	8	9	7 9 9	5	
IET5656		7	7	7	9		
Thailand							
Leb Mue Nahng 111		7	6	8	9 9	5	3
Tapow Gaew 161		2	4	4	1 6 1		4
BKN6986-66-2		5	5	7	9 9		3
BKN6986-81-5		6	7	4	9 8 9		3
BKN6986-167		6	8	5	5 6 8	5	
BKN6986-108-2	4	6	3	8	8 9 7	5	
BKN7022-6-4		4	2	4	9 9 9	5	
BKNFR760-3		6	5	3	7		1
DWCT134-1-3		1	5	7	6 9 3		
RD19	5	6	6	8	7 9 9		
SPR7233-1-24-2-2-1		2	8	5	3 9 3		
Others							
Cula	4	6	5	8	7 9 9	5	
Peta		7	4	3	9 9 9	5	
Thavalu		7	4	9	9 9		3
BH2		7	3	5	7		
B1050-M4-7-3	4	6	7	6	9 9 9	5	
IR442-2-58		6	7	7	8 9 2	5	
IR5825-41-2-P1		3	4	4	3 9 3	5	

[a]Data from the Genetic Evaluation and Utilization program, IRRI, 1977-81. Abbreviations: Sal = salinity, BLB = bacterial leaf blight, BST = blast, GLH = green leafhopper, BPH = brown planthopper, ShB = sheath blight. Scores are by Standard Evaluation System for rice (IRRI 1980).

Table 4 presents data on rice varieties, mostly floating and from Bangladesh, obtained from the Genetic Evaluation and Utilization testing program at IRRI. The following is evident:

- Some degree of resistance to bacterial leaf blight, green leafhoppers, zinc deficiency, and blast is present in about half of the Bangladesh floating rice varieties of the sample.
- No resistance to brown planthoppers was encountered in varieties from Bangladesh or in the floating and rainfed rice varieties from North and Northeast India.

- The Thai traditional varieties listed in Table 4 had no resistance to green leafhoppers, but one did have resistance to brown planthopper.
- RD19, by lacking green leafhopper resistance, misses an apparently essential ingredient for acceptance in Bangladesh, a fact already pointed out by BRRI scientists.
- The requirements of Thailand, Bangladesh, and India for disease and insect resistance seem to be different based on Tables 3 and 4.

Drought tolerance

Drought tolerance data are available only for the 1980 IRDWON in Thailand. By no means were all deepwater varieties drought tolerant in the test. The most tolerant were NPS 270, Madhukar, and Thavalu 15325. Lack of tolerance was shown by GMS 12 and Khama. These data, preliminary as they are, suggest that it may be worthwhile to find out in what (type of) areas drought tolerance is a priority — and where it is not.

IMPLICATIONS FOR FUTURE DEEPWATER RICE BREEDING

The information we highlight here has a bearing on breeding objectives and also on the choice of deepwater progenitors to be used.

Breeding objectives

- Elongation ability, combined with short stature, provides protection against deep water of about 1 m, equivalent to that given by tall stature alone, provided the rise in water level is not more than 5 cm/day.
- Tall stature is still indispensable for places where increases in water depth are more than 5 cm/day. Tall varieties are also needed in case of drought stress and problems of plant nutrition.
- Photoperiod sensitivity is necessary in many deepwater areas. For good adaptation, lines should have their floral induction after the maximum water level has been reached, with the desired cropping pattern determining precisely how long after this point flowering should take place.
- Several areas can be grouped together on the basis of water graphs and corresponding ratings for best varieties. Chinsurah (India) and Barisal (Bangladesh) show similarities in this way, and varieties that performed best in Joydebpur (Bangladesh) and An Giang (Vietnam) were also essentially the same in 1980.
- Submergence tolerance provided needed protection to sudden water movements in many instances. Its role can also be deduced from the fact that in Table 2 all outstanding varieties of category 3 (tall traditional) and one of category 2 (improved elongation), had also been shown submergence tolerant in at least one controlled test. This trait deserves increased attention in the screening of deepwater materials, regardless of parentage.
- Some floating rice types (Table 2, type 4) showed a wide range of acceptability down to water levels of 50 cm. Other floating rices, especially the Bangladesh materials suitable for very deep water, were not among the best rated types when planted in shallow water. To make use of this knowledge breeding objectives should consider a range of water depth, rather than one single depth.

- Due to the complexity of the deepwater environment, a close study of the target environments for one's breeding program is worthwhile. One can do this by a direct observation of the environment, and additionally by a study of the tolerances and resistances present in traditional adapted varieties from such environments. Only then can one set meaningful priorities for a breeding program. The needs for resistance to tungro, brown planthoppers, and green leafhoppers should receive further study and documentation.

Breeding materials

- RD19, which is exotic to all countries except to Thailand, is not necessarily widely adapted, because of site specificity. Yet in Thailand RD19 has performed well in medium-deep rainfed rice areas, with some overlap into floating rice. Crosses between this variety and locally adapted medium-stature and tall rainfed rices should, therefore, be of value.
- BKN7022-6-4, although lacking photoperiod sensitivity, should be a valuable line for crosses because of its elongation ability, moderate tolerance for submergence, and good plant type, and, of course, its frequent selection by IRDWON cooperators.
- BR118-3B-37 should be used in crosses aiming at medium tall stature combined with some submergence tolerance.
- Chenab 64-117 may prove useful in crosses for areas where erratic water level fluctuations are superimposed on medium-deep levels.
- SPR 7233-1-24-2-2-2-23, FRRS 43/3, Saran Kraham, Cula, CNL31, and CNL241 provide well-adapted floating rices for a considerable range of water depths.
- For fast rising water and deep maximum levels, Bangladesh varieties Khama and Chamara may be useful as breeding materials.

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DISCUSSION

DURVASULA: High incidence of rice tungro virus occurred in several deepwater areas in eastern India this year, which suggests the need for incorporation of resistance to this virus.

CATLING: Ragged stunt virus is severe in some deepwater rice fields in Thailand this year. As much as 15% of stems at the water surface show clear symptoms of the disease at the end of elongation stage.

HILLERISLAMBERS: I believe it will be useful to screen local Thai varieties for ragged stunt resistance because we observed varietal differences among varieties that were part of deepwater rice yield trials last year.

PETPISIT: Your slides showed many kinds of varieties matching different levels of water. Do you have any idea about inheritance of this trait in different kinds of material?

HILLERISLAMBERS: Regarding this fast elongation, as exhibited by Bangladesh floating rice varieties like Khama or Baisbish, we have crosses between T442-57 or Pin Gaew 56 and Habiganj Aman VIII which we subjected to fast elongation requirement — elongation starting at 2 weeks seedling age instead of the normal 4 weeks. The survivors were clearly Habiganj Aman VIII and the two crosses with Habiganj Aman VIII, not T442-57 or Pin Gaew 56. We are working with the surviving lines in the F_3 generation. We do not know much about this inheritance in terms of number of genes, and so on, but we were able to pick it up from the F_2s of the crosses.

VEGA: You showed different patterns in which flooding occurs. Are you implying that this is what happens every year or at a particular site or that these things could happen at one site at different times?

HILLERISLAMBERS: At Prajinburi in 1980 high yielding varieties did not survive. But going back to Prajinburi in 1979 there was a different approach to the maximum water level and even high yielding varieties — of course, those that could stand waterlogging survived. So there is variability in water regimes but some of it, I believe, is predictable by the topography. We have to give our characterization of a particular site as a range of likely water regimes.

MULTILOCATION SCREENING FOR RICE VARIETAL TRAITS RELEVANT TO DEEPWATER CULTURE

D. V. Seshu

SUMMARY

The International Rice Deep Water Observational Nursery (IRDWON) was initiated in 1976 by the International Rice Testing Program (IRTP). IRDWON tests in various countries during 1976-80 led to identification of some promising breeding lines with traits important for survival and productivity in deepwater fields of various water depths. Basing on 5 years of experience, IRDWON was reorganized in 1981. Details of those changes are outlined. Responses to a survey of the use of IRDWON entries by different countries are summarized.

Deepwater rice is an important crop in some rainfed areas of several South and Southeast Asian countries, as well as in limited areas of West Africa and Latin America, where water becomes too deep for the modern short-stature varieties. Yields of deepwater rice have remained low despite its major socioeconomic significance.

Water depth, rate of water increase, date of maximum water depth, turbidity, date of sowing, desired date of flowering, and many other factors are all site specific for deepwater rice. On-site testing is, therefore, necessary to identify deepwater-tolerant varieties for the specific environments. The International Rice Testing Program (IRTP), coordinated by the International Rice Research Institute (IRRI), seeks to aid in identifying deepwater-tolerant varieties through the International Rice Deep Water Observational Nursery (IRDWON), which IRTP established in 1976. The IRDWON provides a way for scientists in different regions to conveniently exchange and evaluate genetic materials to develop deepwater rice varieties with improved yield. Since IRDWON started there have been continuous changes in screening methods and test materials to serve the needs of different deepwater areas.

IRDWON had a major reorganization in 1981. I outline that and also summarize the salient results from IRDWON to date.

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IRDWON TEST SITES AND MATERIALS

The sites where IRDWON nurseries were tested during 1976-80 are seen in Figure 1.

The IRDWON entries originate mostly from the breeding programs of Bangladesh, India, Indonesia, IRRI, Thailand, and Nigeria. Several traditional deepwater rices from Bangladesh, India, and Thailand were also included. Initially, most of IRDWON entries were improved lines from Thailand's deepwater rice program but gradually diverse breeding lines were added. In 1979, materials originating from rapid generation advance and deepwater composites were added. Both photoperiod-sensitive and -insensitive lines were included, with the proportion of photoperiod-sensitive lines increased gradually. Leb Mue Nahng 111, IR442-2-58, Pelita I-1, C4-63, and Habiganj Aman II served as check varieties in different years.

IRDWON results 1976-80

The broad parameters of IRDWON tests for 1976-80 are summarized in Table 1.

In 1976 and 1977 the screening consisted of two treatments:

- planted in shallow, controlled water with no danger of flooding, and
- planted in low areas where water more than 50 cm deep was expected sometime during the monsoon.

With the inclusion of more diverse material and with more information on entries, the nursery in 1978 emphasized 2 distinct groups of materials — a group intended for water depths of 50-100 cm and another group for deeper water.

The first group of entries had intermediate plant height but did not necessarily have elongation ability. Most, however, had some submergence tolerance. Their growth duration varied and some were photoperiod sensitive. The entries would grow in rainfed-wetland, waterlogged areas.

The second group of entries had internode elongation ability, were photoperiod sensitive, and were expected to survive water depths of more than a meter.

Observations were recorded mainly on phenotypic acceptability, survival percentage, elongation ability, rooting ability, kneeing ability, drought tolerance, reactions to diseases, and soil stresses.

Phenotypic acceptability. Phenotypic acceptability ratings reflect an overall assessment of the entries' suitability for the conditions in the given region. Widely accepted entries and their other useful attributes are summarized in Table 2. Entries judged good at more than one site in different years were (parentages of the entries are given in Appendix 1, sites in Fig. 1):

- *1st IRDWON (1976).* Based on observations at Yezin (100-cm depth) and Huntra (58-cm depth):

BKN6986-147-2 (RD19)	BKN6987-105-4
BKN6986-66-2	BKN6987-52-1
BKN6987-161-6	BKN6987-68-14

- *2nd IRDWON (1977).* Based on observations at Habiganj (97-cm depth), Pulla (71-cm depth), and Chinsurah (70-cm depth):

BKN6986-81-5	CNL31
Habiganj Aman I	CNL53

- *3rd IRDWON (1978).*

Table 1. Broad parameters of IRDWON tests. 1976-80.

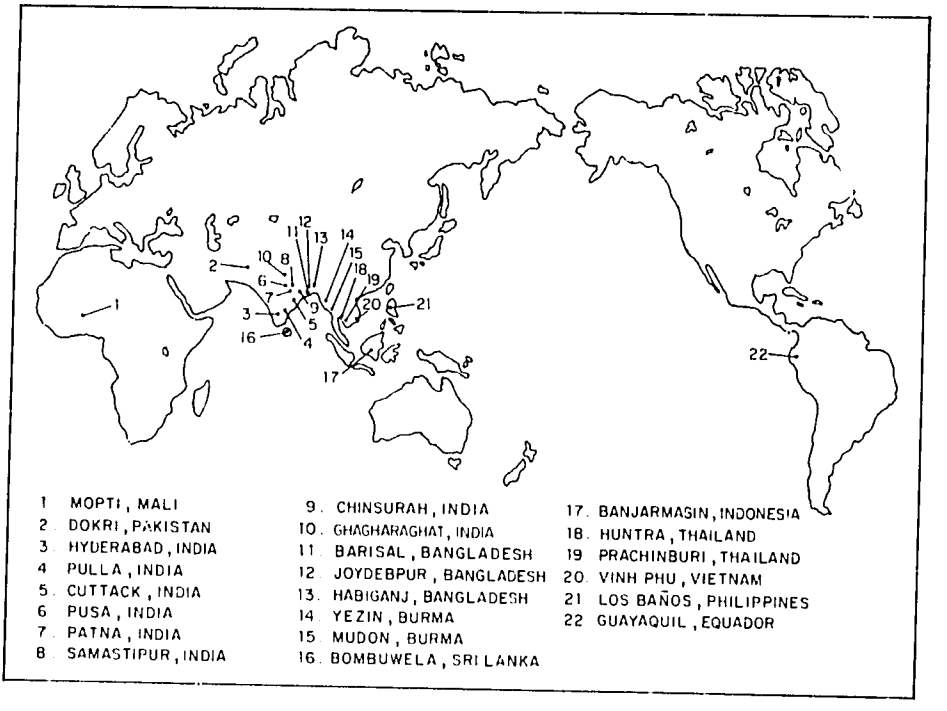
Year	Entries (no.)	Participation: Countries (no.)	Participation: Sites (no.)	Range of water depth (cm)	Data recorded: PAcp[a]	Survival (%)	Elongation ability	Rooting ability	Kneeing ability	Drought tolerance
1976	50	4	4	58-100	x	x		x	x	
1977	70	9	12	30-120	x	x	x			
1978	74	6	9	58-185	x	x	x	x	x	
1979	62	7	13	40-150	x	x	x		x	
1980	53	4	7	63-220	x	x	x			x

[a]Phenotypic acceptability.

Table 2. Desirable attributes of IRDWON entries(1976-80) that had broad phenotypic acceptability.

	Approximate depth[2] of adaptability	Photo-period sensi-tivity	Submer-gence toler-ance	Kneeing ability	Aquatic rooting ability	Drought tolerance	Disease and insect resistance
Short stature							
BKN6986-66-2	5						
BKN6986-108-3	3		x				FSm
BKN6986-147-2	5	x			x		
BKN6987-52-1	5						
BKN6987-68-14	7						
BKN6987-105-4	5						
BKN6987-161-6	5	x					
BKN7022-6-4	5		x				
B922c-Mr-7	7						
B1050c-Mr-7-3	7		x				BLB
CN539		x					RTV
IR7732-B-A96-3	5						
ARC 5955	5			x	x		
Tall							
Beguamon 349	1	x		x	x		GLH
BKN6986-81-5	1	x					
BKN6986-173-5	3	x					
BR118-3B-17	7	x	x		x		BLB
Chamara	1	x		x			
Chenab Sel. 64-177	3	x	x				FSm, BPH 1
CNL31	1	x					
CNL53	1	x	x				
FRRS43/3	1	x	x	x			
Habiganj Aman I	1	x		x			
Madhukar	5	x	x				
Pelita I-1	7				x		
RAU21-168-1-2	7		x				
Saran Kraham	1	x					
Sitpwa	3	x	x		x		
SPR7233-1-24-2-2-2-3	1	x					
SPR7202-151-2-1-B-B	3					x	
Sungwala	1	x					
Yodaya	5	x					

[2]1 = 200 cm; 3 - 150 cm; 5 = 100 cm; 7 = 50 cm.



1. Sites where IRDWON nurseries were tested, 1976-80.

- *50- to 100-cm water depth:* Based on observations at Prajinburi (70-cm depth):

ARC5955	BKN6986-147-2 (RD19)
B922c-Mr-7	BKN7022-6-4
B1050c-Mr-7-3	Pelita I-1
BKN6986-108-3	Sitpwa
	Yodaya

Water depths more than 100 cm: Based on observations at Yezin (150-cm depth), Barisal (100-cm depth), and Joydebpur (100-cm depth):

Habiganj Aman I	Sungwala
Saran Kraham	Beguamon 349

- *4th IRDWON (1979).*

50- to 100-cm water depth: Based on observations at Patna (50-cm depth), Cuttack (70-cm depth), Joydebpur (40-cm depth), Gograghat (40-cm depth), Pusa (58-cm depth), and Vinh Phu (86-cm depth):

Chenab Sel. 64-117	BKN6986-147-2 (RD19)
CN539	BKN7022-6-4
BR118-3B-17	RAU21-168-1-2
BKN6986-173-5	IR7732-B-A96-3
BKN6986-108-3	SPR7292-151-2-1-B-B
	Sitpwa

Water depths more than 100 cm: Based on observations at Yezin (110-cm depth), and Habiganj (100-cm depth):

FRRS43/3	Madhukar

- *5th IRDWON (1980).* Based on observations at Prajinburi (100-cm depth), Huntra (174-cm depth), Vinh Phu (220-cm depth), and Joydebpur (165-cm depth).

Water depths more than 100 cm:

SPR7233-1-24-2-2-2-3	FRRS43/3
SPR7292-151-2-1-B-B	Chamara

Survival percentage

- *1st IRDWON (1976).* At Yezin, where the maximum water depth was 100 cm, the following entries had more than 90% survival: Pelita I-1, BKN6986-58-1, BKN6986-66-2, BKN6986-45-1, BKN6986-105-P, BKN6987-105-4, and BKN6990-63.
- *2nd IRDWON (1977).* At Huntra, where the maximum water depth was 125 cm, 14 of 70 entries had 100% survival: T442-57, Cula, FRRS43/3, HTA7204, BKN6986-167, BKN6986-81-5, Leb Mue Nahng 111, Saran Kraham, Habiganj Aman I, Habiganj Aman II, Habiganj Aman IV, CNL319, CNL180, and CNL241.

  Saran Kraham, CNL31, and CNL53 were among the better survivors at most sites that reported on survival.
- *3rd IRDWON (1978).* The deepwater test at Hyderabad was in an artificial tank with water 185 cm deep. The entries that showed a higher percentage of survival were IR442-2-58, IR5825-41-2-P1, Mura Bazal, Sungwala, Kekowa Bao, Karkiti 87, BR229-B-88, IR5825-41-2-P4, Tadaungpo, and Beguamon 349.
- *4th IRDWON (1979).* Based on data from 7 test sites (Yezin, Mudon, Prajinburi, Cuttack, Patna, Pusa, and IRRI), entries that had overall highest survival percentage were BH2, BKN6990-63, BKN7022-6-4, IR9288-B-B-B5-2, and Sitpwa.
- *5th IRDWON (1980).* The maximum water depth for the test at Vinh Phu was 220 cm and for a greater part of the growing season the water depth was more than 100 cm. Thirty-six of the 53 entries had no surviving tillers. The entries that had 50% or higher survival in that test were FRRS43/3 (95%), SPR7233-1-24-2-2-2-3 (95%), Chamara (90%), DW6167 (80%), SPR7292-151-2-1-B-B (80%), Khama (70%), DW48 (70%), and Jalamagna (50%).

Elongation ability

- *2nd IRDWON (1977).* The test at IRRI varied widely in percentage of increase in plant height. Although greater increase would be advantageous in deep water, it might be disadvantageous in shallow water. Entries with high rates of increase (more than 40%) in plant height included BKN6986-105-P, IR5853-135-3-P3, BKN7022-10-1-4, HTA7204, Leb Mue Nahng 111, and Peta.

  Those with lower rates of increase (less than 10%) included Pelita I-1, IR5825-41-2-P2, BGD-4-7-3-PE-1, BR46, Chenab Sel. 64-117, ARC5955, CN536, and CNL180.

Only 5 entries received good ratings for internode elongation at Joydebpur where the maximum water depth in the test plots was 110 cm: Saran Kraham, Habiganj Aman I, Habiganj Aman II, Habiganj Aman IV, and Habiganj Aman VIII.

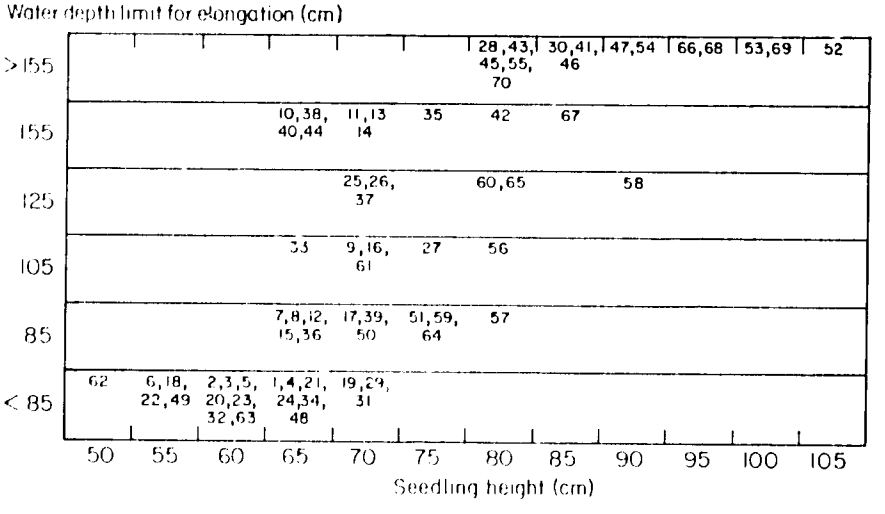
The data from Huntra indicated an association between seedling height at 30 days of age and the limit of water depth for elongation (Fig. 2).

- *3rd IRDWON (1978).* At Habiganj, Prajinburi, and IRRI, entries rated good for elongation ability were Baisbish, Gowai 84, Habiganj Aman I, Kekowa Bao, Leb Mue Nahng 111, Laki 192, Pin Gaew 56, Saran Kraham, Balam, Mura Bazal, and Beguamon 349.

  These entries were all in the set intended for water depth more than 1 m.
- *4th IRDWON (1979).* Entries rated good for elongation at Habiganj were BR223-B-1, BR118-3B-17, BR223-B-38, BR229-B-88, FRRS43/3, Leb Mue Nahng 111, and Saran Kraham.
- *5th IRDWON (1980).* Based on scores given at Huntra, Prajinburi, Habiganj, and Vinh Phu, entries rated good for elongation were SPR7233-1-24-2-2-2-3, BR223-B-38, Chamara, DW48, DW6167, FRRS43/3, GMS12, GMS13, Jalamagna, and Khama.

Rooting ability. Studies at IRRI indicated lines promising for aquatic rooting ability, an important requirement for the performance of deepwater rice.

- *1st IRDWON (1976).* BKN6986-29, BKN6987-108, Pelita I-1, Habiganj DW2, ARC5955.



2. Association between water depth limit for elongation and seedling height at 30 days after seeding, second IRDWON, Huntra, Thailand, 1977. Numbers indicate entry numbers.

- *3rd IRDWON (1978).* B1050c-Mr-7-2, B1050c-Mr-18-2, BKN6986-45-1, BKN6986-66-2, BKN6986-108-2, BKN6986-147-2, BR118-3B-17, IR442-2-58, IR5825-41-2-P1, Sitpwa, CN536, Habiganj Aman I, Leb Mue Nahng 111, Sungwala.

Kneeing ability. Kneeing ability is important for performance in many deepwater situations. Entries rated highly for this trait were:

- *1st IRDWON (1976).* At IRRI, BKN6986-29, BKN6986-71, BKN6986-58-1, BKN6986-59-2, BKN6987-225, ARC5955.
- *3rd IRDWON (1978).* At IRRI, ARC5955, IR4630-22-2-17, Baisbish, CN536, Gowai 84, Habiganj Aman I, Kalar Hasall, Kekowa Bao, Laki 192, BR223-B-38, BR229-B-88, Balam, Beguamon 349, Karkiti 87.
- *4th IRDWON (1979).* At IRRI, Prajinburi, and Habiganj, Baisbish, FRRS43/3, GT53, Chamara, Chota Bawalia, Khama, Lakshmi Digha, Sarsari, GMS12, GMS13, DW48, Jalamagna.

Drought tolerance. Drought tolerance in the early growth stages is important for deepwater rice in many areas.

- *5th IRDWON (1981).* At Huntra, BKN7022-10-1-4, DWCT37-2-B-B, DWCT134-1-3-B, IR13358-73-1-1, SPR7233-1-40-1-1-1-3, SPR7292-151-2-1-B-B, NPS270, and IR8234-OT-20.

Diseases. Entries rated tolerant of some of the important diseases were:

- *2nd IRDWON (1977).* Bacterial leaf blight at Yezin, Huntra, Habiganj, and Samastipue: Saran Kraham, Habiganj Aman VIII, BKN7022-6-4.

Rice tungro virus at IRRI and Joydebpur: IR5853-135-4-P3, Jalaj, CNL241.

- *3rd IRDWON (1978).* Blast at Cali: BR118-3B-17, Baisbish, FRRS43/3 Jalaj, Habiganj Aman IV, IR5853-135-4-P3, BKN6986-173-5, B1050c-Mr-7-3, ARC5955, B922c-Mr-7.

Soil problems

Entries in the 1977 IRDWON were also screened for zinc deficiency and salinity at IRRI. Best entries were IR5825-41-2-P2 and IR5857-10-1E-2 for tolerance for zinc deficiency and IR5825-41-2-P4 and IR5853-135-4-P3 for tolerance for salinity.

UTILIZATION OF IRDWON ENTRIES IN NATIONAL PROGRAMS

The use of entries in IRDWON by cooperating scientists in national programs was monitored. The entries from the 1977-79 IRDWON, reported as tested in the countries in either local-, state-, or national-level trials are listed in Table 3. Several entries were also used in hybridization programs.

Eleven sites from 7 countries have reported inclusion of 61 entries in follow-up trials. The following entries were included in trials at 3 or more sites:

SPR7233-1-24-2-2-2-3	DWCT156-1-B-B
Chenab Sel. 64-117	IR442-2-58
BR118-3B-17	IR7732-RGA-B-A96-1
BR229-B-38	BKN6986-108-3

Table 3. Promising IRDWON entries reported as being further evaluated in various national trials, 1977-79.

Designation	National sites										
	Bangladesh		Burma		India					Thailand	
	Joydebpur	Sylhet	Yezin	Mudon	Cuttack	Pusa	Dokri, Pakistan	Bombuwela, S. Lanka	Rokupr, S. Leone	Prajinburi	Huntra
ARC 5955											
Baisbish	x										
BH2								x		x	x
BIET820					x		x		x		
BKN6986-38-1		x				x					
BKN6986-45-1											
BKN6986-66-2								x			
BKN6986-81-5	x								x	x	
BKN6986-108-3			x	x		x					
BKN6986-147-2											
BKN6987-161-1-3									x	x	
BKN6986-167										x	
BKN6986-173-5	x				x	x				x	
BKN6990-63	x				x	x					
BKN7022-6-4			x	x	x						
BKN7022-10-1-4		x				x			x		
BR118-3B-17					x			x	x		x
BR223-B-1							x				
BR223-B-3								x			
BR229-B-38	x					x			x		
BR229-B-88	x					x			x		
B1050c-Mr-7-3									x		
B1050-Mr-18-2	x							x	x		
B1050-Mr-44-3									x		
Chenab Sel. 64-117	x			x	x	x	x				
CNL319									x		x
CN539						x			x		

Continued on next page

Table 3 continued

Designation	National sites										
	Bangladesh		Burma		India			Bombu-	Ro-	Thailand	
	Joydeb-pur	Syl-het	Ye-zin	Mu-don	Cut-tack	Pusa	Dokri, Pakis-tan	wela, S. Lanka	kupr, S. Leone	Pra-jinburi	Huntra
CR1009									x		
C4-63G								x			
DWCT37-2-B-B				x					x		
DWCT134-1-3-B				x					x		
DWCT135-1-1-B				x					x		
DWCT156-1-B-B	x								x		x
FRG2				x							
FRG10				x							
FRRS423/3			x								
FR13A									x		
IET5656 (PR975-109-2)									x		
IR442-2-58			x					x	x		
IR3464-75-1-1									x		
IR4579-83-3-3-2									x		
IR5825-41-2-P1	x							x			
IR7732-RGA-B-A96-1				x		x			x		
IR7732-B-A96-3						x	x				
IR9288-B-B-B5-2									x		
IR9288-B-B-B252-1									x		
Jalaj	x										
Kekowa Bao	x										
Khama							x				
Lakshmi Digha							x				
Leb Mue Nahng 111			x							x	
Madhukar				x							
RAU21-168-1-2									x		
Saran Kraham			x								
Sarsari							x				
Sitpwa	x								x		
SPR7233-1-24-2-2-2-3	x		x		x	x					x
SPR7272-151-2-1-B-B									x		
SPR7292-296-1-3-B	x										
Sulphan (Bld. Acc559)	x										
Yoyada	x										

BR229-B-88	BKN6986-173-5
B1050c-Mr-18-2	BKN6990-63
BH2	BKN7022-6-4
Baisbish	BKN7022-10-1-4

In Thailand BKN6986-66-2 was named as RD17 and BKN6986-147-2 was named as RD19. In Burma, BKN6986-108-3 was named as Yenet-1 and BKN6986-167 as Yenet-2. In Bihar, India, Chenab Sel. 64-117 was named as Janaki.

REORGANIZATION OF IRDWON

In 1981 the IRDWON nursery was reorganized to serve specific needs for differentiation among the varying situations in deepwater rice culture. The nursery was divided into four screening sets based on water depths, flooding duration, and crop growth duration:

1. flood-tolerant rice,
2. medium-deepwater rice,
3. floating rice, and
4. tidal swamp rice.

Screening procedures for different categories of the reorganized IRDWON are outlined in Appendix 2.

Flood-tolerant rice

Submergence tolerance is an important varietal character in both deepwater and shallow-water wetland rice. The latter needs the ability to survive complete submergence in areas that are annually flooded for periods ranging from a day to a week or more. Deepwater rice needs the ability to survive complete submergence in fields where elongation cannot keep pace with the increase in water depth.

The purpose of the flood-tolerant rice screening set is to evaluate and identify materials appropriate for the areas subjected to temporary flash floods of about 10-day duration. The entries generally do not have any rapid elongation ability. The screening set should preferably be tested in areas prone to flash flood or in controlled water tanks.

Medium-deepwater rice

The ability of plants to elongate is an important trait of rice varieties planted in areas where floodwater exceeds 50 cm and stays in the field for more than a month. In such fields, survival of the rice plant greatly depends on its ability to stay above water, mainly through the elongation of the internodes.

Rice varieties differ in their ability to elongate, both in terms of length of individual internodes and number of elongated internodes. The purpose of this screening set is to provide improved materials for evaluation and identification in areas where water depths from 30 cm to 150 cm occur for prolonged periods. The screening set is designed for testing mainly in areas now planted to tall traditional rice. This set is not intended for areas with water depths greater than 150 cm.

Floating rice

The objective of the floating rice screening set is to provide materials for evaluation in areas where maximum water depths exceed 150 cm. Floating rice varieties planted in these areas need rapid and early elongation ability, kneeing ability, and photoperiod sensitivity. Because the crop is usually broadcast-seeded, the varieties also need drought tolerance.

Tidal swamp rice

Tidal swamp areas are flat and the soils in general are high in organic matter. Some areas have peat layers ranging from 20 to 400 cm in depth. The soils have a pH range of 3.5 to 5.5. Some soils are acid sulfate, and most are poor in plant nutrients. Salt damage to rice may occur in areas near the coast. Water depth varies with tidal action.

Varietal requirements for tidal swamp rice thus include ability to grow in 50-60 cm of water, tolerance for submergence, and tolerance for soil problems found in saline, peat, and acid sulfate soils. Varieties with taller seedling height, high tillering ability in medium-deep water, sturdy and vigorous growth habit, and lodging resistance are essential. Varietal suitability for double transplanting may be useful. Most of the varieties adapted to tidal swamp areas have long growth duration and several, but not all, are photoperiod sensitive.

CONCLUSION

The information I have reported from the 1976-80 IRDWON tests, coupled with information expected from the reorganized nursery, should identify appropriate genetic materials that can contribute to improved yields over a wide range of deep-water situations.

ACKNOWLEDGMENT

The hard work of scientists from different countries that participated in the testing and evaluation of IRDWON is acknowledged. Their excellent cooperation contributed useful information to breeding strategies for improvement of deepwater rice. Names of all cooperating scientists are listed in annual IRDWON reports.

Appendix 1. Parentage of some promising IRDWON entries, 1976-80.

Entry	Cross
B922	B9b-TK-23-5/T5442-36
B1050	Pelita I-2/T442-36
BKN6986	IR262/Pin Gaew 56
BKN6987	IR262/Khao Nahng Nuey 11
BKN6990	IR262/TPG161
BKN7022	BKN6624-46/T442-36
BR118	TKM6/Habiganj Aman VII
BR223	TKM6/Habiganj Aman 11
BR229	Habiganj Boro II/Habiganj Aman III
Chenab Sel. 64-117	Selection from Chenab
CN539	OC 1393 mutant
HTA7204	RD1/Kaho Nahng Nuey 11
IR442	Peta*2/TN1//Leb Mue Nahng 111
IR4630	Pelita I-1/Pokkali//IR2061/IR1820
IR5825	IR34/Nam Sagui 19//IR1416-131-5
IR5853	Nam Sagui 19/IR2071-88//IR2061-214
IR7732	Tarao Bao/IR34
IR9288	Tarao Bao/2*IR34
IR13358	IR42*2/BG90-2
Pelita I-1	IR5/Synthia
RAU21	IR8/BR14
SPR7233	Leb Mue Nahng 111/C4-63
SPR7292	NKG/IR648

Appendix 2. Procedures for screening for flood tolerance and for medium-deepwater and floating rice.

Flood tolerance

Water tank test

- Keep seed packets in bundles of 10 using a rubber band.
- In all sets of tests Nam Sagui 19 or FR13A may be included as basis of comparison. Two replicates per set of varieties tested is desirable.
- Soak the packet bundles in water for 24 hours.
- Incubate the seeds without removing seed from the seed packets for 24 hours at about 30° C.
- Prepare fine clay soil. Apply 1 g ammonium sulfate (21%), 0.5 g muriate of potash (60% K_2O), and 0.5 g solophos (20% P_2O_5)/kg soil and mix thoroughly.
- Place soil in a tray.
- In each row, sow 12 seeds with good germination. Each row should represent a variety or line.
- Cover the seeds with 2-3 mm of soil. Water gently and thoroughly.
- Use scissors to thin the seedlings to 10 seedlings/row by removing the two weakest seedlings.

- Measure the height of 2 plants/row.
- Completely submerge the trays in a water tank for 7 days. Keep the water level constant at 30 cm above the soil level.
- After 7 days of submergence remove the trays and measure plant height again. Duration of submergence can be prolonged if the water used is clear and cool and the light intensity is bright.
- After 5 days of recovery, count the number of plants that have green leaves.

Field test — direct seeding

- Pregerminate the seeds of each entry as in previous procedure.
- Directly plant in single-row plots with two replications.
- When seedlings are 13 days old, submerge them in 45 cm of water for 7 days.
- Drain the field (or plot) on the eighth day.
- Allow plants to recover for 10 days and record survival percentage.

Field test — natural flooding

- Direct-seed or transplant the materials as practiced by the farmers.
- Measure water depth during submergence and note dates and duration of submergence.

Medium deepwater and floating rice

- Keep seed packets in bundles of 10 using a rubber band.
- Soak the packet bundles in water for 24 hours.
- Incubate the seeds without removing from the seed packets for 24 hours at about 30°C.
- Direct-seed pregerminated seed of each entry in a 125-cm row in a wetbed nursery.
- From 0 to 30 days after seeding (DS), manage like shallow-water wetland rice. Water depth should not exceed 10 cm.
- 30 DS: estimate stand percentage in each row.
- 31 DS: increase water depth to 25 cm.
- 33, 35, 37, etc. DS: increase water level by a maximum of 10 cm on alternate days until the target depth is reached. Record scores at or near the target depths (50-150 cm for medium deepwater and 200 cm or more for floating rice). Use IR42 as check for the nonelongation semidwarf, RD19 for limited elongating ability, and Leb Mue Nahng 111 for the best elongating ability. Scores should indicate water depth and elongation behavior. For example, a score of 5 indicates that the entry's response was similar to that of RD19, a score of 1 indicates the entry's response is similar to that of Leb Mue Nahng 111, and a score of 9 indicates a response similar to that of IR42.

DISCUSSION

FRANCIS: Would it be possible to include simple measurements on relative tillering ability in the screening nurseries? This might assist in agronomic screening later on.

DURVASULA: Because of limited seed supply we suggest planting of single rows to collect preliminary data on various traits. Information on tillering will not be reliable from single rows. If more rows are planted we can obtain reliable information. Alternatively, the screening test has to be replicated. We will plan to include this trait in future tests.

GOMOSTA: Do you think that technique used in screening for flood tolerance (appendix 2) should be used in screening for submergence tolerance of floating rice?

DURVASULA: With some modifications it should be possible, but we would first like to establish the adequacy of the test proposed for the submergence tolerance of the flood tolerance set.

TUNEY: Are there likely to be significant differences between direct seeding and transplanting when screening varieties?

DURVASULA: Screening is done as appropriate to individual situations. There is no strong evidence to show that varieties that perform well in transplanted trials do not perform well in direct-seeded trials, or vice versa.

VARIETAL IMPROVEMENT

THE DEEPWATER RICE VARIETAL IMPROVEMENT PROGRAM IN BANGLADESH

D. G. Kanter, Md. Nasiruddin, and M. A. Wahab

SUMMARY

The primary breeding objective of the Bangladesh Rice Research Institute (BRRI) program is to develop deepwater (broadcast aman) rice varieties that will consistently yield more than 3 t/ha in the same fields where traditional varieties now grow. Initial efforts focus on developing varieties adapted to water depths of 50-200 cm. Evaluation and selection during the early generations are in controlled water depths and in the field. The F_4 and following generations are direct-seeded in the field and evaluated simultaneously for several stresses. Different methods of selection and planting the breeding nurseries to increase the numbers of progenies under evaluation are described.

The yields of advance lines from the early crosses were seldom greater than those of the check varieties. Presently, the mean yields of selected lines are comparable to those of the check varieties. It is anticipated that among the large numbers of advance lines in the present pedigree nursery, there are several with higher yield potentials and improved grain quality. Regional testing is required to determine their range of adaptation and performance relative to the locally grown varieties.

In this paper we refer to deepwater rice as broadcast aman floating rice. Most broadcast aman varieties in Bangladesh have genes for elongation. Yields of broadcast aman varieties are low. Estimates of their yields in Bangladesh vary between 1 and 2 t/ha (Hasanuzzaman 1975, Islam 1977). In a 4-year study comprising 291 crop-cut samples on farmer fields in the major production areas, Catling (1981) reported an average yield of 2.2 t/ha. Individual plot yields ranged from 0.5 to 4.2 t/ha. Among the 45 farmer-named varieties sampled across the 4 main floodplains of Bangladesh, the yields of 3 (Pankaish, Khama, and Kartik-Sail) exceeded 3 t/ha in 35-50% of the fields sampled. Based on his assessment of variety yield potentials, Catling (1981)

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indicated that new varieties would need to produce at least 3 t/ha in farmer fields before farmers would consider them superior to traditional varieties.

In Bangladesh, flood depths across the different floodplains vary from almost nil to 6 m during the monsoon season. A major proportion of the deepwater rice crop is grown in water up to about 3 m deep. Water depths fluctuate from week to week, with secondary peaks during the flood season. Flood duration may vary from a few weeks to about 5 months.

Categorizing the different deepwater rice areas into specific water-depth zones can be misleading due to the unpredictability of yearly flood depths. However, an arbitrary assumption is made — that perhaps nearly 50% of the deepwater rice area is subjected to medium-deep flooding (50-200 cm) annually. Deepwater areas are where the water depth exceeds 200 cm. Initial varietal development efforts focus on medium-deep flooding situations where new varieties along with improved agronomic practices may first become available and be adopted quicker by farmers.

Traditional deepwater rices are susceptible to some diseases and insects and plant infection during any growth period may reduce survival or yields. Although the BRRI breeding program focuses on improving agronomic characteristics, parents with resistance to common diseases and insects are regularly used in the hybridizations.

Bangladesh has an estimated 1,500 indigenous broadcast aman varieties, which farmers plant on about 2 million ha throughout the 4 main floodplains. Natural evolutionary processes and farmers' selection over the decades have produced distinctive variety complexes that are grown in each major flood zone. Ordinarily a group of varieties of different maturities (7-9 months) and elongation capacities are grown each year across topographic sequences from shallow to deep flooding. Frequently, these indigenous rices are cultivated in only one particular floodplain (Clay et al 1978). Several factors, known and unknown, determine farmers' choice of varieties for his fields.

We describe the objectives, some of the methods and procedures developed, and our experiences and problems associated with varietal improvement in deepwater rice, and summarize the progress made.

BREEDING OBJECTIVES

The primary objective is to develop broadcast aman varieties that will produce high and stable yields within the limited management technology of the Bangladesh farmer. His system of deepwater rice cultivation and its related field problems will not likely change noticeably in the near future. Consequently, new varieties must retain characteristics that have resulted in the indigenous varieties being well adapted and successful in the diverse deepwater ecosystem. The following are selected varietal characteristics that are important at different growth stages:

- Seedling period — rapid germination and seedling emergence capability, seedling vigor to be competitive with weeds and withstand weeding procedures, drought tolerance, and high basal tillering ability.
- Flood period — internode elongation ability, submergence tolerance, high basal tiller survival, nodal rooting, and nodal tillering.
- Flood receding period — a range of photoperiod sensitivities for synchronization

of flowering stage with different flood patterns, kneeing ability, higher panicle density, improved panicle and grain quality traits including nonshattering habit and high milling recovery, and slow leaf senescence.

The expression of some plant attributes will overlap consecutive growth periods. New varieties will need to be responsive to higher soil fertility conditions during the different growth phases.

Resistance to some diseases and insects is needed when pressures develop during any period of the season. A partial list of these diseases and insects includes: Ufra (stem) nematode, sheath blight, false smut, yellow rice borer, ear-cutting caterpillar, mealy bug, green leafhopper, flea beetle, rice hispa, and leaffolder (Catling 1980). Resistance to viral and bacterial diseases is also needed.

IDENTIFICATION OF PARENTAL SOURCES

In general, parents used in the breeding program fall into three categories:

- locally adapted traditional broadcast aman varieties,
- improved semidwarf or modern lines and varieties, and
- improved broadcast aman rice breeding materials.

BRRI has collected more than 700 traditional broadcast aman varieties, which are preserved in its germplasm bank. These varieties are being characterized for their reaction to different physical and biological stresses and field performance is being evaluated.

Initially, traditional broadcast aman varieties were tested in field trials at Joydebpur and Habiganj and varieties that produced highest yields were used as parents. During the past few years, screening of deepwater rice germplasm and breeding lines against specific physical and biological stresses has expanded. Sources of elongation ability and resistance to, or tolerance for, drought, ufra stem nematode, bacterial leaf blight, bacterial leaf streak, rice tungro virus, and others have been identified or are known. The names of some of the tolerant or resistant materials from Bangladesh are reported by others at this workshop.

BREEDING METHODS AND PROCEDURES

Crosses are made between indigenous broadcast aman varieties, modern varieties with multiple disease and insect resistance, and other improved germplasm with and without deepwater tolerance. Many hybridizations were single crosses but some of the later crosses involved three or four parents. Top and double crosses are used to increase the chance of obtaining more desirable segregates by combining complementary traits from three or four parents.

F_2 population and early generations

Published information on various breeding and selection strategies aimed at developing improved hybrid lines adapted to water depths of 150 to 300 cm is limited. In developing varieties for water depths less than 150 cm, Supapoj et al (1977) suggested that screening and selection for elongation ability be postponed until the lines reached homozygosity.

HilleRisLambers et al (1977) concluded from correlation analysis that materials should first be tested for elongation ability and then selected for plant height and plant types because elongation may be influenced by mutually correlated traits

Nasiruddin et al (1979) indicated that selection for elongation ability and photoperiod sensitivity would be effective in early-segregating generations but water depths should not exceed 150 cm. They used four crosses each having a traditional broadcast aman variety as one parent. They also indicated that selection for elongation could be done in the field in about 100-cm water depth if tank facilities were not available and preliminary yield evaluation could commence with F_5 lines.

We use two procedures for handling early generations — one in controlled water depths and the other in naturally flooded fields.

Controlled water depth. Details on handling the F_2 and F_3 generations in controlled water depths are given by Wahab et al (1982, this vol.). In summary, panicles are selected from agronomically desirable plants in the F_2 populations and screened for elongation ability in the F_3 generation. Selection is made among the surviving plants based on disease reactions and agronomic characteristics. The selected progenies (F_4) are promoted to the field pedigree nursery.

Naturally flooded field. Over a period of 2-3 years most of the commonly recurring physical, meteorological, and biological stresses will occur one or more times and permit effective screening of breeding materials. The exposure of early-generation populations to conditions that are comparable to those in farmers' deepwater rice fields ensures simultaneous field screening of plant reactions to numerous field stresses that occur during the normal crop season (preflood, flood, and postflood periods). Undesirable plant materials are discarded in the early nursery stages.

For F_2 populations, we use a field site where the water depth does not exceed 150 cm, which provides moderate elongation selection pressure and lessens danger of losing the entire population. About 50 m^2 of land area is used for each F_2 population where about 200 g of dry seed are sown in lines at a 40 kg/ha rate. A thinner stand reduces competition among the different plant types for better assessment of their potential. The plots are observed periodically by boat during the flood period. Visual observations are made on the surviving plants at harvest for various plant and panicle characteristics to meet breeding objectives. Panicles are selected from tillers of superior segregates and advanced to F_3 progeny rows for continued evaluation the following year.

Progeny screening nursery

During the first 2-3 years when the breeding effort on deepwater rice was initially expanding, the breeding materials were transplanted in the different nurseries and trials. We observed that transplanted materials were not being subjected to the kinds of stresses occurring in farmer fields because farmers primarily use broadcast seeding on a dryland soil. Catling (1981) found that lines developed in transplanted breeding nurseries were not robust enough to withstand the vigorous treatment during weeding.

Starting in 1979, the early segregating generations were planted by direct seeding. We feel this procedure approximates farmer field conditions and is more effective in exposing breeding materials to several stresses occurring simultaneously throughout

the growing season. Following the adoption of this practice, several advance lines with elongation ability currently in yield trials have shown moderate levels of drought tolerance (Gomosta and Kanter 1982, this vol.).

Pedigree nurseries are managed without insecticide protection. Progeny rows can be inoculated with bacterial leaf blight during the preflood period and their reactions scored.

There is simultaneous screening among the segregating progenies for a number of stresses. During the past 3 years the breeding materials were subjected to soil crusting, drought, bacterial leaf blight, root knot nematode, rice stem borer, tungro virus, and rapid flood rise and the nurseries were not fertilized. Only segregates with resistance to or tolerance for these stresses and with acceptable phenotypic characteristics are advanced in the breeding program.

Panicle selections from the field-grown F_2 populations (noncontrolled flooding) and F_3 plant selections from the elongation screening test are promoted to the progeny screening nursery. A narrow (8 cm) bladed hoe is used to make furrows in which individual panicles are placed. Row spacing is 40 cm with 80 cm between the beginning of each set of rows.

Plant selections are sown in 150- to 200-cm rows made by a hand-pulled 3-row furrower. Row-to-row spacing is 50-75 cm with a wider spacing in deep-flooded plots (more than 200 cm). A 50- to 100-cm footpath is left between each set of rows to facilitate separation of tangled stems at harvest.

At harvest, panicles are selected from those progeny rows with desirable agronomic adaptation and performance characteristics. Superior rows (F_3-F_5) showing fairly uniform culm lengths, flowering dates, and panicle types are bulked for larger observation plots the next year.

These pedigree nursery production and selection procedures are repeated for several generations until the breeding lines become uniform in height, maturity, grain size, and other important characteristics.

At the time of seed preparation, several seed sets of selected lines are prepared for additional screening and evaluation trials — ufra stem nematode, drought tolerance, submergence tolerance, transplanted culture, and grain quality.

Yield testing

We test the adaptation and yield potential of promising lines under a range of field stresses and flood patterns.

Observational plots. Preliminary yield testing of advance lines begins in the F_5 or F_6 generations even though there may be minor segregation for some characters. Observational trials confirm initial evaluation of yield potential, reactions to physical and biological stresses, growth duration, and general adaptability to field conditions. Observational plots are not replicated.

New entries promoted from the pedigree nursery or introductions are usually planted in 4 rows 5 m long. The row-to-row spacing is 25 cm. A spacing of 75 cm between plots facilitates separation of lodged plants from adjacent plots at harvest-time. A 100-cm footpath is left between sets and blocks of plots.

The farmers' seeding rate of about 92 kg/ha is used. Dry seeds are hand-sown in rows and covered immediately.

Check varieties are planted every 20th or 25th plot depending on soil heterogeneity and other field factors. Among the check varieties used are Habiganj Aman II, Shada Pankaish, Sarsari, Chamara, and Gilamyt. These varieties are early to late in duration, adapted to different flood patterns, and exhibit known performance.

Two to three hand weedings may be required to keep the direct-seeded plots weed free. Herbicides may also be used.

Replicated yield trials. Based on yield and other performance data, the better promising lines from the observational plots are promoted to replicated yield trials. The plots are 8 rows each of 5 m length. Land preparation, seeding rate, management, and data collection are the same as for the observational trial. Lines advanced from the observational trial are classified as early or late according to flowering dates and placed in separate yield trials.

Regional testing. Preflood dryland stresses and flood regimes are two noncontrollable variables that significantly affect varietal adaptability and performance. A regional testing program identifies prospective varieties superior to local varieties and determines if they have wide adaptation or are location specific. The most promising lines from the previous season's yield trials are selected for verification trials at regional and zonal stations and in deepwater fields of cooperating farmers. These trials provide information on adaptability and on different characteristics contributing to performance. Our regional testing has been limited, however, because of lack of manpower resources but an expansion is expected.

RECENT PROGRESS IN BREEDING FOR DEEPWATER RICE

BRRI research divisions are actively involved in the screening and evaluation of breeding materials. Papers for this workshop report research by the different disciplines.

A summary of numbers of crosses made, and populations or progenies tested in different breeding nurseries and performance trials from 1971 to 1981 is given in Table 1.

Hybridization

Since 1971, more than 900 crosses between a wide range of indigenous germplasm and improved breeding materials have been made. About 180 of the crosses involved multiple parents.

Many crosses were also made at IRRI to assist the BRRI program. Seeds of the selected parents, together with a list of crosses desired, were sent to IRRI. After making the crosses and confirming the F_1 plants, IRRI sent the F_2 seed to BRRI. BRRI scientists attending the IRRI's Genetic Evaluation and Utilization (GEU) course for those engaged in varietal development programs have also made crosses for deepwater rice.

Breeding and screening nurseries

F_2 populations. Eighty-five F_2 populations were transplanted in shallow-water plots in 1980. Selections were made from all crosses for screening for elongation ability in 1981. Among them, selected parental combinations showed good combining ability as

Table 1. Summary of numbers of hybridizations made and populations or progenies tested in different breeding nurseries and trials from 1971 to 1981. BRRI, 1981.

Year	BR	IR	F_2 populations	Elongation screening	Progeny screening nursery	Trials	
						Observational	Yield
1971-73	26						
1974	16		11		3[a]		
1975	14		10		59[b]	18	4
1976	45		14		5,232	85	10
1977	169	325	14	7,489	252	78	26
1978	14		77	8,349	1,765	1,980	40
1979	14	69	53	4,900	3,404	144	75
1980	60	310	85	3,959	6,889	474	64
1981			168	24,000	18,400	74	61

[a]Screening done in the deepwater tanks [b]Crosses grown in bulk.

observed by the high proportion of segregates with good plant types.

In 1981, 97 F_2 populations were direct-seeded in the field and subjected to natural flooding. Water depth was about 175 cm in the lowest area. Several populations are showing good survival. An additional 71 F_2 populations were transplanted in shallow-water plots.

Elongation screening. Wahab et al (1982, this vol.) report this aspect of our program. This year about 24,000 progenies were screened for elongation ability. When screening was initiated in 1977, advanced breeding and indigenous varieties were screened. Presently, most of our materials are screened in the F_3 generation.

Progeny screening nurseries. From 1976 to 1980, about 17,000 F_4-F_6 generation progeny lines were grown in pedigree nurseries. In 1981, 18,400 F_4-F_7 progenies are being evaluated in the field nursery. These progenies survived water depth of 250 cm or more in the 1980 nursery. Included also are 1,451 F_4 progenies selected from surviving parent plants during elongation screening in 1980. Nearly all the crosses involve an indigenous broadcast aman variety and an improved elite line. The selected progenies combine the desirable characteristics of both parents and reflect an improved plant type.

Yield trials. Annual nonreplicated and replicated trials critically assess the adaptability, plant characteristics, and yields of promising lines. These trials are presently grown at Joydebpur (BRRI) and Habiganj (BRRI Regional Station) in conventional field plots. Selected advance lines are also tested in yield trials with controlled flooding.

Yield data for selected lines and varieties tested in 1980 are summarized in Table 2. BR232-2B-3-4/A gave a mean yield of 3.3 t/ha over 3 sites. BR311-B-5-4 produced 4 t/ha at Habiganj. Some lines had yields more than 3 t/ha in the 1980 observational yield trials and are being tested in 1981 replicated trials.

Yields more than 4 t/ha were obtained with controlled flooding in 1980. The maximum water depth was 160 cm for several weeks. The results suggested that

Table 2. Yields of selected deepwater advance lines and varieties grown in the field and under controlled flooding. BRRI, 1980.

Line or variety	Yield (t/ha)					Heading date
	Joydebpur (280-cm depth)	Habiganj (75-cm depth)	Habiganj (125-cm depth)	Mean	Deep-water tank[a] (160-cm depth)	
Replicated yield trials						
BR232-2B-3-4/A	3.1	3.7	3.0	3.3		20 Oct
BR224-2B-2-5	3.1	3.5	3.0	3.2	3.0	20 Oct
Shada Pankaish	3.0	3.7	2.9	3.2	3.9	20 Oct
Habiganj Aman II	3.0	3.6	2.6	3.1	4.2	17 Oct
Ejuli Khama	3.2	3.2	2.7	3.0		15 Oct
BR311-B-5-4	2.3	4.0	2.7	3.0	3.5	19 Oct
BR306-8-3-2	2.8	3.4	2.7	3.0	3.5	19 Oct
BR314-8-4-6	2.3	3.4	2.9	2.9	2.1	21 Oct
Kartiksail	2.6	3.2	2.7	2.8	3.7	14 Oct
BR232-2B-3-4	2.2	3.2	2.7	2.7	4.0	17 Oct
BR308-B-2-9/A	1.7	3.2	2.4	2.4	3.5	19 Oct
BR222-B-233-6	1.3	3.0	2.5	2.3	4.5	16 Oct
Habiganj Aman I	2.3	2.3	1.3	2.0		11 Oct
Nonreplicated trials						
BR516-333-1	3.7					24 Oct
BR523-193-3	3.3					31 Oct
BR524-11-1	3.1					27 Oct
BR516-341-1	3.0					24 Oct
DWCB-B-112-3-B	3.0					25 Oct

[a]Plots were transplanted.

Table 3. Parentage of deepwater rice advance lines currently in replicated yield trials. BRRI, 1981.

Cross number	Parentage
BR222	TKM6/Habiganj Aman I
BR224	TKM6/Habiganj Aman III
BR232	Habiganj BoroII/TKM6/Habiganj Aman II
BR306	IR20/Habiganj Aman
BR308	Habiganj Aman II/BR3
BR311	Habiganj Aman VIII/IR20
BR314	Habiganj Aman IV/BR3
BR516	BR51-49-6/Habiganj Aman IV
BR523	BR4/Habiganj Aman II
BR524	BR4/Habiganj Aman IV
DWCB	Deepwater composite of 40 crosses made at at IRRI; F_2 population grown at Barisal regional station.

deepwater rices may have higher yield potentials than those commonly associated with them in natural field conditions. Further research is needed to understand plant responses with favorable conditions and to know whether higher yields are possible in the field.

In earlier trials we found considerable variation among the traditional varieties tested for yield and other important characteristics. Until new improved varieties are released, efforts can be made to identify the best yielding traditional varieties of each production zone and farmers can be encouraged to grow only these varieties.

Advance lines in yield trials. The parentage of the advance lines in yield trials is given in Table 3. In contrast to the first crosses where TKM6 was used, modern varieties (IR20, BR3, and BR4) were used as donors of improved plant types in later crosses (BR306, BR308, BR311, BR523, BR524). The Habiganj Aman series of recommended varieties were used as the locally adapted parents.

When we initially began yield testing of advance lines from the early crosses in natural field conditions their performance did not measure up to their indigenous parents or check varieties and many materials were soon discarded. As indicated by the yield results (Table 2), present advanced broadcast aman rice lines with better plant types are performing at about par with the check varieties in 100- to 250-cm water depth. We anticipate that among the large numbers of advance lines currently in the pedigree nursery there are lines whose yields and grain quality will be superior to the check varieties in medium-deep flooding.

As the program progresses, more of the indigenous germplasm is being screened for yield potential and various stresses to characterize the range of genetic variation among them. The hybridization program will benefit more as those with the best characteristics are used systematically for parents.

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DISCUSSION

CHOUDHURY: What factors contribute to high grain yield in farmer fields in Bangladesh?

KANTER: A combination of factors, including cultural practices, choice of variety, preflood drought stress, incidence of diseases and insects, and characteristics of the flood, contribute to grain yield fluctuations in farmer fields. Examples of specific variables influencing grain yield in Bangladesh are presented in the agronomy papers from Bangladesh at this workshop.

FRANCIS: Perhaps I can give some more information on that. I think the high yield referred to is probably that of the variety Gilamyt in Narsingdi. This variety is almost always transplanted and is not deeply flooded. With transplanting there are no problems of weed control after direct seeding. The fields are normally fertilized and Gilamyt has a long panicle. Panicle densities are high. Farmers normally get high yields from this variety. I think it's only fair to say that in flooding of more than 2-2.5 m we rarely expect to get more than 3 t/ha.

MCGEACHIE: You mentioned root knot infection in one of your nurseries and that this was

unevenly distributed. Can you make use of an uneven stress and if so, how do you go about this?

KANTER: Naturally, greatest screening efficiency results when the stress is applied uniformly to all test materials. Root knot nematode infestation in the soil in our fields is not uniform, generally. Presently, we merely take advantage of its infestation where it does occur in the soil to identify nursery materials showing a susceptible reaction. This additional information on those specific materials is considered during the final selection and harvesting.

PETPISIT: In your pedigree nursery, especially the F_2 bulk populations, how did you make individual plant selection where you used bulk seeding?

KANTER: The direct seeding rate was reduced by about one-half for F_2 populations. A lower seeding rate may be used for those F_2 populations where, based on a knowledge of the parents, a fairly high proportion of the F_2 segregates are expected to survive. Plant density is reduced during the flood season due to elimination of photoperiod-insensitive and nonelongating segregates. In F_2 population plots where only a small percentage of the segregates survive, individual plants can usually be identified for selection. Otherwise, panicles are selected to form a modified bulk population.

PETPISIT: Where F_2 populations are drilled directly in the soil, how can you make individual plant selections?

KANTER: We reduce the seeding rate to some degree and pick out individual plants. But we harvest mostly by panicles and we direct-seed the panicles the next year. Of course, we can get 2 or 3 panicles/plant but I'm not much concerned about that because where a plot is drought stressed the space required would not be anymore than line seeding. Also, with line seeding you only have one line from one plant and if that line happens to be in a bad site you may get a poor test. But, if you have two or three panicles you get some replication in that single plant. So it is a trade-off against the variety of conditions we encounter within a field. In this way we are not strictly using the pedigree method but the bulk method. The generation after this, we use the pedigree system.

STATUS OF DEEPWATER RICE DEVELOPMENT IN INDIA

S. Saran, S. Biswas, S. Mallick, and V. N. Sahai

SUMMARY

The climate of India is highly conducive to diversified rice culture. Areas of prolonged flooding and areas of flash flooding are prevalent. Deepwater rices are grown in the areas of prolonged flooding and many factors are responsible for their poor performance. Since 1975 various states in India have developed research programs to develop stable-yielding deepwater varieties. Recent research has identified some promising deepwater varieties. There is more of vertical than horizontal adaptability among deepwater rice varieties. Some observations drawn from deepwater rice trials are indicated. Future plans for deepwater rice research in India have been suggested.

India's annual rainfall varies from 250 mm in the northwestern region to 12,000 mm in the northeastern region. In the major rice growing areas, rainfall is within the range of 750-2,500 mm.

The climate of India is highly conducive to diversified rice culture. The interaction between rainfall and the land contour has resulted in two types of flooding in the low-lying areas. Prolonged flooding occurs in areas where water stagnates in different regimes ranging from 50 cm to 500 cm. These areas were recently divided by De Datta (1981) into *deepwater rice culture,* where standing water for a certain period of time is more than 50 cm and water depths vary between 51 and 100 cm for more than half of the growth duration, and *floating rice culture,* where maximum water depth ranges from 1 to 6 m for more than half of the growth duration. Figure 1 shows the deepwater rice areas of India.

In flash-flooded areas the water recedes after 1-15 days. This type of flood generally occurs near rivers or the ocean and its frequency and duration vary from place to place and year to year.

One of the major challenges confronting India's rice breeders is the development of

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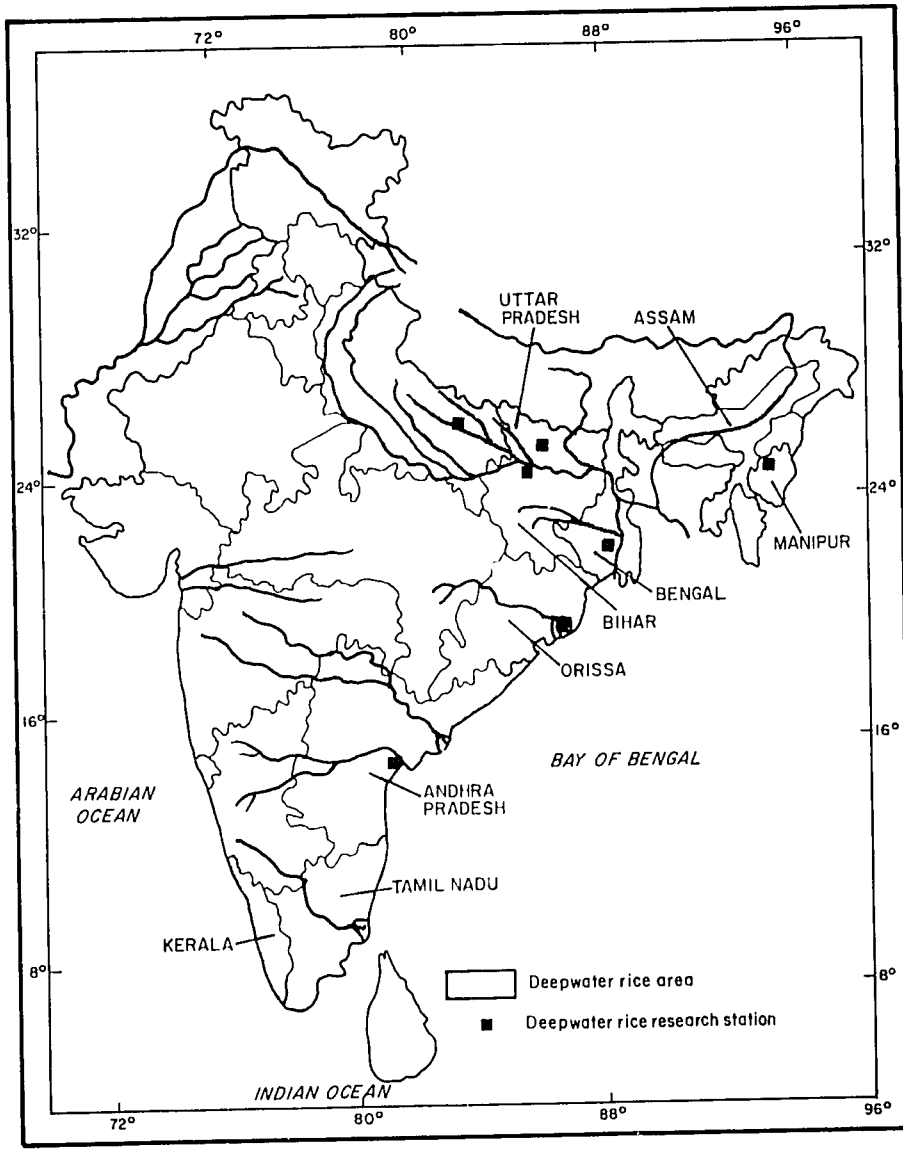


1. Deepwater rice areas of India.

varieties suitable for vast rainfed lowland areas (20-100 cm). Factors responsible for poor performance in deepwater fields have been studied by several workers (Biswas et al 1979, Maurya 1979, Murty and Venkateswarlu 1979, Swaminathan 1979, and Vamadevan and Jha 1979). To summarize the factors:

- drought in early vegetative stage (April-June) in deepwater rices;
- seedling mortality, poor establishment, and tillering due to submergence;
- reduced dry matter production (DMP) and impaired harvest index (HI);
- shattering and poor grain quality;

- soil toxicity problems such as salinity, alkalinity, and zinc deficiency in waterlogged rice fields; and
- insects and diseases.

PROGRESS OF INDIA'S DEEPWATER RESEARCH

Research on deepwater rices started in 1934 with the inception of the deepwater rice research station at Habiganj, now in Bangladesh (Swaminathan 1979). The early work resulted in the isolation of certain promising pureline selections such as Baisbish, Gobura, Maliabhangar, Dolamon, Matia Aman, Laki, and Badel. At Sabour Station in Bihar, two Jaisuria selections, named BR14 and BR46, were identified about the same period.

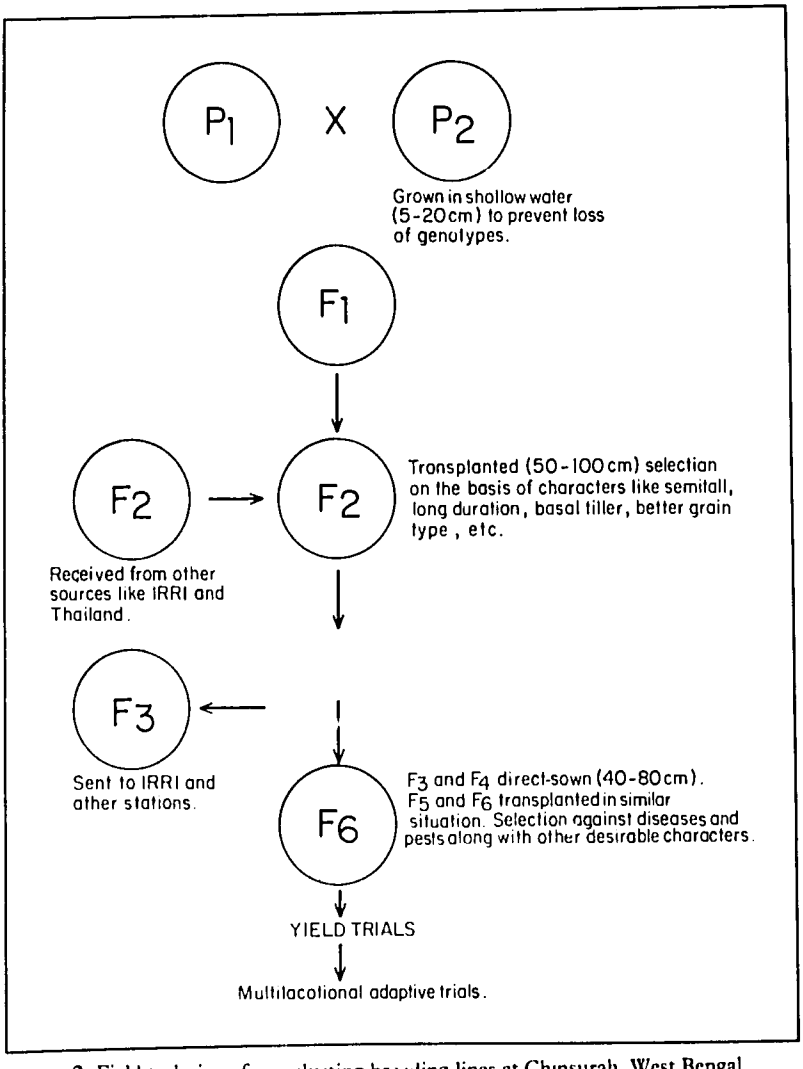
The use of modern semidwarf rices started in India in 1965 but semidwarfs were generally not suitable for areas with water deeper than 20 cm. However, some semidwarf varieties — Pankaj (selection from IR5), Jagannath (T141 mutant), IET3257 (MNP/CR12/Pankaj derivative), and IET5656 (RP 6-13/Sona) — were found promising for waterlogged areas of Uttar Pradesh, Bihar, West Bengal, and Orissa where water remains below 50 cm. Two semidwarf lines introduced from IRRI (IR442-2-50 and IR442-2-58) performed well in Bihar and were released as Panidhan 1 and Panidhan 2 (Saran 1977). But none of these varieties have attributes that make them adaptable to deepwater fields. The challenge is to develop superior genotypes that will adapt in the vast deepwater areas.

Since 1975, efforts to develop stable-yielding deepwater varieties have intensified in West Bengal, Bihar, Uttar Pradesh, Orissa, and at the Central Rice Research Institute at Cuttack and All India Coordinated Rice Improvement Project in Hyderabad. The characters sought in the new varieties are semitall height (140-150 cm), good basal tillering ability, submergence tolerance, drought tolerance at the early vegetative stage, aquatic rooting, heavy panicles, culm stiffness, photoperiod sensitivity, seed dormancy, and ability to achieve good stand establishment in fluctuating water depth.

Current status of breeding and varietal development

Chinsurah. At the Rice Research Station, Chinsurah, development of suitable deepwater rices through hybridization has received attention since 1976. Crosses involving well-adapted indigenous tall indica varieties and high yielding semidwarf breeding lines and varieties received major emphasis. All the breeding lines were exposed to selection pressure under natural environmental stress (Fig. 2). Many early-generation breeding lines were also received from IRRI and Thailand. Thailand experiences environmental stress similar to that in many parts of India. A few promising advanced lines, which experienced flooding at the late vegetative stage in 1978, drought in 1979, and early submergence in 1980 are listed in Table 1. Screening and yield trials were also conducted at Chinsurah and other sites in natural flooding regimes. Water depth, duration of flooding, rate of increase in water level, and period of inundation varied greatly even in the same field (Fig. 3).

Screening trials in waterlogged, flash-flooded plots revealed that CN540 and CN643 (selection from IR262/Khao Nahng Nuey 11) had good submergence tolerance and produced high grain yield. A yield trial in 1977 identified CNL231 B/B



2. Field technique for evaluating breeding lines at Chinsurah, West Bengal.

and CNL108, both pureline selections, as good performers in intermediate water depth and in deep water. Multisite yield trials during 1978-80 proved the superiority of CN540, CN643, and CNM539 (OC1393 mutant) in water 30-100 cm deep. Mean yields were 4.2 t/ha for CN540, 3.2 t/ha for CN643, and 3.6 t/ha for CNM539.

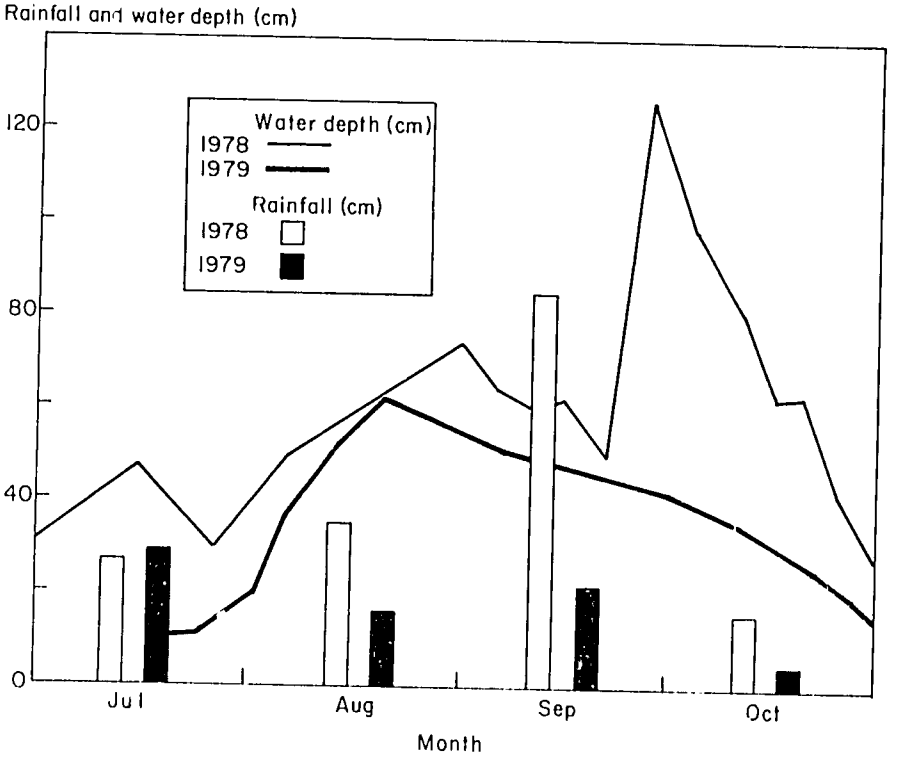
Bihar. About 70% of the deepwater rice area (350,000 ha) in Bihar has water depths ranging from 50 to 150 cm. The major thrust in Bihar, therefore, is to develop varieties suitable for those water regimes. A breeding program initiated in 1972 made crosses of promising local deepwater lines and semidwarf indicas. Simultaneously a large

Table 1. Performance of some promising deepwater[a] lines at Rice Research Station, Chinsurah, 1980.

Line	Yield (t/ha)
CN692	2.8
CN690-2	2.6
CN506-15-5-2	2.4
CN689-1	2.4
CN690	2.6
CN689-2	2.2
CN691-2	2.1
Mahsuri	1.8
Pankaj	1.3

[a]Maximum water depth - 55 cm.

number of local deepwater cultivars were collected. Several promising lines from other Indian States, IRRI, and Thailand were introduced. Screening and evaluation of these diversified materials at the Patna, Pusa, and Sabour stations of Rajendra Agricultural University, Bihar, resulted in the selection of highly promising lines suitable for water regimes of 50-100 cm. These are C64-117 (Janaki), Jalaj (IR8/BR8),



3. Rainfall and water depth in a wetland rice plot at Chinsurah, West Bengal.

BIET820 (IR8/BR14), BIET821 (IR8/BR14), BIET757 (IR8/BR14), BIET799 (IR8/BR14), BIET757 (IR8/BR14), BIET763 (IR8/BR14), and Jaladhi 1.

Promising entries in a Bihar semi-deepwater variety trial during 1976-80 are presented in Table 2. Studies on tolerance for waterlogging, kneeing ability, reaction to photoperiod sensitivity, seed dormancy, and other desirable traits for deepwater rices were made simultaneously and promising lines were selected (Table 3).

Bhubaneswar. The Rice Research Institute, Bhubaneswar, developed some varieties suitable for waterlogged fields. OR1004 (sel. Badakalasura) and OR1105 (sel. Khujuriachanar) performed well. Other varieties like OR117-8 (T141/Jagannath), OR142-105 (Pankaj/Sigadis), and OR143-7 (Pankaj/W1263) were also promising in water 50-100 cm deep.

Uttar Pradesh. The Ghagraghat Station of Uttar Pradesh seeks to develop varieties suitable for intermittent flooding and deepwater and floating rice areas (areas with a water depth of more than 100 cm). The station has developed promising floating

Table 2. Performance of promising entries on semi-deepwater[a] variety trial, Bihar, during 1976-80.

Year	Entry	Yield (t/ha)
1976	Jalaj	2.6
	C64-117	2.6
	RAU21-53-1-1 (BIET757)	2.4
	RAU21-71-1-2 (BIET763)	2.4
	RAU82-1-3	2.2
1977	Jalaj	3.0
	RAU21-10-3-3 (BIET755)	2.9
	RAU21-53-1-1 (BIET757)	2.8
	RAU21-71-1-2 (BIET763)	2.8
	C64-117	2.8
1978	RAU21-82-1-3 (BIET822)	1.8
	RAU21-35-3-5 (BIET821)	1.8
	RAU21-71-1-2	1.8
	C64-117	1.7
	Jalaj	1.7
1979	RAU21-147-1-4 (BIET807)	1.7
	KLG161-7-P	1.2
	KLG70-P	1.2
	RAU21-35-3-5 (BIET821)	1.1
	Jaladhi	1.1
1980	C64-117	1.3
	BR14	1.1
	Jaladhi 1	1.1
	RAU21-82-1-3	0.9
	Bajol	0.8

[a]Water depth in the fields ranged from 40 to 90 cm.

Table 3. Promising lines that combine photoperiod sensitivity, seed dormancy, good yield, and tolerance for waterlogging.

Entry	Parentage
RAU21-29-3-1 (BIET820)	IR8/BR 14
RAU21-35-3-5 (BIET821)	IR8/BR 14
Jalaj	IR8/BR 8
C64-117	Pureline selection from Chenab rice of North Bihar
C62-2	Pureline selection from Jonsria rice of North Bihar
C62-31	Pureline selection from Bajra rice of North Bihar
C62-10	Pureline selection from Barobar rice of North Bihar
C62-63	Pureline selection from Kabra rice of North Bihar
C74-1	Pureline selection from Bhuthahi rice of North Bihar

varieties like DW48 and GMS13. Baisbish, Habiganj Aman II, ARC5955, and Gouri did well in water 3 m deep; FRG7, and FRG10 were found promising for intermittently flooded areas.

Orissa. At the Central Rice Research Institute, Cuttack, several highly productive, photoperiod-sensitive, nonlodging lines were developed from Pankaj/Jagannath, Pankaj/Koda, and CR70/Pankaj crosses. The Pankaj/Jagannath cross has produced highly promising lines designated as CR1000 lines. Some of these lines are doing well in the waterlogged areas in different parts of the country. Several promising lines were also derived from the crosses CR1014/Jagannath, Waikokku/CR1014, Dwarf 36 (Baok/T141)/T141, which are in advanced testing. CR1030 (Waikokku/ CR1014-211) has shown promise.

All India program. Initial success in recent years led to an All India Programme of Uniform Variety Trial-6 (UVT 6) and a lowland screening nursery (LISN) where elite materials from cooperating states are pooled in national deepwater trials. Since 1979 promising materials from different stations have been tested at the deepwater rice research stations.

During 1979, maximum water depth in different stations varied from 33 to 90 cm, except at Ghagraghat where water depth exceeded 100 cm in both trials (Tables 4 and 5). Varieties like CN603, Jalaj, RAU21-168-2, Chenab 64-117, FRG7, CN540, NC486/78, CNL108, and OR1105 (sel. Khujuriachanar) were promising in water depths that range from 33 cm to 90 cm. Chakia 59, Jalmagna, GMS13 and DW48, all floating types, performed well where water was more than 100 cm deep.

In 1980 the deepwater variety trials were at 7 sites where maximum water depth varied from 55 to 80 cm. The promising entries were CN643, NC487/77, C62-31, CNM539, OR117-8, CN540, OR1105, C181-1, and C183-1. Yields ranged from 0.9

Table 4. Performance of promising entries in semi-deepwater varietal trial. Source: AICRIP (1979).

Station	Entry	Yield (t/ha)	Maximum water depth (cm)
Chagraghat	Chakia 59	1.4	114
	NPT	0	
	Chenab 64-117	0	
	FRG7	0	
	FRG10	0	
Haldia (Dt. Puri)	CN603	1.6	90
	NC486/78	1.6	
	FR438	1.6	
	OR142-105	1.5	
	Achra 108/1	1.2	
Wangbal	Jalaj	3.3	75
	RAU21-168-1-2	2.9	
	NC488/77	2.6	
	Chenab 64-117	2.3	
	BR46	2.1	
Pusa	Chenab 64-117	2.3	52
	RAU21-168-1-2	1.9	
	62-68 (Kabra)	1.9	
	62-31 (Bajra)	1.8	
	CN603	1.8	
Patna	Jalaj	2.8	50
	FRG7	2.6	
	CN540	2.4	
	IET6857	2.3	
	Achra 108/1	2.2	
Chinsurah	CN603	5.8	33
	CN540	5.7	
	CN643	5.4	
	Tilakkachari	4.6	
	NC487/77	4.4	
	Mean	2.4	

t/ha for C180-4 to 3.6 t/ha for CN643 (Table 6).

Some significant observations drawn from the above trials are:

- Varieties behave differently at various sites.
- There is more vertical adaptability than horizontal adaptability among varieties grown in deep water.
- Yields fluctuate from place to place and year to year.
- Growing conditions show considerable year-to-year variation.

IRDWON. The International Rice Deep Water Observational Nursery (IRDWON) materials from different countries are tested at various places in India. On the basis of 1980 performance, the following entries were found promising:

Water depth less than 100 cm	*Water depth more than 100 cm*
Sitpwa	Saran Krahan

Table 5. Performance of promising entries in deepwater variety trial. Source: AICRIP (1979).

Station	Entry	Yield (t/ha)	Maximum water depth (cm)
Ghagraghat	Jalmagna	1.6	203
	GMS13	0.8	
	DW48	0.8	
Haldia	Kajura Chonar	2.5	90
	Bada Kalasura	2.2	
	Sona Kalasura	1.8	
	CNL231 B/B	1.6	
Pusa	Chenab 64-117	2.1	52
	CNL108	1.8	
	CNL31	1.7	
	CNL231 B/B	1.6	
	BR14	1.1	
Chinsurah	CNL108	3.0	43
	Jaladhi 2	3.0	
	Chenab 64-117	2.9	
	Jalaj	2.6	
	CNL231 B/B	2.6	
	BR46	2.6	
	Mean	2.0	

BKN6986-147-2	Chamara
BNK7022-6-4	Chota Bowalia
BH5	Khama
SPR7292-151-2-1-B-B	Lakshmi
IR7732-B-A96-3	Digha
BR118-38-17	Jalmagna
Sarsari	Jaladhi 1
C64-117	DW48

Coastal areas. About 2 million ha in the coastal region of India are saline and waterlogged (30-70 cm). Yields are generally poor (1-2 t/ha). Promising entries identified for these areas are Getu, MR18, Mamilton, SR26 B, Pokkali, and Dasal.

FUTURE PROSPECTS FOR DEEPWATER RICE

Considerable progress has been made in the development of varieties suitable for the existing water regimes and other stresses. Because 60% of the waterlogged rice area in India has water regimes of 50-100 cm, more attention should be given to deepwater rices for these areas. Plans in India should include:

- strong seedling vigor and drought tolerance during the early vegetative phase,
- transfer of genes for submergence tolerance from traditional flood-tolerant

Table 6. Performance of promising entries in deepwater variety trials. Source. AICRIP (1980).

Station	Entry	Yield (t/ha)[a]
Chinsurah	CN643	3.6
	CN487/77	3.5
	CNM539	3.4
Ghagraghat	C62-31	1.1
	CNM539	1.1
	BIET820	1.0
Bhubaneswar	OR117-8	2.0
	CN540	1.9
	NC487/77	1.7
Patna	C62-31	1.6
	OR1105	1.1
	NC487/77	1.1
Pusa	C181-1	1.2
	C183-1	1.0
	C180-4	0.9
Cuttack	CN540	3.4
	NC487/77	2.9
	OR1105	2.4
Pulla	NC487/77	2.8
	C62-10	2.5
	C62-31	2.5
	Mean	2.0

[a]Water depth ranged from 55 to 80 cm.

varieties to the intermediate-statured (140-150 cm) high yielding varieties,

- moderate elongation ability combined with submergence tolerance,
- plant type with ability for effective photosynthetic activity even when submerged,
- increased basal tillers and erect leaves,
- incorporation of genes for lodging resistance,
- strong and deep rooting system,
- strong photoperiod sensitivity and seed dormancy, and
- acceptable grain quality.

More basic work has to be taken up on varietal variation for:

- more internodes per culm with less internode elongation,
- high metabolic activity of roots, and
- more spikelets and increased weight per panicle with better harvest index.

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DISCUSSION

CHOUDHURY: Varieties released in Bihar are given BR numbers and Bangladesh varieties also have BR numbers. Something should be done to distinguish one group from the other.

DURVASULA: IRTP, in consultation with its cooperators, is trying to solve the question of some instances of common breeding codes, for example BR used in Bangladesh, Bihar, Thailand, and Brazil. We hope this confusion will be eliminated in the future.

AHMAD: What is your suggestion? How can we do that?

DURVASULA: Where there is this problem of duplication we have asked the respective stations if they have any alternatives. In Thailand they changed to BKNBR. We are trying to find out if others have alternatives.

THAKUR: For Bihar only varieties released sometime in 1940 and 1945 are numbered BR. We are now releasing our varieties as RAU but we may not be able to rename the old and popular varieties.

DURVASULA: What is the yield advantage of Chenab selection 64-117 over the original Chenab? How is the grain quality?

SARAN: Chenab selection 64-117 yields 15-20% more than the original Chenab and it has long, bold grains with red kernel, and the taste is good.

AHMAD: FR13A was observed as not tolerant of tidal submergence, compared to the local varieties, when we tried it at our Barisal station.

HILLERISLAMBERS: I do not think it is fair to drop FR13A from consideration for Barisal conditions just because it was not better than the locally adapted varieties, such as Dudmona. Factors other than submergence tolerance are likely to have influenced this and I think that FR13A should still be used, as a parent in crosses with local varieties. I say this because I saw the experiment in question and noticed that FR13A performed better than the other new introductions in the trial.

STATUS OF DEEPWATER RICE VARIETAL IMPROVEMENT IN BURMA

P. B. Escuro, U Ohn Kyaw, and U Aung Kha

SUMMARY

Deepwater rice varietal improvement in Burma during the past decade has consisted of selections from introductions and from local hybridization work. From the introductions, selections that performed satisfactorily in preliminary tests in both shallow and deep water were BKN6986-3, BR223-B-1, BKN6986-66-2 (RD17), BKN6986-11-3, BKNFR76023, and BKN6986-147-2 (RD19). Of those recently selected from hybridization X73-16-13, X73-18-1, and X73-20-19 appear promising. All selections need further tests before any is recommended for release. The currently recommended introduced varieties BKN6986-108-3 and BKN6986-167, although fairly adapted to shallow to medium water depths, do poorly in medium-deep water and are susceptible to attack by insects and diseases.

Deepwater rice occupies about 486,000 ha (9% of the total rice area in Burma) mostly in the delta region formed by the tributaries of the Irrawaddy River in southern Burma and in the lower parts of Pegu and Rangoon divisions. In those areas water rises gradually during the monsoon season and usually reaches maximum depth in August. Close to the mountains in the lowland regions of southeastern Burma water generally rises rapidly during the monsoon season and causes flash floods over wide areas.

Flooding in these deepwater areas varies from shallow (about 30 cm) to deep.

DEEPWATER RICE GROWING PRACTICES

Traditional deepwater (floating), photoperiod-sensitive varieties, such as Sitpwa, Tadaungpo, and Taungdi, are grown in the medium deepwater zones of Irrawaddy, Rangoon, and Pegu divisions. They are dry-seeded toward the end of the dry season

Plant breeder, Cooperative IRRI-Burma Project; deputy general manager; assistant deputy general manager, Agricultural Research Institute, Yezin, Pyinmana, Burma.

or occasionally transplanted at the onset of the monsoon rains and harvested when the monsoon rains are over. Yields of 1-1.5 t/ha are generally obtained. Where floodwater rises rapidly crop failures are common.

In places where water recedes gradually in October or November farmers prefer to grow a transplanted crop of improved early-maturing, photoperiod-insensitive, high yielding varieties when the flood recedes. In general no land preparation or weeding is required and the crop matures on residual soil moisture. Varieties used are medium statured and vigorous and can withstand transplanting at water depths greater than that normal for irrigated rice. From this cropping method, yields of 3-4 t/ha are possible. Although the practice appears attractive, it is not always possible to adopt it in the vast areas where water recedes too rapidly to allow a short-duration variety to mature. In such places there is no alternative but to grow deepwater rice. In the deeper areas or where weeds, mostly wild rice, predominate, the field is simply abandoned.

DEEPWATER RICE VARIETAL IMPROVEMENT

Work on deepwater rice improvement presumably started during the colonial period and consisted of selections from existing indigenous deepwater floating varieties. Varieties released then persist today and include those popularly grown such as Sitpwa, Taungdi, and Tadaungpo. A brief summary on these earlier breeding efforts was reported during the 1976 Deepwater Rice Workshop (Kyaw et al 1977).

During the past decade some attention was given to deepwater rice improvement, principally at the Agricultural Research Institute (ARI), Yezin. With the initiation of the International Rice Testing Program (IRTP), a number of improved deepwater lines from Thailand and various sources were introduced for testing through the International Rice Deep Water Observational Nursery (IRDWON).

The numbers of entries grown and selected from deepwater rice observation nurseries, including IRDWON, are indicated in Table 1. At ARI, Yezin, 774 entries

Table 1. Numbers of entries grown and selected from deepwater rice observation nurseries at the Agricultural Research Institute, Yezin, and Mudon Central Farm, Burma, 1976-81 wet seasons.

Year	Entries grown (no.)		Entries selected (no.) for preliminary test	
	Yezin	Mudon	Yezin	Mudon
1976	61	0	21	0
1977	104	47	48	15
1978	147	0	0	0
1979	323	10	115	0
1980[1]	139	22	39	12
1981	147	0		

[1]Nursery grown in shallow water; in other years nurseries were grown in medium water depths.

Table 2. Agronomic traits of selections from deepwater rice preliminary performance tests grown in shallow water (30 cm), Agricultural Research Institute, Yezin, Burma, 1980 wet season.

Entry	Grain yield (t/ha)	Days to heading[a]	Plant height (cm)	Panicles (no.) /hill	Stress rating[b]
Group 1					
BKN 6986-108-3 (M ck)	2.3	118	190	10	LG,
IR 4630-22-2-17	3.6	111	120	12	lg
Group 2					
Taungdi	2.6	122	157	12	
BKN 6986-3	2.7	118	154	12	lg
BKN 6986-108-3 (M ck)	1.9	119	190	10	LG
BR 223-13-3	2.0	115	162	22	LG
Leb Mue Nahng 111	2.0	128	180	11	LG
BKN 6990-63	2.6	110	173	11	LG
BR 223-B-1	2.9	112	173	20	lg
Sitpwa (local ck)	2.2	120	116	12	LG
Group 3					
BKN 69886-68-14	4.1	121	110	16	
BKN 6986-66-2 (RD 17)	5.1	122	124	10	
BKN 7022-42-4	3.2	128	129	12	
Cula	2.9	119	122	14	LG
BGD 4-7-2PE-1	4.4	126	128	10	lg
BKN 6986-11-3	3.1	120	130	12	
BKN 6986-108-3 (M ck)	2.4	117	196	10	LG
BKN 6987-161-1-3	3.3	130	165	14	LG
C4-63 G	3.0	119	126	10	
Jalaj	2.8	128	167	12	LG
CN 536	2.8	120	124	14	lg
BKN 6988-21	3.6	119	180	11	LG
BKN 6987-161-1-3	3.8	120	119	14	
Sitpwa (local ck)	3.7	122	166	12	LG
Group 4					
BKN 6986-66-2 (RD 17)	3.7	122	166	12	
BKN 6990-63	4.8	122	168	12	
BKN FR 76023	3.1	129	142	13	
Saran Kraham	3.3	120	126	18	
BKN 6986-108-3 (M ck)	3.6	118	175	14	LG, exs
Saran Kraham	3.8	121	155	9	LG
BH 2	3.3	116	159	8	
Sitpwa (local ck)	2.4	120	168	12	lg

[a]Days to heading + 30 days = life period. Seeding date 16 Jul, transplanting date 13-14 Aug. [b]In abbreviations of stress, capital letters = serious, small letters = moderate. LG, lg = lodging; EXs, exs = unexserted panicles.

were grown from 1976-80 from which 223 lines were selected and entered in preliminary performance tests. The agronomic and grain traits of 32 selections from 122 entries in preliminary performance tests grown in shallow water in 1980 wet season are summarized in Tables 2 and 3. Sown in mid-July, the life period of the entries ranged

Table 3. Grain traits of selections from deepwater rice preliminary performance tests grown in shallow water (30 cm), Agricultural Research Institute, Yezin, Burma, 1980 wet season.

Entry	Milling recovery (%)		Chalkiness[a]	Grain	
	Total	Head rice		Length	Length-width ratio
Group 1					
BKN 6986-108-3 (M ck)	62	49	O	7.0	3.5
IR 4630-22-2-17	66	53	O	6.0	2.0
Group 2					
Taungdi	64	54	O	6.8	2.6
BKN 6986-3	66	58	O	7.2	2.9
BKN 6986-108-3 (M ck)	62	50	O	7.0	3.5
BR 223-13-3	65	57	wc	5.2	2.1
Leb Mue Nahng 111	65	54	O	7.0	3.5
BR 223-B-1	65	54	wc	5.0	2.0
Sitpwa (local ck)	66	56	WC		
Group 3					
BKN 6986-68-14	66	59	O	7.0	3.2
BKN 6986-66-2 (RD 17)	66	60	O	6.9	3.4
BKN 7022-42-4	63	55	wc	7.0	2.8
Cula	62	51	O	7.5	3.7
BGD 4-7-2PE-1	64	50	wc	7.0	2.8
BKN 6986-11-3	64	34	wc	7.0	3.2
BKN 6986-108-3 (M ck)	62	50	O	7.2	3.6
BKN 6987-161-1-3	66	54	O	6.0	2.1
C4-63 G	65	62	gl, O	6.1	2.8
Jalaj	63	51	wc	6.1	3.0
CN 536	64	48	wc	7.0	3.0
BKN 6988-21	64	53	O	7.0	3.0
BKN 6987-161-1-3	65	52	wc	7.0	2.8
Sitpwa (local ck)	65	55	WC		
Group 4					
BKN 6986-66-2 (RD 17)	63	53	O	7.0	3.3
BKN 6990-63	64	50	O	7.0	3.5
BKN FR 76023	64	51	wc	6.5	2.4
Saran Kraham	65	54	wb	6.1	2.9
BKN 6986-108-3 (M ck)					
Saran Kraham	62	58	O	7.0	2.8
BH 2	62	46	O	7.0	2.7
Sitpwa (local ck)	66	55	wc	5.0	1.7

[a]Abbreviations of chalkiness: Capital letters = >20% chalky; small letters = 10-20% chalky; O = grains transluscent; WC, wc = white center; Wb, wb = white belly.

from 140 days (BKN6990-63) to 160 days (BKN6987-161-1-3). If these were sown in the usual seeding time for deepwater rice — late April — the spread in their life periods could be wide due to differential photoperiodic reaction. It is, therefore, possible to select varieties with life periods suitable for the varying growing conditions

for deepwater rice cultivation. Grown in shallow water (about 30 cm deep), the highest yielders compared to the high yielding check in each group are IR4630-22-2-17 in Group 1; BR223-B-1, BKN6986-3, BKN6990-63, and Taungdi in Group 2; BKN6986-66-2 (RD17), BGD4-7-2 PE-1, and BKN6986-68-14 in Group 3; and BKN6986-63, Saran Krahan, and BKN6986-66-2 (RD17) in Group 4. Three of these selections (IR4630-22-2-17, BKN6990-63, and BR223-B-1) matured a week earlier and the rest matured a week or more later than BKN6986-108-3, the improved check. All 11 selections have high total milling and head rice recovery and except for 2, which have slight white center, have translucent kernels.

The phenotypic acceptability and stress ratings of these same 32 selections grown in deep water in 1979 and 1981 are shown in Table 4. Of the 11 selected in shallow-water tests, those with the best combination of phenotypic acceptability, survival, and other stress ratings in deep water were BKN6986-3, BR223-B-1, and BKN6986-66-2 (RD17). BKN6986-11-3 and BKN FR76023 also had very good combination of those traits, particularly survival. These 13 highly promising selections will be tested in an advanced uniform test at a few deep water sites next year and then increased simultaneously in case any are eventually released. BKN6986-108-3, a deepwater rice recently recommended for general cultivation, matured a few days earlier than most of the selections, but was highly susceptible to bacterial leaf blight and sheath blight in deepwater nurseries.

In Mudon, 79 entries have been tested in various nurseries since 1977. From 47 entries grown in actual medium-to shallow-water fields in 1979 and 1980 wet seasons, 5 entries were selected (Table 5). BKN6986-66-2 (RD17) had the best survival (90%) but it matured the latest (167 days) in the 1979 test.

Attempts to develop improved deepwater varieties through hybridization started in 1971 at ARI, Yezin. Since then 67 crosses, mostly indigenous deepwater varieties with exotic deepwater and shallow wetland selections introduced from Thailand and IRRI, have been made. Crosses made until 1976 were reported in the 1976 Deepwater Rice Workshop (Kyaw et al 1977). Among the recent crosses, 10 involved deepwater varieties, such as BKN6986-108-3 and BKN6986-167, whereas 26 crosses had Ngakywe and Payzanhmwe, which are indigenous tall, high grain quality varieties adapted to shallow- to medium-water depth.

From the earlier crosses, 149 uniform lines — 59 from the 1977 dry season breeding nursery and 90 from the following wet season nursery — were selected and entered in preliminary performance tests (Table 6). The lines selected from the dry-season nursery were photoperiod insensitive and those from the rainy-season nursery ranged from photoperiod insensitive to varying degrees of photoperiod sensitivity.

These locally derived selections, together with selected introductions, were first grown in preliminary performance tests in 1978 and 1979 in medium deepwater (110 cm deep) ponds at ARI, Yezin. Selections were then grown in 1980 in a field that normally accumulates water to medium depths. Because of drought, however, the plants grew and matured at shallow water depth (30 cm). The agronomic and grain traits of the selected entries in the 1980 yield tests are summarized in Tables 7 and 8.

In shallow water in 1980, entries that yielded the same as, or higher than, the high yielding check (T442-57) were X73-16-6, X73-20-14, X73-20-15, X73-16-13, and X73-20-19. These locally developed selections matured 2-3 weeks earlier than T442-

Table 4. Phenotypic acceptability and stress ratings of 1980 preliminary performance test selections grown in deep water,[a] Agricultural Research Institute, Yezin, Burma, 1979 and 1981 wet seasons.

Group and entry	Phenotypic acceptability[b]		Stress ratings[c] Survival (%)		Stress ratings[c] Other stresses	
	1979	1981	1979	1981	1979	1981
Group 1						
BKN 6986-108-3 (M ck)	4	5	80	65	0	BLB,ShB
IR 4630-22-2-17	3	4	80	40	lg	0
Sitpwa (local ck)		3		85	0	0
Group 2						
Taungdi	3	4	70	40	0	0
BKN 6986-3	3	4	80	65	0	0
BKN 6986-108-3 (M ck)	4	3	75	65	BLB	0
BR 223-13-3	3	5	70	40	0	0
Leb Mue Nahng 111	4	3	65	85	lg	blg,lg
BKN 6990-63	4	3	50	65	lg	lg
BR 223-B-1	4	2	55	85	lg	0
Sitpwa (local ck)		3		85		0
Group 3						
BKN 6986-68-14	3	5	80	40	0	0
BKN 6986-66-2 (RD 17)	3	2	90	65	0	0
BKN 7022-42-4	3	4	90	40	0	0
Cula	3	4	70	40	0	0
BGD 4-7-2PE-1	3	4	70	40	0	blb
BKN 6986-11-3	3	3	90	85	0	0
BKN 6986-108-3 (M ck)	4	4	75	65	0	BLB
BKN 6987-161-1-3	3	4	80	40	0	0
C4-63 G	3	6	90	40	0	0
Jalaj	3	5	70	40	0	LG
CN 536	3	7	80	40	0	0
BKN 6988-21	3	5	70	40	0	0
BKN 6987-161-1-3	3	7	80	85	0	blb
Sitpwa (local ck)		3		85		0
Group 4						
BKN 6986-66-2 (RD 17)	3	3	70	65	0	blb
BKN 6990-63	3	4	70	40	0	0
BKN FR 76023	3	3	70	85	0	blb
Saran Kraham	3	3	90	40	0	0
BKN 6986-108-3 (M ck)	4	4	75	40	0	0
Saran Kraham	4	5	65	40	lg	shb
BH 2	4	4	50	40	lg	0
Sitpwa (local ck)		3		65		0

[a]Maximum water depths = 110 cm in 1979 and 150 cm in 1981.
[b]Phenotypic acceptability ratings (1 = best to 9 = poorest) were made at maturity in 1979 observation nurseries and at maximum tillering to early reproductive stage in 1981 yield trials. [c]In abbreviations of stress, capital letters = serious and small letters = moderate. LG, lg = lodging, ShB, shb = sheath blight; BLB, blb = bacterial leaf blight; and 0 = no incidence. Transplanted 22 Aug 1979, 29 Jun 1981.

57. Except X73-20-15, which was not evaluated for grain characteristics, these selections have high milling recoveries and long, relatively slender, translucent grains (Table 8).

In deepwater ponds in 1978 and 1979, the highest yielders were X73-16-13 and X73-18-1 (Table 9). Those two selections had fair survival in 110 cm water in 1978 and 1979, but had an emergence problem in 150 cm water in 1981. X73-20-19 and BKN6986-147-2 had good survival at 110-cm and 150-cm water depths. These four selections, together with those that may be found better than the high yielding check in the 1981 performance tests, will be tested further in uniform performance tests at a few deepwater sites before any is considered for release.

Table 5. Agronomic traits of five selections from 47 introduced deepwater rices tested at Mudon Central Farm, Burma, in medium-shallow water fields, 1979 and 1980 wet seasons.

Entry	Year	Maturity (days)	Plant height (cm)	Productive tillers (no.)	Survival (%)	Seeds (no.)/panicle
BKN 6986-59-12	979	161	84	4	40	181
	1980	158	99	6		128
BKN 6986-30-1	1979	158	105	5	60	173
	1980	148	118	7		192
BKN 6987-52-1	1979	150	104	5	40	182
	1980	151	106	7		152
BKN 6986-66-2	1979	167	93	4	90	143
	1980					
BKN 6986-108-2	1979					
	1980	158	94	7		123

Table 6. Number of uniform lines selected from segregating generations of deepwater rice crosses, Agricultural Research Institute, Yezin, Burma, 1977.[a]

Line	Cross	Selections (no.) 1977 dry season	1978 wet season
X73-14	IR24/D 25-4	9	12
-16	C4-63/D 25-4	17	14
-18	IR24/Ngakywepyu	7	11
-20	C4-63/Ngakywepyu	22	48
-22	IR1364/D 25-4	4	5

[a]Water depth in dry season was shallow; wet season was medium deep.

Table 7. Agronomic traits of selected deepwater rice entries from uniform performance tests in shallow water at the Agricultural Research Institute, Yezin (Yzn), and Mudon (Mdn) Central Farm, Burma, 1980 wet season.

Entry	Grain yield (t/ha)		Days to heading[a]		Plant height (cm)		Panicles (no.)/hill		Stress score[b]	
	Yzn	Mdn	Yzn	Mdn	Yzn	Mdn	Yzn	Mdn	Yzn	Mdn
BKN 6986-147-2	2.4	2.1	127	144	116	125	9	6	0	lg,sb
BKN 6986-81	1.9	1.9	121	144	155	153	10	6	lg	lg
BKN 6986-3	1.6	1.3	119	126	163	160	12	8	0	0
Pelita I-1	2.2	1.4	119	131	153	162	11	7	0	0
X 73-16-1	2.2	1.4	112	121	123	125	14	7	lg	0
X 73-14-2	1.5	2.5	118	121	130	135	14	7	0	0
X 73-16-6	2.2	2.5	112	121	122	117	11	7	0	0
T442-57 (ck)	2.1	2.4	123	142	107	113	9	7	lg	Lg
X 73-20-14	2.9	2.3	115	123	130	130	12	7	lg	sb
X 73-20-15	2.9	1.6	117	123	144	163	10	7	lg	0
X 73-16-13	2.8	1.7	111	120	135	133	12	8	lg	0
X 73-18-1	1.4	1.7	112	121	151	140	11	7	Lg	0
X 73-20-19	2.6	2.0	118	121	146	135	13	7	0	0
BKN 6986-108-3	1.7	1.7	118	131	182	179	15	8	Lg	Lg
BKN 6986-167	1.2	2.2	132	144	164	172	12	8	lg	sb
Sitpwa (local ck)	2.3	2.2	120	144	169	172	15	6	Lg	0

[a]Days to heading + 30 days = maturity period. [b]In abbreviations of stress, capital letters = serious; small letters = moderate; LG, lg = ledging; SB, sb = stem borers; and 0 = no incidence.

Table 8. Grain traits of selected deepwater rice entries from uniform performance tests in shallow water at the Agricultural Research Institute, Yezin, Burma, 1980 wet season.

Entry	Milling recovery (%)		Chalkiness[a]	Grain	
	Total	Head rice		Length (mm)	Length-width ratio
BKN 9686-147-2	67	50	wc	8.0	3.2
BKN 6986-81	64	50	wc	7.0	2.8
BKN 6986-3	63	50	0	7.0	2.3
Pelita I-1	69	55	wb	6.5	2.6
X 73-16-1	63	52	0	7.0	2.8
X 73-16-6	62	52	0	7.0	2.8
T442-57 (ck)	61	46	WC	7.0	2.8
X 73-20-14	63	50	0	8.0	3.2
X 73-16-13	63	56	0	7.0	2.8
X 73-20-19	63	52	0	7.0	7.8
BKN 6986-108-3	63	51	0	7.0	3.5
BKN 6986-167	62	40	wc	7.0	2.8
Sitpwa (local ck)	65	53	wb	6.0	2.0

[a]wc = white center, 10-20% chalky; wb = white belly, 10-20% chalky; WC = white center, 20% chalky; 0 = translucent.

Table 9. Agronomic traits of 1980 deepwater rice performance test selections grown in deepwater in 1978, 1979, and 1981 wet seasons, Agricultural Research Institute, Yezin, Burma.

Entry	Life period (days)		Plant height (cm)		Panicles (no.)/ hill		Grain yield (t/ha)		Stress ratings[a] Survival (%)			Stress ratings[a] Other stresses		
	1978	1979	1978	1979	1978	1979	1978	1979	'78	'79	'81	'78	'79	'81
BKN 6986-147-2	155	147	161	127	6	6	1.5	0.8	50	55	85	SB,lg	lg	blb
BKN 6986-81	149	147	190	151	5	5	1.5	0.5	55	50	85	SB,lg	lg	0
BKN 6986-3	146	139	168	152	5	6	1.1	0.6	25	30	85	lg	lg	lg
X 73-16-1	165	136	133	138	3	8		1.1	5	55	15	lg	0	0
X 73-14-2	147	148	165	141	5	5	1.4	0.8	30	30		lg	sb	
X 73-16-6	146	138	162	129	4	6	1.4	0.8	35	45	15	lg	0	0
T 442-57 (ck)	146	145	160	127	6	7	1.7	0.9	60	30	40	lg	0	0
X 73-20-14	147	141	160	142	5	6	1.7	0.6	50	50	40	Sb,lg	lg	0
X 73-20-15	149	144	161	151	4	8		0.6	25	70	85	lg	sb	BLB
X 73-16-13	150	133	160	149	3	10	0.8	2.1	30	70	15	lg	sb	0
X 73-18-1	144	131	172	158	4	9	1.7	0.9	40	60		lg	sb	
X 73-20-19	154	141	172	145	4	6	1.6	0.7	55	65	40	lg	0	0
BKN 6986-108-3											65			BLB,Shb
BKN 6986-167	149		219		6		1.4		85		40	lg		shb
Sitpwa (local ck)	130	124	181	155	4	7	1.5	0.4	55	40	85	lg	sb	0

	1978	1979	1981
Sowing date	14/7	25/7	26/5
	16/8	20/8	29/6

Maximum water depths = 110 cm in 1978 and 1979 and 150 cm in 1981.

[a] I. abbreviations of stress, capital letters = serious, small = moderate. Lg, lg = lodging, SB, sb = stem borers: BLB, blb = bacterial leaf blight; Shb, shb = sheath blight; and 0 = no incidence.

PRESENTLY RECOMMENDED VARIETIES

A number of promising selections are being field tested. BKN6986-108-3, based mainly on visual observation from various deepwater nurseries grown previously at Yezin, was released in 1980 and named as Yenet 1 by the ARI Rice Division. From breeder seed produced in normal wetland fields in 1978, 0.7 t of foundation seed was harvested in 1979 and distributed in 1980 to several divisions and states. Because of unfavorable weather, however, good results were obtained only in a few places in Pegu division and Shan state. Although BKN6986-108-3 performs well in shallow water, in medium water depths it tends to be susceptible to bacterial leaf blight or other diseases. Another selection, BKN6986-167, is being considered for release, again without adequate field tests. Some 1.6 t of foundation seed of BKN6986-167 were distributed to deepwater farmers in Pegu division this year.

After this year's trial at three sites it may be possible to identify fairly good deepwater selections with good survival and yield at varying water depths.

REFERENCE CITED

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DISCUSSION

HILLERISLAMBERS: Your paper brings out the importance of the approach of the water depth as opposed to just the maximum water depth. Water depth by itself was apparently not the decisive factor, but the speed of water depth increase was the important thing. Water level graphs are indispensable when interpreting results like this.

GOMOSTA: Some entries exhibited higher percentage of survival in higher water depth. Please comment.

ESCURO: The higher percentage of survival of certain entries in deep water could be attributed to gradual rise in water in the deeper-water treatment compared to the shallower-water treatment. The transplanting of slightly older seedlings in the deeper-water treatment could also have led to greater survival.

HOQUE: You are placing emphasis on grain quality in the Burmese breeding program. Do you sometimes have to sacrifice yield for grain quality?

ESCURO: No, grain yield has to be at least satisfactory.

VARIETAL IMPROVEMENT AND GENETICS STUDIES

DEEPWATER RICE IN NORTHERN VIETNAM

Dao The Thuan, Nguyen Duy Tinh,
and Nguyen Huu Thanh

Flooding is one of the most important limiting factors for rice production in Vietnam, especially in northern Vietnam. Every 2 or 3 years floods severely reduce the yield of wet-season rice and limit the intensification of this crop.

CHARACTERISTICS OF FLOODING

In northern Vietnam flooding is not from the overflow of rivers as in southern Vietnam but from short-duration flash floods during heavy rains. Such floods are noncyclic and unpredictable.

Table 1 shows the frequency of heavy rains. Normally when it rains more than 3 consecutive days at more than 150 mm/day, low-lying rice fields are flooded. Flooding occurs every 2-3 years and heavy floods occur once every 5 years. The rice crop may be flooded in all phases of the growth period, but flooding is most frequently from the end of tillering to flowering. The area flooded varies from year to year. Recently it varied from 30 to 60% of the cultivated area, which is about 1.3 million ha in northern Vietnam. To reduce the flood hazard, drainage systems, dams, and

Table 1. Frequency of occurrence of heavy rains in Hanoi area, Vietnam, 1966-79.

Month	Years (%) with rains more than 3 consecutive days		
	More than 150 mm	More than 200 mm	More than 300 mm
July	17	4	0
August	26	13	4
September	34	4	0
October	17	0	0
Whole season	70	22	4

Deputy director; deputy head; and research fellow, Water Management Department, Vietnam Agricultural Science Institute, Hanoi.

Table 2. Selected entries from 1980 IRDWON for Type I deepwater areas of northern Vietnam.

Variety	Growth duration (days)	Plant height (cm)	Seedling height (cm)	Elongation (cm/day) After transplanting	Elongation (cm/day) 20 days after transplanting[a]	Submergence survival (% after 7 days)	Grain yield (t/ha)	Resistance to bacterial leaf blight[b]
BR118-3B-17	160	140	58	6.2	-	90	4.4	MR
Madhukar	140	160	62	7.4	2.9	90	3.5	P
GMS 13	140	150	62	6.4	-	100	3.4	R
FRG 7	140	175	46	7.6	3.4	60	3.3	R
CNL319	150	170	55	7.6	5.3	80	3.2	R
FRG 2	140	155	52	6.6	4.9	60	3.2	R
FRG 10	140	152	57	7.4	-	90	3.0	R
M 1 (check)	140	120	40	4.5	1.7	60	3.0	R

[a]Dash indicates no data. [b]R = resistant, MR = moderately resistant.

Table 3. Selected entries from 1980 IRDWON for Type II medium-deep areas of northern Vietnam.

Variety	Growth duration (days)	Plant height (cm)	Seedling height (cm)[a]	Elongation (cm/day)[a] After transplanting	Elongation (cm/day)[a] 25 days after transplanting	Submergence survival (%) After transplanting	Submergence survival (%) 25 days after transplanting	Grain yield (t/ha)	Resistance to bacterial leaf blight[b]
BKN6990-63	150	152	52	10.4	4.3	57	63	3.6	R
BR14	145	133	42	9.4	4.1	63	77	3.5	MR
BKN6986-66-2	150	148	50	7.4	4.5	27	60	3.4	MR
CN540	150	115	50	7.4	2.8	15	68	3.6	R
RAU 21-168-1-2	140	140	47	6.0	-	34	70	3.6	R
SPR7292-296-1-3-B	152	145	55	7.4	-	62	60	3.4	R
BKN7022-10-1-4	150	110	-	8.0	-	45	-	3.1	R
ARC5955	120	145	-	6.0	4.4	-	-	3.0	R
Moc tuyen (check)	150	100	30	-	1.7	0	0	2.5	R

[a] Dash indicates no data. [b]R = resistant, MR = moderately resistant.

Table 4. Selected entries from 1980 IRDWON for submergence tolerance in Type III deepwater areas of northern Vietnam.

Variety	Growth duration (days)	Plant height (cm)	Seedling height (cm)	Submergence survival (%)			Grain yield (t/ha)	Resistance to bacterial leaf blight[b]
				25 DT[a]	7 DT	10 DT		
L1050C-Mr-44-3	145	115	40	82	60	-	3.6	R
R5857-3-2E-2	130	100	36	16	65	47	3.6	MR
FR13A	145	100	36	70	-	-	3.6	R
DWCT 135-1-1-B	130	115	42	71	73	-	3.6	R
CR5857-64	137	110	-	20	65	20	3.5	R
IR5825-41-2P4	145	110	38	40	30	14	3.4	R
CR1009	145	90	-	75	14	0	3.2	R
RD1	145	110	45	70	60	-	3.5	R

[a]DT = days after transplanting. [b]R = resistant, MR = moderately resistant.

pumping stations were built in areas seriously affected — about 270,000 ha.

We distinguish three types of flooded areas:

- *Type I*, a deep, seasonally flooded area (about 15-20% of the cultivated area). It is in areas of depressions where the water is about 1.0-1.5 m deep during the rainy season. Those areas grow only transplanted dry season rice. Only a part bounded by dams is cultivated during the wet season and there is risk of yield loss.
- *Type II*, a medium-deep area of prolonged flooding (about 15-20% of cultivated area). Water depth is 0.5-1.0 m during the rainy season. In the 1980 wet season local tall rice varieties were replaced by the improved tall varieties like Moc Tuyen and Pelita I/1, M 1, but the yield was strongly affected by floods and remained unstable.
- *Type III*, a shallow, irregular, and briefly flooded area (about 30-40% of the cultivated area). After heavy rains the fields are flooded during 1-2 weeks with a water depth of 0.5-0.8 m. These areas are now transplanted to high yielding varieties like IR22, V13, and BR52, but the yields are still affected by floods.

DEEPWATER RICE VARIETAL TESTING

Since 1977 we have started the International Rice Deep Water Observational Nurseries (IRDWON) to find suitable varieties for our deepwater areas.

First we selected entries with good phenotypic acceptability and that flower at the right time (mid-October) to avoid cold damage. After that we screened for elongation and submergence tolerance in water tanks. The selected entries are divided into three groups according to types of flooding and tested in corresponding field conditions. Some entries (Tables 2, 3, and 4) showed good performance.

— Type I : BR118-3B-17, Madhukar, and FRG7.

— Type II : BKN6986-66-2, BKN6990-63, and BR14.

— Type III: B1050C-MR-44-3, IR5857-3-2E-2, and PR13A.

The IRDWON is useful to us to resolve the problems of deepwater rice.

We hope to propose some varieties for the flooded areas this year. Further testing for deepwater acid sulfate soils and for photoperiod sensitivity is in progress.

DISCUSSION

JACKSON: Dr. Kanter, during your recent trip to Vietnam did you observe or hear any comments on the variety RD17?

KANTER: RD17 was among nine entries observed in a replicated yield trial in the Red River Delta's Phy Xuyen district. It is being tested for areas that flood to about 100-cm depth. Its growth duration seems to be about optimum for their cropping pattern. I observed seed multiplication of RD17 at the Institute of Agricultural Sciences near Hanoi.

GRAIN YIELD AND YIELD COMPONENTS OF DEEPWATER RICE IN WEST AFRICA

A. I. Toure, M. A. Choudhury, M. Goita, S. Koli, and G. A. Paku

SUMMARY

Most of Africa's deepwater rice areas are in West Africa. Annual rainfall, land contours, and rivers contribute to regular annual flooding, which is of short duration in most areas. Farmers recognize and maintain distinct deepwater varieties for different growing conditions. In the remote areas *O. glaberrima* varieties are grown. Poor varieties, rainfall distribution, weed infestation, and poor land preparation are the most important yield constraints. Varietal improvement includes hybridization, introduction, coordinated evaluation and yield trials, local trials, and farmer field trials. The 1980 results of these trials are presented. Results of selected agronomy trials are also presented.

Most of the deepwater rice areas in Africa are in West Africa. Annual flood zones along the Niger, Gambia, Casamance, and Hadejia rivers make up the main deepwater rice areas. Low-lying plains on the Atlantic coast and areas surrounding Lake Chad constitute additional deepwater areas.

Deepwater rice is grown on about 25% of the total rice area of West Africa (Table 1). The potential areas, however, have been estimated at a million hectares (Choudhury and Will 1977).

The annual rainfall, land contours, and rivers of the West African region contribute to regular annual flooding. The flooding usually starts sometime between the middle of August and the beginning of September. The rate of water rise varies from 2 to 10 cm/day after the onset of flooding. The deepwater rice is grown at the maximum water depth of 2.5 m. The floods may start subsiding any time after October.

Deepwater rice varieties grown by farmers in remote areas are *O. glaberrima*. *Oryza sativa* is grown near reclaimed, government-controlled areas. Land preparation is mechanized in areas in Mali, Niger, and Nigeria but elsewhere deepwater rice is

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Table 1. Distribution of deepwater rice in West Africa.

Water status	Area covered (ha)	% of total rice area	Countries	Av yield (t/ha)
No water control	506,000	22	Mali, Niger, Nigeria, Senegal, Gambia, Sierra Leone, Guinea, and Guinea Bissau	1.0-1.5
Partial water control (dam or polder)	69,000	3	Mali, Senegal, and Nigeria	1.5-2.0
Total	575,000	25		

grown on poorly prepared lands.

Farmers recognize and maintain distinct varieties for different growing conditions. Longer-duration varieties with better elongation ability are grown in deeper areas and short-duration varieties are grown in shallow areas. Canoes are used for early harvest. The soil fertility of deepwater areas is enriched annually by silt deposition (Choudhury and Will 1977). Most *O. glaberrima* varieties have some photoperiod sensitivity and generally initiate panicles in November. Harvesting is usually in January.

YIELD CONSTRAINTS

Oryza glabberima varieties are adapted to local deepwater conditions but low productivity is caused by:

- low yielding ability of varieties,
- inadequate rains before flooding,
- poor land preparation,
- weeds, including wild rices,
- blast,
- stem borers,
- grain shattering, and
- harvest losses.

VARIETAL IMPROVEMENT

The varietal improvement work at the West Africa Rice Development Association (WARDA) Deepwater Rice Research Project at Mopti, Mali, consists of hybridization, introduction, WARDA-coordinated Initial Evaluation Tests (IET), coordinated variety trials, local yield trials, and farmer field trials. Recently, some rapid generation advance (RGA) populations have been introduced from IRRI. So far, the yearly coordinated IET has been an effective tool in selecting new entries for yield trials. Varieties selected from IET are advanced to multisite yield trials. The IRDWON is

Table 2. Characteristics of varieties selected from BRRI introductions at Mopti, Mali (WARDA 1979).

Varieties	Blast reaction[a]	Maturity (days)	Plant height (cm)	Panicle exsertion	Grains (no.)/ panicle	Sterility (%)	Weight (mg)
Jalmagna	1	103	106	3	–	–	16.6
Bagdar 105	3	105	156	1	61	12	17.2
Aswina 322	1	108	130	5	49	9	15.6
Bhadoia 688	1	108	142	5	81	–	22.4
Laki 720	3	108	133	5	59	8	21.2
Bhadoia 695	3	110	132	3	36	8	16.0
Laki 544	1	110	146	1	67	9	18.4
Laki 557	3	110	152	3	72	27	20.4
Laki 645	1	114	145	1	57	13	18.6
Bamoia 341	3	115	141	3	76	9	21.2
Fulkari 368	3	115	160	3	65	19	18.0
Porsum 67813	1	115	155	3	101	17	19.0
Karkati	3	115	145	3	62	9	22.8
Laki 540	1	115	141	3	94	10	20.0
Laki 724	3	115	150	3	59	8	21.2
Laki 659	3	116	137	3	73	8	19.4
Patuakhali	3	117	135	5	62	13	23.0
Laki 34/2	3	120	154	1	45	11	17.8
Laki 396	3	120	147	3	100	10	20.0
Laki 550	3	120	151	3	94	7	18.2
Laki 642	3	120	155	3	113	14	20.0
Khama 380	3	122	147	5	73	9	22.2
Rajasail	1	122	134	5	82	12	26.0
Laki 146	1	123	152	1	62	8	19.2
Karkati 87	1	125	151	3	104	12	24.0
Kumragoir	1	135	135	3	69	9	27.4
D.A. 29	1	138	131	3	80	8	31.0
Dholaman 219/6	3	140	178	3	86	8	23.0

[a]Ratings based on Standard Evaluation System for Rice (IRRI 1980).

Table 3. The 15 best varieties of the 1980 IET in shallow-water tests at Mopti (Mali), Daikaina (Niger), Sikasso (Mali), Djibelor (Senegal), and Genoi (Gambia). (WARDA 1980)

Varieties	Flowering duration (50 %)	Plant height (cm)	Panicles (no.)/m^2	Yield (t/ha)
SR 26B	104	140	52	3.1
BKN6323	112	151	44	2.7
Farox 126/68/8	118	138	45	2.5
Adny 301	124	140	39	2.4
Farox 126/67/19	117	138	41	2.4
Farox 126/64/13	114	141	50	2.4
Bakutu	131	143	31	2.3
MSP 10	126	187	57	2.3
DM 16	110	160	54	2.1
Farox 127/59/6	117	177	45	2.0
Gissi 27	119	131	35	2.0
Pa Kenema	129	177	38	1.9
BKN6987-161-1-3	106	108	46	1.9
BKN6986-147-2	131	108	54	1.9
Farox 126/69/9	118	158	36	1.9

planted every year and has revealed several good varieties but none was good enough for release. Varieties selected from IRDWON are included in the WARDA-IET in the following year.

New introductions

In 1979, about 200 pure lines, received from Bangladesh, were field tested for adaptability. Twenty-eight varieties were selected for further tests (Table 2). These lines matured too early for Mali conditions but they will be tested in Nigeria where early-maturing varieties are appropriate.

Initial Evaluation Test (IET)

In 1980, the IET was at five sites in five countries. All tests were at shallow water depth. Major characters of the 15 best varieties are shown in Table 3. The varieties selected at Mopti on the basis of their phenotypic acceptability are shown in Table 4. Many Thai and Nigerian varieties showed good performance in shallow water depth at several sites. Maturity of 130-135 days is appropriate at these shallow water depth (about 61 cm).

Coordinated variety trials

Two sets of coordinated variety trials, one for shallow water and one for deep water, were grown in 1980. The shallow-water trial was grown at five sites in four countries. The performance of the entries is shown in Table 5.

The deepwater trial of 1980 was at two sites in two countries. The performance of the varieties is shown in Table 6.

Table 4. Agronomic characteristics of selected varieties from the 1980 IET grown in shallow water at Mopti, Mali (WARDA 1980).

Varieties	Deadhearts score[a]	Maturity (days)	Plant height (cm)	Grains (no.)/ panicle	Kernel weight (mg)	Grain yield (t/ha)
SR 26B	3	130	167	143	30.4	3.8
Adny 301	1	140	158	163	23.6	3.6
DM 16	1	135	174	175	30.2	3.1
Pa Kenema	3	150	164	194	18.1	3.0
Bakutu	3	140	165	111	19.3	3.0
BKN 6323	1	140	165	138	25.3	2.8
Farox 126-69-9	3	132	175	65	28.6	2.6
Fraox 126-67-19	5	130	154	145	23.9	2.5
Gissi 27	5	140	128	175	18.4	2.2
Farox 127-59-6	5	135	135	108	25.0	2.1
Farox 126-68-8	5	130	133	116	24.0	2.0
IR4683-53-2-2-3	1	145	147	145	24.2	1.7
BKN6987-161-1-3	1	135	130	118	20.3	1.5
BKN6986-147-2	1	140	133	95	28.3	1.5
DA 29	3	130	132	68	29.0	1.4

[a]Scoring based on Standard Evaluation System for Rice (IRRI 1980).

Table 5. Performance of varieties in 1980 shallow water depth trials at Mopti (Mali), Sikasso (Mali), Daikaina (Niger), Medina (Gambia), and Djibelor (Senegal).

Variety	Score[a]				Maturity (days)	Plant height (cm)	Panicles (no.)/m^2	Yield (t/ha)	
	Blast	Leaf scald	White head	Sterility				Range	Av
DA 29	1	1	5	1	135	152	181	2.2-4.3	2.9
IR2071-586-5-6-3	1	1	3	1	137	107	261	1.1-3.8	2.6
BKN6986-17	1	3	3	-	155	202	225	1.6-3.4	2.4
Adny 301	1	2	3	2	157	135	203	0.7-4.1	2.4
BKN6323	2	1	-	1	136	159	178	1.2-3.7	2.3
Bakutu	2	1	3	4	158	158	223	0.6-3.8	2.3
Gissi 27	1	2	3	2	153	134	236	1.0-3.9	2.3
Dachina Gochya	1	1	3	1	137	115	194	1.3-3.4	2.3
IR442	1	1	3	1	141	110	222	1.1-2.7	2.1
Faro 14 (FRRS43)	1	1	3	1	152	186	209	0.8-4.2	2.1
Pa Kenema	1	3	1	-	164	185	232	1.1-3.0	1.9
Bhadoia	1	1	-	2	146	106	91	0.6-2.1	1.4
Habiganj Aman II	4	1	-	1	103	105	162	0.2-1.2	0.8

[a]Scoring based on Standard Evaluation System for Rice (IRRI 1980).

Table 6. Performance of varieties in deep water at Mopti (Mali) and Daikaina (Niger) 1980.

Variety	Leaf blast[a]	Maturity (days)	Plant height (cm)	Panicles (no.)/m^2	Yield (t/ha)		Remarks
					Range	Av	
Faro 14	-	-	-	-	3.0-3.0	3.0	One site
DA 29	1	138	173	161	1.9-3.2	2.5	
Nang Kiew	1	158	221	231	2.3-2.6	2.5	
DM 16	-	-	-	-	2.1-2.1	2.1	One site
MSP 10	1	158	202	245	1.2-2.6	1.9	
Cula	-	-	-	-	1.8-1.8	1.8	One site
BKN6986-167	1	159	212	265	0.9-2.4	1.6	
MSP 11	1	131	136	137	0.8-1.8	1.3	
BKN6323	-	-	-	-	1.3-1.3	1.3	One site

[a]Scoring based on Standard Evaluation System for Rice (IRRI 1980).

Table 7. Yield performance of 10 varieties in deep (102 cm) and medium deep (85 cm) water at Mopti, Mali (WARDA 1980).[a]

Varieties	Maturity (days)		Plant height (cm)		Grain yield (t/ha)	
	Deep zone	Medium zone	Deep zone	Medium zone	Deep zone	Medium zone
DM	145	138	195	200	3.0	3.3
BKN6323	147	140	183	184	3.0	3.3
Cula	157	146	217	212	3.0	3.3
Khao Gaew	161	158	220	230	2.9	3.2
Nang Kiew	160	154	221	228	2.7	2.8
BKN6986-108-3	161	146	188	186	2.6	2.9
BKN6986-167	158	150	198	199	2.5	2.9
MSP 11	158	150	190	203	2.4	2.9
Mali Sawn	173	160	221	228	1.9	3.2
BKN6986-81-5	157	150	195	199	1.8	2.2

[a]Deep (102 cm) zone seeded 16 July, medium-deep(985 cm) zone seeded 25 July.

Table 8. Yield performance of 10 varieties in medium (85 cm) and shallow (50 cm) water at Mopti (Mali), WARDA, 1980.[a]

Varieties	Duration (days)		Plant height (cm)		Grain yield (t/ha)	
	Medium zone	Shallow zone	Medium zone	Shallow zone	Medium zone	Shallow zone
BKN6986-105-P	136	128	150	118	4.4	4.8
T442-36	139	135	156	129	3.8	4.1
BKN7022-6-4	141	135	155	133	3.7	4.4
DA 29	130	125	178	167	3.7	3.6
DA 16	134	133	216	171	3.5	3.9
BKN7022-10-1-4	136	127	152	123	3.5	4.3
BKN6986-38-1	141	136	150	123	3.5	4.5
BH2	141	136	175	161	3.3	4.0
DM 17	136	136	201	165	3.2	4.3
D52-37	130	127	182	163	2.8	3.3

[a]Medium (85 cm) zone seeded 27 July, shallow (50 cm) zone seeded 9 August.

Local variety trials

At the WARDA Deepwater Rice Research Project at Mopti, several yield trials are conducted every year to test the newly identified varieties at different water depths. Results of two 1980 yield trials are shown in Tables 7 and 8.

Agronomy and farmer field trials

Every year, several agronomy trials at Mopti develop the most efficient and economic packages for the farmers. In 1980 trials Khao Gaew, Nang Kiew, and Mali Saron had

the highest yields (1.4-1.5 t/ha) in a 10 July seeding. Yields of plots seeded 31 July dropped below 1 t/ha. Plots seeded 8 August were destroyed by floods.

In seeding methods tests, drilling and broadcasting were clearly superior to transplanting.

In cooperation with the local extension agency, several multisite farmer field yield trials are conducted annually. In 1980, yields of BKN6986-38-1, DM17, BH2, and DM16 in farmer fields ranged from 3.2 to 4.7 t/ha at 2 shallow-water sites. Yields of Khao Gaew, Cula, MSP10, and MSP11 ranged from 1.7 to 2.4 t/ha in farmer fields in deepwater areas.

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DISCUSSION

JENNINGS: Is African deepwater rice *O. glaberrima* or *O. sativa*? If it is *O. glaberrima* did the floating habit evolve in Africa in *O. glaberrima*?

TOURE: Many deepwater rice varieties in West Africa are *O. glaberrima*. You can find *O. sativa* varieties only in the rice research stations in Nigeria or Mali but in Mali there are rice projects on about 80,000 ha where *O. sativa* varieties are exclusively grown. Those who grow *O. glaberrima* varieties in these project areas must leave the project. Outside the station farmers grow *O. sativa* varieties mostly because they found that those varieties can withstand flooding.

OHTA: The eating quality of *O. glaberrima* and *O. sativa* varieties should be different. What is the people's attitude toward introducing the *O. sativa* varieties of deepwater rice?

TOURE: In field interviews of farmers after harvesting, they did not say precisely what made the *O. glaberrima* varieties more attractive, but they said that those varieties give them more of a full-stomach feeling. Urban people tend to prefer the *O. glaberrima* varieties. We have to do more farmer interviews on this and develop a good program of rice-quality testing.

FRANCIS: You compared direct seeding and transplanting and got much lower yields from transplanting. What spacing did you use in transplanting and how many seedlings/hill?

TOURE: We used 25 × 25 cm spacing and transplanted 2 seedlings/hill. The problem was that we transplanted 45-day-old seedlings into 20-30 cm water. We got only meager tillering.

FRANCIS: We had a similar experience. If you plant late you have to use closer spacing.

GENETICS OF PLANT AND INTERNODE ELONGATION ABILITY IN RICE

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SUMMARY

The genetics of plant and internode elongation ability were studied in parents, F_1, and F_2 populations in controlled flooding. The F_2 population range was within the limits of the parents, indicating the absence of transgressive segregation. Few segregates in F_2 populations had the elongation ability of the elongating parents; there were more of the intermediate types. F_2 distribution for both plant and internode elongation ability was continuous with a single peak. Multigenic control of the plant and internode elongation with partial dominance was indicated but there were cases where dominance was indicated. From the F_2 distribution, the possibility of dominance is less likely. In all the crosses for plant and internode elongation more than one loci were involved. More studies with different techniques will be required to confirm the results of this study.

In many parts of South and Southeast Asia plant and internode elongation ability is an important trait of deepwater (floating) rice varieties adapted to water depths of 1-4 m. There is, however, little information available on the genetics of plant and internode elongation ability in floating rice.

Ramiah and Ramaswami (1941) reported two major duplicate recessive genes responsible for the floating habit in rice. Later, Kihara et al (1962) concluded that three factors, "a", "b", and "c", are responsible for deepwater tolerance. The authors did not mention the genes involved for each factor or the number of genes for floating habit. Supapoj et al (1977) reported that populations from the crosses of floating and nonfloating varieties segregated with only a small portion of true floating type — more of the intermediate types. They supposed that the characters might be controlled by dominant or recessive genes.

Partial dominance and a multigenic nature of floating ability were identified by Hamamura and Kupkanchanakul (1979). They also observed that F_2 populations

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showed a continuous distribution with a single peak. Maurya (Gagraghat, India, unpubl.) reported discrete segregation of floating and nonfloating types with complementary gene action.

This study was undertaken to generate more information on the genetics of plant and internode elongation ability, and the nature and number of genes involved. The information will be helpful in designing breeding work in studies of the genetics of floating habits in rice.

MATERIALS AND METHODS

Five crosses — two for plant elongation and three for internode elongation ability — were studied. The crosses were Habiganj Aman II/IR26 and Habiganj Aman V/Pajam for plant elongation and BR4/Raybhog, Raybhog/Habiganj Aman II, and BR4/Habiganj Aman VII for internode elongation. IR26 is semidwarf, BR4 and Pajam are intermediate with modern plant type, and Raybhog is a tall traditional variety. These varieties do not possess any elongation ability. Habiganj Aman II, V, and VII are traditional deepwater (floating) rice varieties of Bangladesh and possess different degrees of elongation ability when grown in rising floodwater.

Crosses for plant elongation ability were made in 1976. Parents and F_1 populations were seeded 1 June 1977, transplanted in a deepwater tank at 3 weeks of age, and subjected to flood at 6 weeks of age. Water was increased 10 cm every other day to a maximum depth of 120 cm. F_2 populations seeded in March 1978 received the same flood treatments as parents and F_1 populations.

Crosses for internode elongation ability were done in 1979. Parents and F_1 populations were seeded on 5 April 1980 and F_2 populations on 20 April 1981. Seedling age at flooding time, flood rate, and the maximum water depth were the same as for plant elongation ability.

Plant length for parents, F_1, and F_2 populations was measured from the plant base to the tip of the tallest leaf. For internode length, the plants were uprooted and removed from the tank; the leaf sheaths and leaf blades were also removed and only the internode length was measured.

The number of genes, the potence ratio, and the epistasis gene action were calculated according to Castle and Wright (1921), Griffing (1950), and Jinks (1955), respectively. Population size for the plant elongation ability study was 2-5 plants each for parents and F_1 populations, and 803-906 plants for F_2 populations. For the internode elongation ability study, population size was 5 plants each for parents and F_1 populations, and 389-456 plants for F_2 populations.

RESULTS AND DISCUSSION

Plant elongation

Plant elongation includes elongation of internodes, leaf sheaths, and leaf blades. Table 1 shows the means and variances of parents and F_1 and F_2 populations of both crosses at 120-cm water depth. Table 1 also shows the dominance values, the possible number of genes involved, and the nonallelic interaction (epistasis) controlling plant elongation in these two crosses

Table 1. Analysis of means and variances of parents, F_1, and F_2, dominance value, number of genes, and epistasis for plant elongation ability in rices involved in two crosses. BRRI, 1978.

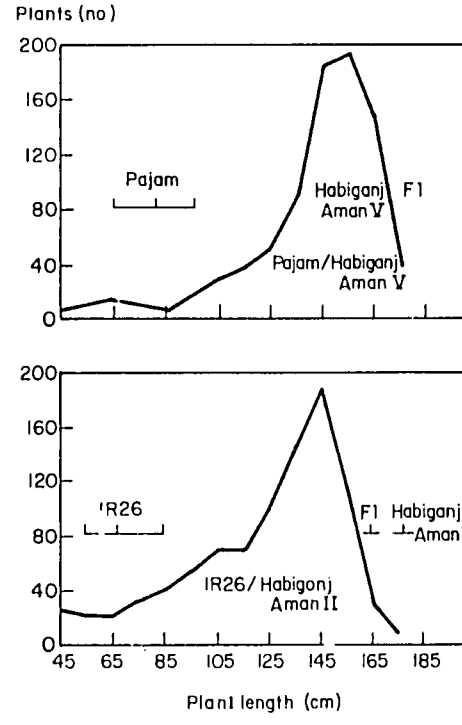
Crosses	Means		Variances		Genes (no.)	Potence ratio (hp)	Epistasis
	F_1	F_2	F_1	F_2			
				Plant length (cm)			
Habiganj Aman II 2/IR26	164	123	18	580	3.75	0.82	20.75
Habiganj Aman V/Pajam	185	142	9	900	2.37	1.42	12.75
Parents							
Pajam	82		91				
IR26	74		106				
Habiganj Aman II	173		7				
Habiganj Aman V	167		27				

The mean of F_1 populations for Habiganj Aman II/IR26 is intermediate between the two parents whereas for Habiganj Aman V/Pajam it is higher than that of the better parent, indicating partial and full dominance, respectively, in the two crosses. But the mean of F_2 populations is lower than that of the F_1 populations in both crosses, indicating inbreeding depression. Potence ratio also indicated partial dominance in Habiganj Aman II/IR26 and overdominance in Habiganj Aman V/Pajam (Table 1). The possible number of genes involved in the cross Habiganj Aman II/IR26 is more than three; it is more than two in Habiganj Aman V/Pajam. Nonallelic interaction (epistasis) was indicated in both crosses.

The distribution of plant length in F_2 population of the two crosses is shown in Figure 1. F_2 population size was 803 for Habiganj Aman V/Pajam and 906 for Habiganj Aman II/IR26. Plant length ranged from 45 to 175 cm for both crosses. The F_2 distribution of both crosses was continuous with a single peak. Hamamura and Kupkanchanakul (1979) reported similar results. But Maurya (Gograghat, India, unpubl.) reported discrete segregation in F_2 populations with complementary epistasis. F_2 populations also showed no transgressive segregation. It is evident from F_2 distribution in the two crosses that there are more intermediate and fewer true, floating types. Nasiruddin et al (1979) and Supapoj et al (1977) reported similar results. Continuous distribution in F_2 populations with a single peak indicates multigenic control of plant elongation.

Internode elongation

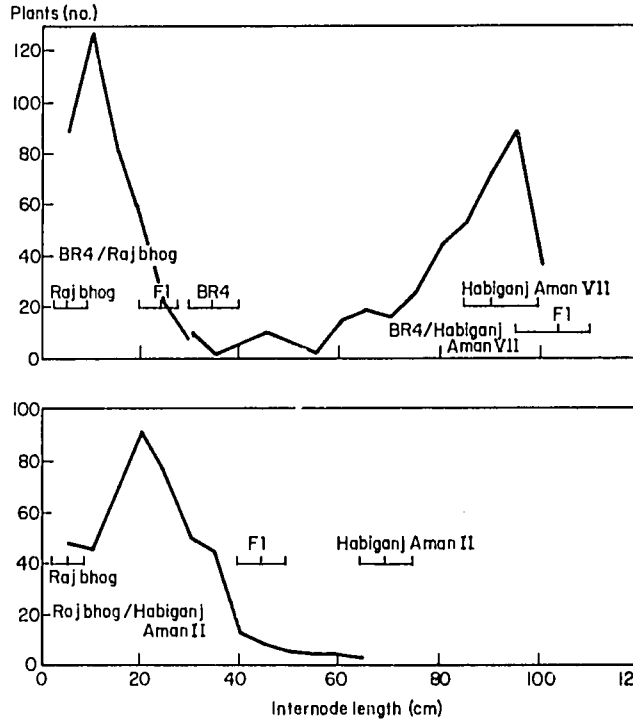
Table 2 shows means and variances of parents and F_1 and F_2 populations of the crosses



1. Distribution and means of parents, F_1, and F_2 plants for plant elongation ability in the crosses of Pajam/Habiganj Aman V and IR26/Habiganj Aman II in controlled flooding. Solid horizontal lines show ranges and means of parents and F_2 populations. BRRI, 1978.

Table 2. Analysis of means and variances of parents, F_1, F_2, dominance value, and number of genes and espistasis for internode elongation ability in rices involved in three crosses. BRRI, 1981.

Crosses	Means		Variances		Genes (no.)	Potence ratio (hp)	Epistasis
	F_1	F_2	F_1	F_2			
					Internode length (cm)		
BR4/Raybhog	26	13	8	40	2.4	0.47	9.25
Raybhog/Habiganj Aman II	48	22	14	130	3.8	0.27	21.25
BR4/Habiganj Aman VII	92	81	53	275	3.7	1.30	5.50
Parents							
BR4	35		17				
Raybhog	2		3				
Habiganj Aman II	75		16				
Habiganj Aman VII	83		19				



2. Distribution and means of parents, F_1, and F_2 plants for internode elongation ability in crosses of BR4 and Raybhog, BR4 and Habiganj Aman VII, and Raybhog and Habiganj Aman VII in controlled flooding. Solid horizontal lines show the ranges and means of parents and F_1 populations. BRRI, 1981.

in the internode elongation study. It also shows the potence values, the number of genes involved, and epistasis in controlling internode elongation ability. Genes in BR4/Raybhog and Raybhog/Habiganj Aman II are partially dominant whereas those in BR4/Habiganj Aman VII are overdominant. There are more than 2 dominant genes in BR4/Raybhog and 3 to 4 in Raybhog/Habiganj Aman II and BR4/Habiganj Aman II. The mean of populations is lower than the mean of F_1 populations in all three crosses, indicating inbreeding depression for the characters. Distribution of internode elongation in F_2 populations is shown in Figure 2. It is continuous, nonsymmetric, and is skewed with a single peak in all three crosses. F_2 distributions range from 5 to 30 cm in BR4/Raybhog, 5 to 65 cm in Raybhog/Habiganj Aman II, and 30 to 100 cm in BR4/Habiganj Aman VII. The distribution is within the limit of the parents, indicating the absence of transgressive segregation.

In all crosses nonallelic interactions are involved, indicating that more than one loci control the internode elongation ability. Both plant and internode ability seemed to be controlled by an identical genetic mechanism, even though F_2 distribution in two situations is not identical. This may be due to the F_2 population size in two studies. F_2 population size was much higher for plant elongation than for internode elongation.

To study the genetics of either plant or internode elongation ability, the parents, the F_1, and the F_2 populations might be grown together to avoid unwanted variations in these generations. With many differing segregates, discrepancies exist in F_2 populations in their ability to elongate under a particular flood rate and flood duration.

A study could be conducted with a short flood duration, say for 10 days (Nasiruddin and Siddique 1978), and the poorly elongating and nonelongating segregates measured accurately before they are decomposed in prolonged submergence.

Decomposed plants may not be recorded properly. Submerged nonfloating varieties also show some elongation ability as is exhibited by BR4 and Raybhog. BR4 showed better nodal differentiation than Raybhog, a tall variety. It suggests that BR4 is more desirable than Raybhog to cross with floating types for more desired elongating segregation in F_2 or later generations.

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DISCUSSION

HILLERISLAMBERS: When interpreting results of elongation ability we have to keep three problems in mind:

1. As you mentioned, F_2s were grown in different years from parents and F_1s, and introduced factors beyond your control.
2. Plant height segregation will show up as if it was elongation gene segregation in measurements like this, because elongation ability is a threshold character (at least in the way it is measured) and it will get more expressions in tall genotypes compared to short ones.
3. Flowering behavior, if it segregates, also affects elongation ability. Early flowering sometimes helps, but sometimes depresses, elongation scores. It boosts elongation scores considerably if the need for stem elongation coincides with the period just before floral initiation when normal prefloral elongation and water-level-induced elongation coincide.

As a result, the statistical analysis here will include plant height and flowering genes as if they were elongation genes.

NASIRUDDIN: We agree with your comments but we measured plant length 72 days after seeding. That was still the vegetative stage of the plants, not reproductive. Therefore, flowering gene(s) may not confuse or interfere with elongation gene(s) at that age.

KARIM: What percentage of elongation ability is heritable? What other factors could possibly contribute to, or trigger, internode elongation — environmental effect?

NASIRUDDIN: Elongation ability is a highly heritable character. It is controlled by a few genes. At the moment we do not know whether there is any mechanism that triggers elongation ability.

OHTA: Have you specified a particular internode or a few connecting internodes of a specific portion of the stem or have you measured plant length, which should be total culm length plus ear length?

NASIRUDDIN: Our genetic analysis is based on total culm length, excluding ear length. Plant length was measured at 120-cm water depth 72 days after seeding. At that age plants had not flowered.

INHERITANCE OF SUBMERGENCE TOLERANCE IN DEEPWATER RICE

H. K. Mohanty, B. Suprihatno, G. S. Khush,
W. R. Coffman, and B. S. Vergara

SUMMARY

Inheritance of submergence tolerance in rice was studied in two experiments, an 8 × 8 diallel population and the other P_1, P_2, F_1, F_2, B_1, and B_2 generations of seven crosses. Estimates of genetic parameters and combining ability analysis showed highly significant additive and nonadditive gene effects. The nonadditive gene action was due solely to dominance. Tolerance was completely dominant over susceptibility. There was significant gene asymmetry and the recessive alleles were slightly more frequent in the diallel population. The dominant alleles were more concentrated in the tolerant parents FR13A, Kurkaruppan, FR43B, and Goda Heenati in that order. Diallel analysis suggested involvement of at least one major gene besides polygenes.

Narrow-sense heritability of 0.71 showed the importance of additive gene effects. The cross FR13A/IR42 was the most promising and there was high possibility of isolating homozygous recombinants with higher tolerance than FR13A. Analysis of generation means corroborated diallel analysis in showing importance of both additive and nonadditive gene action. However, the latter contained a significant amount of epistasis besides dominance. Epistasis appeared to be primarily of duplicate type.

A sizable area of the world's rainfed lowlands remain under water depth ranging from 51 to 100 cm during a major part of the monsoon season. Rice workers appear to wobble between the two designations — semideep water versus deepwater — in naming these rice lands (IRRI 1979, De Datta 1981). There is, however, a general realization that the modern rice technology that evolved around the semidwarf plant type is not suitable for the rainfed lands where even the presently grown tall types suffer from water stagnation as well as periodic submergence due to monsoon flood. Flood submergence may occur at any growth stage of the rice crop and yield loss in severe cases may be 100%. The 1978 International Rice Research Conference on

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rainfed lowland rice recommended breeding of lowland rice varieties with adequate level of submergence tolerance (IRRI 1979).

Incorporation of submergence tolerance into the floating rice varieties would greatly improve their adaptation to situations where elongation might not keep up with rise in floodwater. Elongation ability and submergence tolerance are two separate plant traits and elongation is considered an avoidance mechanism (Richharia and Misro 1960, De Datta and Banerjee 1972).

Existence of varietal differences for submergence tolerance in rice has been reported by several workers (Ramiah and Rao 1953, Alim et al 1962, De Datta and Banerjee 1972). Systematic screening of rice germplasm at the International Rice Research Institute has highlighted the merits of some of the traditional flood-resistance rice varieties as donors for submergence tolerance. Among those, special mention may be made of FR13A and FR43B from India, and Kurkarrupan, Goda Heenati, and Thavalu from Sri Lanka.

At present we have no information on the mode of inheritance of submergence tolerance. This is attributed to lack of suitable screening methods for genetic study. In addition, use of field tanks for submergence tolerance is too crude because of various interfering factors such as water temperature, water depth, light intensity, etc., which are beyond the control of the researcher. The greenhouse submergence method of Vergara and Mazaredo (1975) was a significant step ahead.

Submergence inheritance studies have been carried out by biometrical techniques. We present results of two such studies.

MATERIALS AND METHODS

Experiment 1

Experiment 1 used diallel analysis to obtain information on the nature of gene action in submergence tolerance. Eight varieties (FR13A, FR43B, Kurkaruppan, Goda Heenati, Sungail, RD19, IR42, and IR34) and their 28 F_1 hybrids constituted an 8×8 half diallel set. Submergence tolerance was tested in the 1980 wet season by the greenhouse screening method of Vergara and Mazaredo (1975) with minor modifications.

Ten plants of each entry were grown in a separate clay pot (12 cm diameter, 12 cm height) filled with 700 g of Maahas clay soil containing 0.8 g of ammonium sulfate, 0.5 g of solophos, and 0.4 g of muriate of potash. Ten pregerminated seeds were sown in a circular row. The experiment was in two replications. When the seedlings were 10 days old the pots were submerged for 8 days in the greenhouse submergence tank with water 30 cm deep above the soil levels in the pots. The water temperature was kept constant at 40° and the light intensity was maintained at 400 lux at the pot level. At the end of the treatment period pots were placed outside the submergence chamber for recovery.

On the 10th day of the recovery period a survival count was made and phenotypic scoring for submergence tolerance was done on a 1-9 scale on the basis of survival percentage and growth vigor of the recovered plants. With good growth recovery, survival percentages of 0, 1-20, 21-40, 41-50, 51-60, 61-70, 71-80, 81-90, and 91-100

were scored as 9, 8, 7, 6, 5, 4, 3, 2, and 1, respectively. With poor growth recovery, the scores from 1 to 8 were increased by unity. The lower score indicated higher tolerance.

Statistical analysis. Phenotypic scores were used in statistical analysis. Variances of the replicated data were computed to have a general test of significance. Four second-degree statistics, such as V: variance of all the eight parental means (Yr); Vr: variance of offspring of the rth array, an array being constituted of a parent and all its offspring; W: covariance of the offspring of the rth array with the nonrecurring parents; and $\bar{V}r$: variance of array means, were computed directly from the diallel table (Table 1). The environmental component of variation E was derived from the error term in the analysis of variance (Table 2).

The Wr and Vr values and the standardized deviations of Yr and Wr + Vr were subjected to graphic analysis to deduct genetic relationships among the parents following Hayman (1954a) and Johnson and Aksel (1959). WR + Vr and Wr − Vr heterogeneity tests were carried out by Mather and Jinks (1971) to determine adequacy of the additive-dominance model. Analysis of variance of the diallel table was carried out following Hayman (1954b) modified by Jones (1965). The second-degree statistics Vr, Vr, Vp, Wr, and E were used in estimating genetic parameters measuring additive (D), dominance (H_1, H_2, and h_2), and both additive and dominance (F) effects. The genetic parameters, in turn, were used in estimating ratios. Combining ability effects were computed as by Griffing (1956).

Experiment 2

The main objective of experiment 2 was to understand genetic architecture in submergence tolerance by partitioning of genetic means and also by segregation analysis. The materials consisted of P_1, P_2, F_1, F_2, $B_1(F_1 \times P_1)$, and B_2 $(F_1 \times P_2)$ populations of seven different crosses involving FR13A, Kurkaruppan, Thavalu (Acc. no. 15314), Goda Heenati, IR36, and B 2433b-Kn-10-1-1-1 (henceforth written as B2433). The crosses were made during the 1979 wet season and the seedlings were grown in enamel trays following the wet season for evaluation of submergence tolerance by the method of Vergara and Mazaredo (1975). Populations of each generation were grown in a separate tray; the tolerant and susceptible parents were planted as check in every tray.

When the seedlings were 10 days old the trays were put in the submergence tank as in Experiment 1. Duration of submergence was 7 days. Scoring was on the 1-9 scale on the basis of growth recovery of individual plants on the 7th day of the recovery period. Scoring was 1 = 3 full-size, dark-green leaves; 2 = 2 full-size, dark-green leaves; 3 = 2 medium-size or 1 full-size dark-green leaves; 4 = 2 green leaves, about 1/3 the normal size; 5 = 2 green or slightly yellowish leaves, about 1/4 the normal size; 6 = new developed leaves; 7 = new developed leaves ; 7 = new leaves not completely emerged; 8 = stem green but new leaves not emerged; and 9 = completely dead (Suprihatno 1980).

Statistical analysis. Means and variances were computed for the different genetic populations. Scaling tests A, B, and C and joint scaling test were carried out as per Mather and Jinks (1971) to test adequacy of the additive-dominance model and thereby choose an appropriate model to estimate the genetic parameters.

Table 1. Diallel table showing mean phenotypic score for the parents, the F_1 and array mean ($\bar{X}$), variance ($V\bar{r}$), and covariance (Wr) in Experiment 1 for submergence tolerance, IRRI, 1980.

Parent	No.	Mean phenotypic score in parents (P) and F_1								X	Vr	Wr
		1	2	3	4	5	6	7	8			
FR13 A	1	4.0	3.0	4.0	4.0	3.0	4.0	3.5	3.5	3.63	0.196	-0.295
FR43B	2		5.0	4.0	6.0	5.0	4.0	5.5	4.0	4.56	0.960	0.585
Kurkaruppan	3			4.5	4.0	3.5	4.5	5.5	4.0	4.25	0.357	0.446
Goda Heenati	4				5.0	7.5	5.0	7.5	5.5	5.56	1.888	2.013
Sungail	5					8.0	7.5	8.5	8.0	6.38	4.839	3.545
RD19	6						8.0	3.0	7.5	6.06	3.388	3.370
IR42	7							9.0	8.5	7.00	3.786	3.250
IR34	8								7.0	6.00	4.000	3.714

$\bar{P}$ = 6.31; $\bar{F}$ = 5.30; Vp = 3.6384; $V\bar{r}$ = 1,3941;
r (parental means, array means) = 0.936

ble alysis of variance for general test of signifi- periment 1 for submergence tolerance, IRRI, 1980.

ource	DF	MS[a]
enotypes	(35)	6.94**
Parents (P)	7	7.28**
F_1	27	6.64**
P vs F_1	1	12.62**
Error	36	0.36

[a]**Significant at the 1% level.

RESULTS AND DISCUSSION

Experiment 1

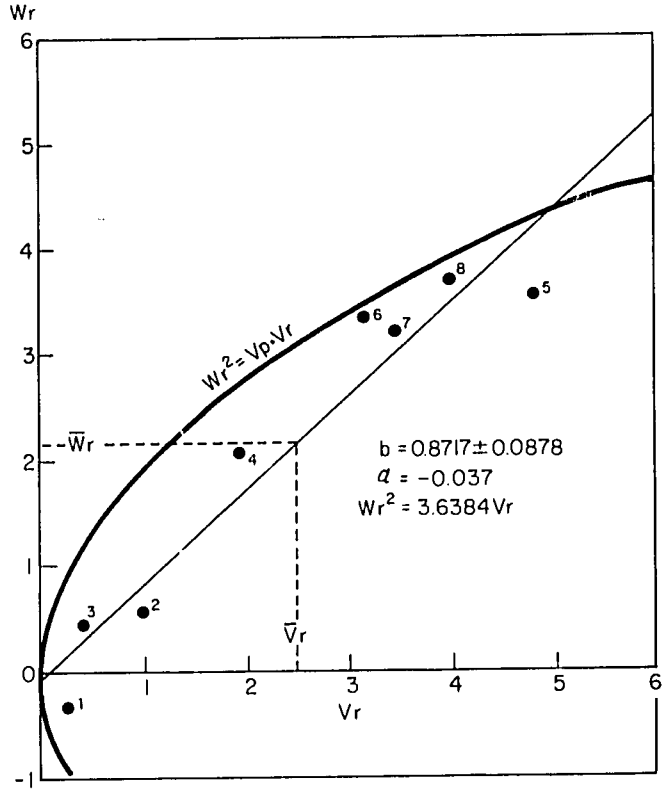
Performance of the parents and the F_1s. Analysis of variance showed highly significant differences in submergence tolerance among the parents (P), among the F_1s, and for P versus F_1 (Table 2). The rank order of the parents earlier (IRRI 1979); FR13A exhibited the highest tolerance and IR42 the least (Table 1). The overall score of the (5.30) against that of the parents (6.31) indicated dominance of tolerance. However, F_1 performance differed greatly from cross to cross depending on the level of tolerance of the parents used in the cross. The close correspondence between the parental means and their array means ($r = 0.936$) suggests high prepotency of the parents in transmitting submergence tolerance to their offspring (Table 1).

Graphic analysis of Wr, Vr: A regression graph of covariance (Wr) and variance (Vr) of the arrays provides a useful means of assessing genetic relationship among the parents. As Jinks (1954) and Hayman (1954a) have shown, in the absence of nonallelic interaction (epistasis) and with independent distribution of genes among the parents, the linear regression of Wr on Vr has a unit slope and the Wr, Vr array points would remain along the regression line Wr - a + b Vr and within an area delimited by the parabola, $Wr^2 = Vp.Vr$ where Vp is the variance of the parental means. Further magnitude and sign of the intercept cut off by the regression line shows the level of dominance. Thus, the graph prospectively provides a test for absence of epistasis that is validity of the additive-dominance model.

In this study, the regression coefficient, $b = 0.8717 + 0.0878$, differed significantly from zero but not from unity suggesting absence of epistasis (Fig. 1). The heterogeneity test for Wr + Vr and Wr - Vr values further corroborated regression analysis and reinforced validity of the additive-dominance model (Table 3). Heterogeneity of Wr + Vr values over the arrays implied presence of nonadditive gene action whereas homogeneity of Wr - Vr indicated that the nonadditive gene action could be ascribed solely to dominance effects of genes, which were independently distributed among the parental lines.

Thus, with the validity of the simple additive-dominance model the following conclusions could be drawn from the Wr, Vr regression graph.

1. The regression line intercepted the Wr axis just below the origin suggesting that



1. Covariance (Wr), variance (Vr). A regression graph for submergence tolerance in Experiment 1. IRRI, 1980.

the average dominance was slightly within the range of overdominance.

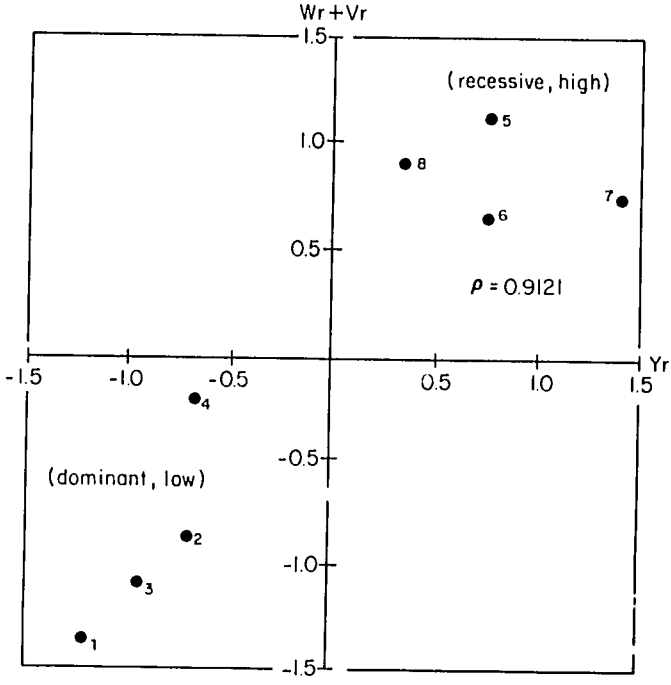
2. The position of the array points on the regression graph showed that there was concentration of dominant alleles in the three tolerant parents — FR13A, Kurkaruppan, and FR43B. On the other hand, Sungail, IR34, IR42, and RD19 showed higher concentration of recessive alleles. The somewhat intermediate position of Goda Heenati suggests that it has dominant and recessive alleles in more or less equal proportions.
3. The striking discontinuity in the positions of the array points suggest possible involvement of one or more genes in submergence tolerance.

Graphical presentation of the standardized deviations of Yr (parental means) and of

Table 3. Heterogeneity test for Wr + Vr and Wr - Vr estimates[a] in Experiment 1 for submergence tolerance, IRRI, 1980.

Due to	DF	MS[b]
(Wr + Vr) array differences	7	24.10**
(Wr + Vr) block differences	8	0.88
(Wr - Vr) array differences	7	0.61
(Wr - Vr) block differences	8	9.32

[a]Wr = covariance; Vr = variance. [b]**Significant at the 1% level.



2. Standardized deviation graph of Yr and Wr + Vr in Experiment 1 for submergence tolerance. IRRI, 1980.

Wr + Vr showed dominance order of the parents as 1 3 2 4 6 7 8 5 (Fig. 2). The high positive correlation between Yr and Wr + Vr (r = 0.912) indicated dominance of tolerance and the expected value of the completely dominant parent was computed as 2.68.

Analysis of variance of the diallel table. Both additive (a-item) and nonadditive (b-item) gene effects were highly significant (Table 4); in breeding, parlance a and b items are Griffing's (1956) general combining ability (gca) and specific combining ability (sca) effects, respectively. Partitioning of b effects showed significant:

- unidirectional dominance (b_1) i.e. overall deviation of the F_1s from the midparent,

Table 4. Analysis of variance of the diallel table in Experiment 1 for submergence tolerance, IRRI, 1980.

Due to	DF	MS[a]
a (gca)	7	24.76**
b (sca)	(28)	2.49**
b_1 (unidirectional dominance)	1	12.66*
b_2 (gene asymmetry)	7	1.61**
b_3 (residual)	20	2.29**
Error	36	0.36

[a] **Significant at the 1% level.

- gene asymmetry (b_2) i.e. some parents contained more dominant alleles than others, and
- residual (b_3) showing that only certain F_1 hybrids differed significantly from the midparents.

Thus, the results of analysis of variance are in conformity with the conclusions from the means as well as the Wr, Vr graph.

Genetic parameters. The second-degree genetic parameters — D estimating additive component; H_1, H_2, and h_2 showing dominance effects; and F indicating additive, dominance, and gene asymmetry — were highly significant (Table 5). The four ratio estimates computed from the above parameters supplied the following information, which are in general agreement with conclusions from the Wr, Vr graph and the analysis of variance:

- $(H_1/D)^{1/2}$ measuring average dominance was slightly in the overdominance range (1.1451).
- The estimate of 0.2077 for $H_2/4H_1$, whose maximum possible value of 0.25 is expected under equal frequencies of positive and negative alleles, showed existence of some degree of gene asymmetry and this was in favor of recessive alleles as evidenced by the negative sign of F.
- The ratio of h_2/H_2 close to unity suggests involvement of at least one major gene or group of genes having dominance.
- High narrow-sense heritability value (0.7114) showed the importance of additive gene action in submergence tolerance.

Combining ability effects. As mentioned earlier both gca (a-item) and sca (b-item) were highly significant (Table 4). FR13A, Kurkaruppan, and FR43B showed signifi-

Table 5. Genetic parameters and ratio estimates in Experiment I for submergence tolerance, IRRI, 1980.

Genetic parameter	Estimate
D (additive)	3.4578 ± 0.3431
H_1 (dominance)	4.5338 ± 0.8144
H_2 (dominance)	3.7664 ± 0.7923
h^2 (dominance)	3.0384 ± 0.6893
F (additive, dominance and gene asymmetry)	-1.3061 ± 0.4623
E (environment)	0.1806 ± 0.1149
$(H_1/D)^{1/2}$ (average dominance)	1.1451
$(H_2/4H_1)$ gene asymmetry)	0.2077
h^2/H_2 (number of gene blocks)	0.8067≅ 1
$\frac{1/2D + 1/2H_1 - 1/2H_2 - 1/2F}{1/2D + 1/2H_1 - 1/4H_2 - 1/2F + E}$	(heritability in narrow sense) 0.7114

Table 6. The gca (diagonal) and sca (off-diagonal) effects for submergence tolerance in IRRI, 1980.

Parents	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
FR13A	-1.68	-0.03	1.27	0.17	-1.78	-0.53	-1.88	-0.88
FR43B		-0.82	0.42	1.32	-0.63	-1.38	-0.73	-1.23
Kurkaruppan			-1.12	-0.38	-1.83	-0.58	-0.43	-0.93
Goda Heenati				-0.02	1.07	-1.18	0.47	-0.53
Sungail					0.92	0.37	0.52	1.02
RD19						0.68	0.27	0.77
IR42							1.52	0.92
IR34								0.52

SE (gi) = 0.1275; SE (gi-gj) = 0.1927; SE (Siji) = 0.3399; SE (Sij-Sik) = 0.5782; SE (Sij-Skl) = 0.5451

cant favorable (lower score) gca effects. There was strong correspondence between the gca effects and the parental means ($r = 0.985$). The sca effects varied greatly from cross to cross and in most of the crosses the effects were marginal. As expected, hybrids involving tolerant and susceptible parents exhibited more favorable sca effects (Table 6). Among the crosses FR13A/IR42 followed by the two hybrids of Sungail with FR13A as well as Kurkaruppan showed the most favorable sca effects.

Experiment 2

Overall performance of the parents and the hybrids. In five out of the seven crosses mean submergence scores of the F_1s were less than their respective midparent values and three of them had scores close to their respective tolerant parents, thus suggesting dominance for tolerance. The two deviating crosses were Thavalu/B2433 and Goda Heenati/B2433 (Table 7). The general low mean score and low variance in B_1 compared to B_2 further attested dominance of tolerance; the two deviating crosses were Kurkaruppan/B2433 and Goda Heenati/B2433.

Scaling test and selection of genetic model. The appropriate model was selected on the basis of the four scaling tests, which showed the significance, or otherwise, of the deviations between the observed generation means and the expected means as per the additive-dominance model. If the model is adequate the quantities A, B, and C will each be equal to zero within the limit of sampling error and the chi square value for the joint scaling test will be insignificant. Inadequacy of the additive-dominance model was clear from the highly significant level of chi square in all the 7 crosses and A in 6, B in 5, and C in 3 (Table 8). The digenic or six-parameter epistatic model of Hayman (1958) was used to partition generation means with different genetic effects.

Estimates of genetic parameters. The genetic parameters d (additive), h (dominance), the three epistatic components i (additive × additive), j (additive × dominance), and l (dominance × dominance) are shown in Table 9.

Additive genetic (d) effects were significant in all the 7 crosses followed by the l in 6, h in 5, i in 4, and j in 3 crosses. In six out of the seven crosses h and l showed opposite

Table 7. Generation means (X), midparent value (MP), and variances (S^2) in Experiment 2 for submergence tolerance, IRRI, 1980.[a]

Cross	P_1		P_2		MP	F_1		F_2		B_1		B_2	
	$\bar{X}$	S^2	$\bar{X}$	S^2		$\bar{X}$	S^2	$\bar{X}$	S^2	$\bar{X}$	S^2	$\bar{X}$	S^2
FR13A/IR36	2.16 (104)	1.74	7.70 (110)	2.37	4.93	3.57 (99)	2.98	4.87 (103)	3.61	3.66 (110)	2.24	6.48 (115)	3.03
FR13A/B2433	2.72 (86)	1.33	4.95 (116)	3.10	3.84	2.95 (118)	1.55	3.25 (118)	4.63	3.47 (109)	1.72	4.37 (115)	2.42
Kurkarrupan/IR36	2.83 (84)	2.97	5.92 (117)	4.36	4.38	2.89 (110)	2.02	3.01 (120)	3.29	3.18 (107)	1.56	5.02 (113)	3.74
Kurkarrupan/B2433	3.58 (80)	3.19	5.67 (109)	2.95	4.63	3.41 (118)	1.45	4.48 (106)	6.66	4.26 (106)	2.22	4.40 (110)	2.13
Thavalu/IR36	3.17 (119)	1.77	6.57 (118)	3.74	4.87	4.76 (85)	1.98	3.56 (120)	4.31	4.88 (112)	2.79	5.70 (113)	3.41
Thavalu/B2433	2.96 (113)	0.97	4.58 (117)	2.52	3.77	3.68 (109)	1.93	3.42 (115)	3.41	3.78 (115)	2.27	5.86 (111)	3.45
Goda Heenati/B2433	3.54 (120)	3.49	5.48 (110)	4.11	4.51	5.01 (115)	4.27	5.14 (119)	6.09	5.04 (114)	3.99	6.12 (118)	2.92

[a]Figures in parentheses are sample sizes.

Table 8. Scaling tests for adequacy[a] of the additive-dominance model in Experiment 2, IRRI, 1980.

Cross	Deviation from expectation with SE in scaling tests			Chi square in joint scaling test (for B_1, B_2, and F_2)
	A (for B_1)	B (for B_2)	C (for F_2)	
FR13A/IR36	1.59 ± 0.358**	1.69 ± 0.396**	2.48 ± 0.848**	32.70**
FR13A/B2433	1.27 ± 0.303**	0.84 ± 0.352*	0.57 ± 0.851	23.95**
Kurkaruppan/IR36	0.62 ± 0.335	1.23 ± 0.433**	2.49 ± 0.765**	31.25**
Kurkaruppan/B2433	1.53 ± 0.368**	0.28 ± 0.341	1.85 ± 1.059	20.29**
Thavalu/IR36	1.83 ± 0.371**	0.07 ± 0.419	5.02 ± 0.845**	74.70**
Thavalu/B2433	0.92 ± 0.322**	3.46 ± 0.406**	1.22 ± 0.759	88.44**
Goda/Heenati/B2433	1.53 ± 0.454**	1.76 ± 0.417**	1.52 ± 1.017	24.36**

[a]**Significant at the 1% level.

Table 9. Estimates of genetic parameters in Experiment 2 for submergence tolerance. IRRI, 1980.

Cross	Genetic parameters[a]		
	m	d	h
FR13A/IR36	4.87 ± 0.03**	-2.82 ± 0.22**	0.56 ± 0.89
FR13A/B2433	3.25 ± 0.04**	-0.90 ± 0.19**	1.79 ± 0.80*
Kurkaruppan/IR36	3.01 ± 0.03**	-1.84 ± 0.22**	2.87 ± 0.82**
Kurkaruppan/B2433	4.48 ± 0.06**	-0.44 ± 0.20*	-1.81 ± 1.09
Thavalu/IR36	3.56 ± 0.04**	-0.82 ± 0.23**	6.81 ± 0.91**
Thavalu/B2433	3.42 ± 0.03**	-2.08 ± 0.22**	5.51 ± 0.84**
Goda Heenati/B2433	5.14 ± 0.05**	-1.08 ± 0.24**	2.76 ± 0.84**
	i	j	l
FR13A/IR36	0.80 ± 0.86	-0.05 ± 0.23	-4.08 ± 1.21**
FR13A/B2433	2.68 ± 0.88**	0.22 ± 0.22	-4.79 ± 1.14**
Kurkaruppan/IR36	4.37 ± 0.79**	-0.30 ± 0.25	-6.23 ± 1.16**
Kurkaruppan/B2433	-0.60 ± 1.07	0.91 ± 0.23**	-0.65 ± 1.32
Thavalu/IR36	6.92 ± 0.89**	0.88 ± 0.25**	-8.82 ± 1.26**
Thavalu/B2433	5.60 ± 0.82**	-1.27 ± 0.24**	-9.98 ± 1.17**
Goda Heenati/B2433	1.76 ± 1.03	-0.11 ± 0.27	-5.04 ± 1.37**

[a]*, ** significant at the 5 and 1% levels, respectively.

signs thus suggesting that epistasis interactions were predominantly of a duplicate type (Mather and Jinks 1971). The diallel analysis and the analysis of generation means were in close agreement in showing that submergence tolerance was, without exception, conditioned by genes having additive effects. The observed discrepancy between the two studies was primarily with regard to the low dominance level as well as presence of epistasis detected in the latter analysis. This could be attributed to the new genetic situation in the segregating populations B_1, B_2, and F_2 arising out of reshuffling of genes. Similar results were reported by Jinks (1954, 1956) who recorded no epistasis in F_1 diallel analysis for flowering time in *Nicotiana rustica* while the F_2 and backcross generations revealed significant duplicate gene interaction. The insensitivity of the F_1 Wr, Vr graph to ascertain interactions were also reported by Ganashan and Whittington (1976). Thus, the observed low level of dominance could be due to separation of the part attributed to epistasis of l and to a lesser degree j types (Jinks 1955).

BREEDING IMPLICATIONS

In a self-fertilizing crop like rice, most breeding projects aim at developing a superior homozygous genotype. The occurrence of significant additive and additive × additive types of genetic variation and the moderately high narrow-sense heritability indicate the possibility of recovering homozygous recombinants with adequate level of tolerance for submergence in the current breeding projects. The general high prepotency

of the parents in transmitting the trait further strengthens this possibility.

The theoretical estimate of a submergence score of 2.68 for the completely dominant parent, against an actual score of 4.00 in the top dominant parent FR13A, shows promise of isolating recombinants superior to the best available tolerant parent.

Among the tolerant parents, FR13A and Kurkaruppan appear to be the best in that order. Among the hybrids, FR13A/IR42, which shows favorable heterotic effect (lowest sca effect), appears to be most promising. Success in isolating superior homozygous types from highly heterotic hybrids has been reported by several workers (Smith 1952, Williams 1959, Mohanty and Mohapatra 1973).

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DISCUSSION

JENNINGS: Are we reasonably certain that genes that control tolerance for submergence are distinct of genes that control elongation (floating) habit?

SESHU: (read paper for author). Yes, because elongation is a sort of escape mechanism, and also because we have parents with distinct habits — some are good for submergence and not for elongation, some have elongation and not submergence.

PETPISIT: How large is the genetic variability in this trait?

DURVASULA: A number of varieties were screened and there is a wide source of availability for submergence tolerance. In fact, screening-trial reports this morning show that several are good.

PETPISIT: Do you plan to use *O. glaberrima* in submergence? Do you think it has the same gene or same source of genetic material for submergence tolerance?

DURVASULA: I do not know of anyone working on the genetics of submergence tolerance in *O. glaberrima*.

JACKSON: Do you think a similar genetic interpretation would have been made had the material been subjected to 120 cm of muddy water in a deep pond for 10 days rather than the laboratory?

DURVASULA: The results relate to submergence of 10-day-old seedlings in 30-cm water depth for 8 days. Duration of submergence and growth stage of crop during submergence are important factors, irrespective of whether the test is in the greenhouse or in the field. Greenhouse and field studies have some disadvantages. For example, for genetic studies the conditions should be uniform for all plants in F_2 and other segregating generations, which is difficult to accomplish in the field.

HILLERISLAMBERS: I can give you an answer. I have done screening for submergence tolerance with the conditions you just mentioned and I can accept the conclusions of this study. F_2 populations that I observed gave segregation ratios compatible with a one-gene dominant expression of submergence tolerance.

TILLERING BEHAVIOR AND INTERNODE ELONGATION IN DEEPWATER RICE IN BANGLADESH AND THAILAND

Yasuo Ohta

SUMMARY

Intact plants of 10 floating or deepwater rice varieties were collected in direct-broadcasted farmers' fields or at experiment stations. Each plant was examined for node, internode length, and tillering to establish profiles of tillering and internode elongation. The characteristics of floating or deepwater rice varieties are summarized:

1. The main culm is not always the tallest; tillers can often be the tallest, especially in some varieties.
2. Tillers with more nodes than the main culm are common — the rate of such individuals reached 50% in 3 varieties. In nonfloating rice, this is rare.
3. Tertiary tillers appeared often in three varieties. Even a quaternary tiller was observed, something not expected in nonfloating rice.
4. The tillering ability is kept continuously from node 3 to node 25. It is impossible to fix a node number that distinguishes basal tillers from aquatic tillers.

The development of the rice plant, especially the tillering system of nonfloating rice, has been studied extensively. The theory of simultaneous development of leaves and tillers has been established (Katayama 1951) and is generally accepted. However, there has been little study of the development of floating rice. Because floating rice can produce tillers from higher nodes and at later stages of growth than nonfloating rice, its development may differ from that of nonfloating rice.

This paper deals with anatomical studies of several floating or deepwater rice varieties grown in Bangladesh and Thailand.

MATERIALS AND METHODS

Rice plants at the stages of heading to near maturity were removed with roots and soil. To ensure that intact stem bases were obtained, several plants close to each other were

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removed together.

About 25 plants/variety were collected at each site to ensure 10 intact complete individuals. I call this random sampling because nobody knew at digging how many of which individuals would be collected — some had several tillers and some had only the main culm.

Obtaining a complete sample was difficult for several reasons:

- The whole plant had to be dug from the paddy so that the base of the primary root could be clearly identified by tracing the basal portion of the main culm.
- Some of the stems, both main culm and tillers, had often been cut by crabs, rats, or other pests.
- Some tillers had started to decompose and were easily separated from the tillering node when taken out of water. Whenever this separation was confirmed, the plant was taken as a sample, but the tiller was designated as trace of tillering (*t*).

Thus, sample size became unavoidably small for each variety at some sites.

Local variety names were given by the farmers. Variety name, sampling date and site, water depth at sampling and at its deepest, and final number of individuals analyzed are listed in Table 1. Hama (Khama) had awned and awnless individuals. The awnless Hama looks like Khama. Maximum water depth of the site for that season was estimated from traces of the highest water level clearly remaining or from information from the farmers.

The anatomical observation and recording of tillering system, as well as measurement of every node position, were done on the spot, or 1 or 2 days later in Dacca or Bangkok. The stem base of every individual was opened with a sharp knife, and a magnifying glass was used to identify the tillering scheme. An example is shown in Figure 1. The nodes were counted and the distance of each node from the stem tip (the coleoptile node) was measured.

RESULTS AND DISCUSSION

Schematic drawings of stems — main culm, primary to quaternary tillers, and number and position of nodes — were made for each individual. One drawing was according to the relative length of internodes, another according to the node number (order).

A schematic presentation of a *standard* rice plant is given in Figure 2, and a few examples of this study are given in Figures 3-5. The variation in tillering of Sonadigha is seen in Figure 6.

The lowest node is designated C, because it is one from which the coleoptile develops at germination; below it the primary or first root emerges at germination of the seed. The first leaf develops from the next node (no. 1), but the leaf blade usually is never formed. Node 2 is the one from which the first complete leaf with leaf blade comes and the first tiller appears in the case of direct-seeded nonfloating rice. Node 2, therefore, is the lowest possible position to produce a tiller. No case of such tillering was observed in this study of direct-seeded floating rice.

In all figures, tillers from odd number nodes are drawn to the left, and tillers from even number nodes to the right. Any tiller that developed from the main culm is called a primary tiller. Any tiller from a primary tiller is a secondary tiller.

Table 1. List of varieties, their sampling site, and water depth at sampling and at the highest 1979 water level.

Variety	Sampling site	Sampling date	Water depth (m)	Estimated maximum water depth (m)	Plants analyzed (no.)
Lakshmidigha	Kalkini, Faridpur, Bangladesh	11 Oct	0.3	0.7	6
Manikdigha	Madsudpur, Faridpur, "	11 Oct	0.7	1.1	10
Lakhidigha	" , "	11 Oct	0.7	1.1	10
Sonadigha	Talma, Nagarkanda, Faridpur, Bangladesh	12 Oct	0.5	1.4	10
Kartiksail	Khadgoir, Debidwar, Comilla, Bangladesh	17 Oct	0.4	1.3	10
Habiganj Aman VIII	BRRI Habiganj Substation	16 Oct	1.3	2.6	10
Khama	Gopalnagar, Debidwar, Comilla, Bangladesh	17 Oct	1.0	2.3	10
Hama (Khama)	Dhorichondibar, Bhairab, Mymensingh, Bangladesh	23 Oct	0.8	2.4	5
Leb Mue Nahng 111	Rice Division Huntra Station, Thailand	16 Nov	1.0	1.0	6
Sai Bua	Maharaj, Maharaj, Ayudhaya, Thailand	17 Nov	2.5	2.6	10

1. The stem base of a rice plant opened with a sharp knife to identify the tillering scheme.

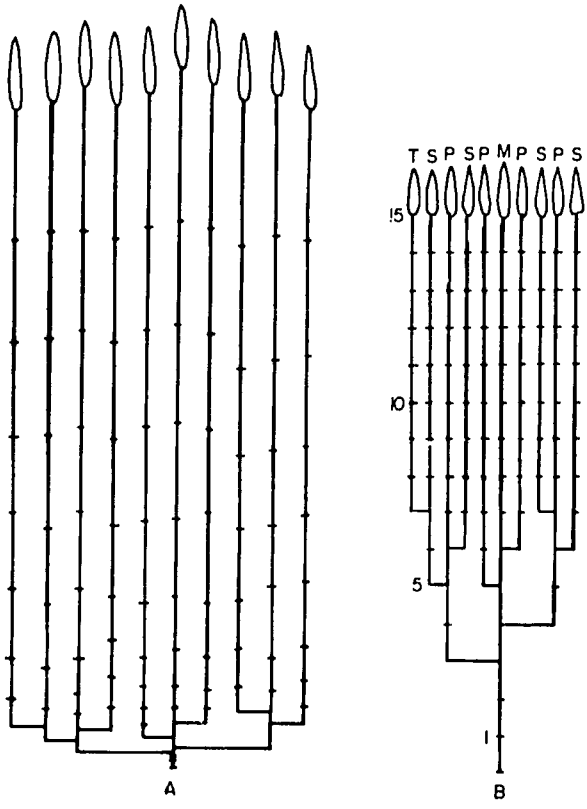
Culm length

Mean lengths of the main culm and of the tallest culm of each variety are presented in Table 2. In all varieties, the tallest culm exceeded the main culm; that is, the tallest culm is usually not a main culm but a tiller. The rate of individuals with tillers taller than the main culm was calculated (Table 2). It was 50% or more for 6 varieties. It can be said, therefore, that one of the characteristics of floating rice is the dominance of tillers over the main culm.

Number of nodes

The mean number of nodes on the main culm is also given in Table 2. Again, in all varieties, the most nodes appeared on tillers not on the main culm. This phenomenon — tillers having more nodes, thus more leaves, than the main culm — is rather common in floating rice varieties, but identified as rare in nonfloating rice. This can be said, therefore, to be an outstanding feature of floating rice.

The *theory* of simultaneous development of leaves and tillers states that the number of leaves on tillers decreases by one as the tillering node number increases by one. Therefore, all flag leaves of the main culm and of all tillers should develop simultaneously (Katayama 1951). Therefore, the node number of tillers should be equal to



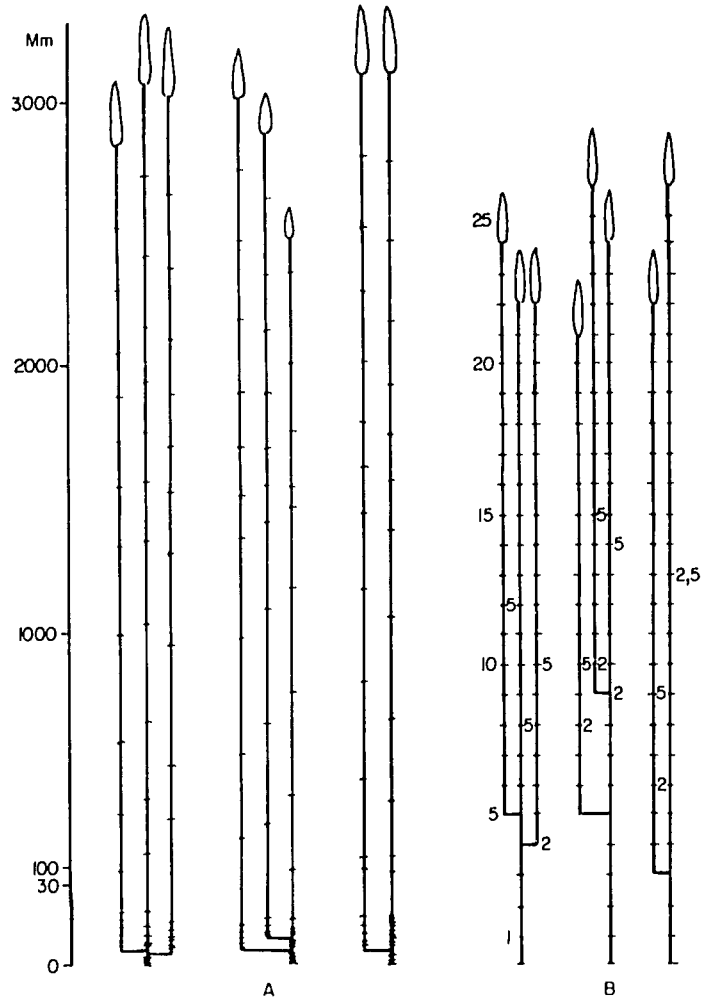
2. Schematic presentation of tillering and internode elongation for a *standard* rice plant. A: with proportional internode lengths, showing plant shape more closely to natural shape, B: with a fixed internode length indicating node number clearly.

that of the main culm (Fig. 2). Actually there is a decrease in the node number of flag leaves, usually ± 1. An exception has been known where the node number exceeds by one or rarely two the theoretical one in tertiary tillers from the higher nodes. All of the above is based on studies of nonfloating rice, wheat, and barley.

The present study reveals that such aberration is rather common in floating rice as the number of nodes on the tillers, especially primary tillers, exceeds that of the main culm by two (Table 3, Figs. 3-5). In Lakhidigha, Kartiksail, and Leb Mue Nahng 111, the percentage of individuals with a tiller or tillers with more nodes reached 50%.

The growth habit of floating rice must be somewhat different from that of the nonfloating rice because of its prolonged duration of vegetative growth, its high number of nodes, and its special ability to produce tillers from higher nodes at later stages of growth.

The tallest culm of an individual plant was classified as the main culm, primary tiller, or secondary tiller (Table 4). It then appeared that some of the tallest culms are basal tillers and some others are so-called *aquatic* tillers. In Kartiksail and Habiganj Aman VIII, some of the secondary tillers were the tallest, which would not be expected in nonfloating rice.

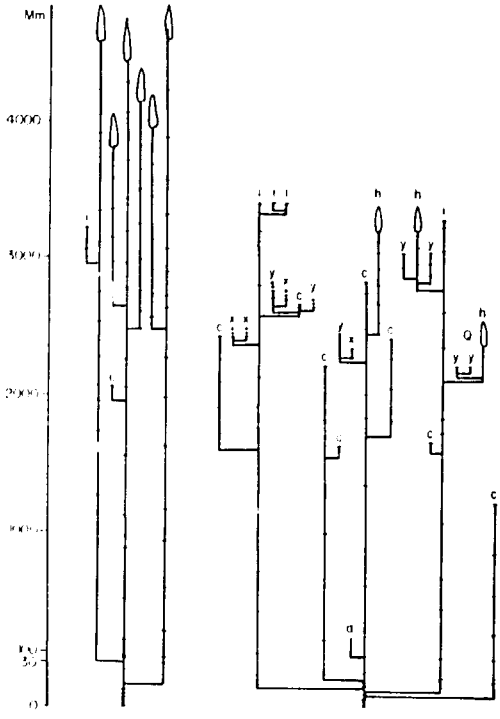


3. Profiles of three individuals of Lakhidigha. A and B are same as Fig. 2 except that the portion up to 30 mm from the base is enlarged 10 times so that individual nodes can be identified. 2 or 5 at the right of a node in B indicates the node to which the internode length is less than 2 or 5 mm, respectively.

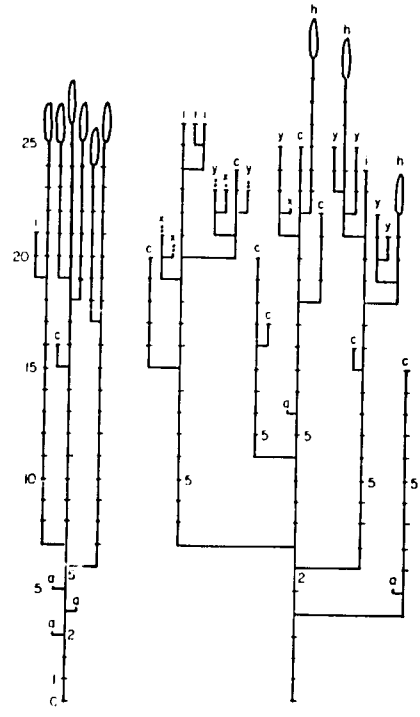
Tillering

The number of tillers per individual plant and a breakdown into primary to quaternary tillers are given in Table 3. Although the number of tillers can be widely varied by stand density, plant nutrition, and other environmental factors, the Bangladesh varieties generally indicated that earlier varieties produce fewer tillers whereas later varieties produce more tillers.

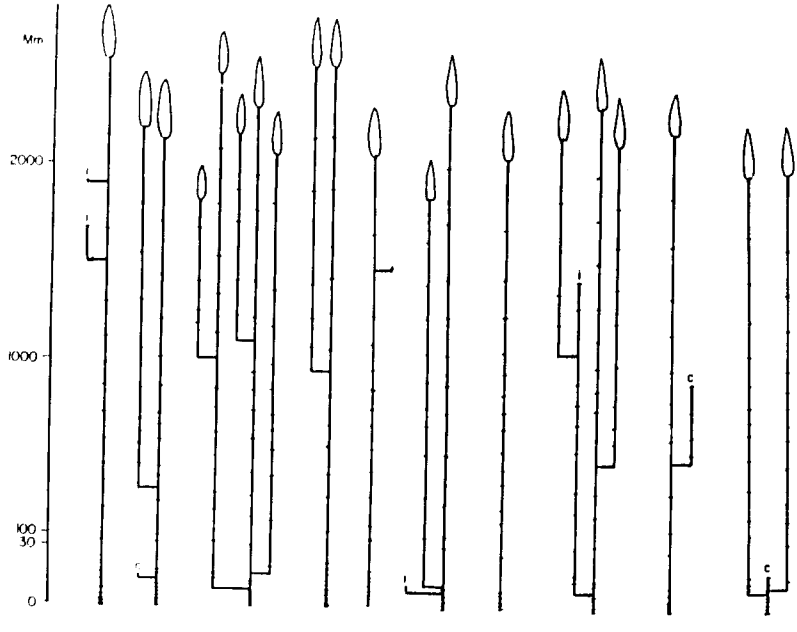
It must be mentioned that in the variety Hama a quaternary tiller was observed (Figs. 4-5), which hardly happens in nonfloating rice. This individual (right side of Figs. 4 and 5) is a good example of severe damage by crabs, rats, insects and other



4. Profile with proportional internode lengths of two individuals of Hama (Khama). a: arrested; c: cut off by crabs or rats, or broken; h: at heading; i: damaged by insects; Q: quaternary tiller; x: panicle not yet emerged; and y: young panicle.



5. Profile with a fixed internode length of two individuals of Hama (Khama). a: arrested; c: cut off by crabs or rats, or broken; h: at heading; i: damaged by insects; x: panicle not yet emerged; and y: young panicle.



6. Ten individuals of Sonadigha with proportional internode lengths demonstrating variation in tillering. c: cut off by crabs or rats, or broken; i: damaged by insects.

Table 2. Culm length and number of nodes.

Variety	Mean culm length		Rate of individuals with tillers taller than the main culm (%)	Mean no. of nodes on main culm	Highest number of nodes on any culm	Rates of individuals with tillers with more nodes than the main culm (%)
	Main culm (mm)	Tallest culm (mm)				
Lakshmidigha	1883	1890	17	19.7	21	0
Manikdigha	2888	2911	33	22.2	27	0
Lakhidigha	3076	3136	33	23.3	26	50
Sonadigha	2271	2297	60	22.2	27	0
Kartiksail	2143	2251	60	22.9	27	50
Habiganj Aman VIII	3199	3468	72	>25.7[a]	>29[a]	25
Khama	3887	3963	50	26.0	31	17
Hama (Khama)	4231	4313	67	26.0	29	33
Leb Mue Nahng 111	1717	1850	33	>15.7[b]	>22[b]	50
Sai Bua	3316	3334	50	23.7	26	0

[a]Not headed. [b]The coleoptile node could not be identified because trial was transplanted.

Table 3. Number of tillers per individual plant[a] according to tillering system.

Variety	Primary tillers (no.)	Secondary tillers (no.)	Tertiary tillers (no.)	Quaternary tillers (no.)	Total
Lakshmidigha	0-3 (1.71)	0-4 (1.57)	0	0	0-6 (3.28)
Manikdigha	0-2 (0.40)	0	0	0	0-2 (0.40)
Lakhidigha	0-2 (0.80)	0	0	0	0-2 (0.80)
Sonadigha	0-3 (1.60)	0-1 (0.20)	0	0	0-4 (1.80)
Kartiksail	1-5 (3.00)	0-6 (1.70)	0-2 (0.40)	0	1-12(5.10)
Habiganj Aman VIII	1-9 (3.80)	0-4 (0.90)	0	0	1-11(4.70)
Khama	0-3 (1.80)	0-4 (0.60)	0-1 (0.10)	0	0-8 (2.50)
Hama (Khama)	1-7 (4.00)	0-9 (2.60)	0-7 (1,60)	0-2 (0 40)	1-25(8.60)
Leb Mue Nahng 111	2-5 (3.17)	0-4 (1.50)	0	0	2-9 (4.67)
Sai Bua	0-4 (0.90)	0-4 (0.40)	0	0	0-8 (1.30)

[a] Numbers in parentheses are averages/plant.

Table 4. Frequency in percentage of culm with highest number of nodes and tallest culm among the main culm (M), primary (I), or secondary (II) tillers.[a]

Variety	Maximum no. of nodes		Tallest culm			
	M	I	M	I	II	I + II
Lakshmidigha	100	0	83	17		17
Manikdigha	100	0	67	33		33
Lakhidigha	50	50	67	33		33
Sonadigha	100	0	40	60 (40)		60
Kartiksail	50	50	30	60 (20)	10	70
Habiganj Aman VIII	75	25	28	58 (44)	14(14)	72
Khama	83	17	50	50 (17)		50
Hama (Khama)	67	33	33	[illegible]		67
Leb Mue Nahng 111	50	50	67	33		33
Sai Bua	100	0	50	50		50

[a] In certain cases, where main culm and primary tiller were equivalent, they were counted as tillers. Figures in parentheses indicate those of *aquatic* tillers.

Table 5. Tillering scheme given in an index[a] according to the node number and to the tillering system.

Variety[b]		Node no. 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Lakshmidigha	I		2	22	32	2					2	2												
	II						2		7	3	2			2										
Manikdigha	I						11	11																
	II																							
Lakshmidigha	I	2	2	12				1																
	II																							
Sonadigha	I			21	1	21			2		1	1						3	1	1				
	II													1		1								
Kartiksail	I	1	5	13	1	31	1	2	4	1	2	1	1		1	2								
	II			1	11	1					2		2	4	2	1	1	1	1					
Habiganj Aman VIII	I	1	12	21	2	1		2	2		3	5	4	2	3	2	1	1	1			1		
	II				1				1	1	1	1		3		1								
Khama	I		3	31	11		12	1		1	1					1			2					
	II				1										1	1	1	1			2			
Hama (Khama)	I		2	22	22	22	2			2		2		2	2		4	4	4	2	2			
	II													4	4	4	4	6	6	4	8	2	2	2
Leb Mue Nahng 111	I		3	55	2	2	3	2	8	5														
	II				2			3	7	2	2													
Sai Bua	I		11	1	1					3	2													
	II								1	1	1					1								

[a] The index, ten times the real number of tillers per individual plant, in an underlined figure means tillering from nodes with internodes less than 2 mm long; in italic from nodes with internodes 2-5 mm long, and in Roman from nodes with internodes more than 5 mm long. [b] I means primary tillers and II the sum of the secondary to the quaternary tillers.

pests. Tillering, at least partially at later stages of growth, is compensation for earlier tillers destroyed.

Tillering was scored according to node number. Table 5 shows the results given in an index that is 10 times the real number of tillers per individual plant. The use of I after the variety names designates primary tillers from the main culm and II the sum

of the secondary to the quaternary tillers. Figures underlined indicate tillering from nodes, regardless of whether on main culm or tillers, with internodes less than 2 mm long. Those in italics indicate tillering from nodes with internodes 2-5 mm long. Roughly speaking, tillers given in italics or underlined are the basal tillers, and other tillers are the aquatic tillers. A 5 mm length is arbitrarily taken, but some reports define the first elongated internode as more than 5 mm (Suetsugu 1968, Inouye and Hagiwara 1981).

Table 5 shows that there is no clear-cut separation of aquatic tillering and basal tillering. Tillering can actually take place at any node continuously from the base of the main culm. Several instances can be seen in Table 5 in which a particular node produces both basal and aquatic tillers. A good example is Kartiksail.

It can be said, nevertheless, that one of the characteristics of floating rice is that it keeps its tillering ability continuously up to the higher nodes whose internodes are elongated to some 40-50 cm.

No particular indication of the relation between tillering and internode elongation could be drawn. The question on the causal agent or agents that decide whether a node will produce a tiller or not remains unanswered.

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DISCUSSION

ESCURO: Which of these tillers flower at the same time and give productive panicles?

OHTA: All tillers at a same node number should flowrer simultaneously, and those at a higher node number later. There must be a time limit to produce productive panicles. Tillering too late, probably compensating for those damaged earlier, will produce nonproductive panicles.

VARIETAL EVALUATION

DEEPWATER RICE YIELD IN BIHAR, INDIA

R. Thakur

SUMMARY

Of 6 million ha of rice grown in areas subjected to excess water in India, about 2 million ha are in Bihar. Lowland in Bihar is classified into two broad groups — medium flooded lowland where water depth remains below 50 cm and deep flooded lowland where water depth may exceed 50 cm. Similarly, deepwater areas are of two types — medium-deep, where water depth reaches 2.5 m, and typical deep, with water depths to 4 m.

One hundred test entries from different sources were subjected to flash floods after transplanting and differences were found in quick establishment of seedlings. Deepwater entries, namely 64-117, 62 68, 62-31, RAU21-168-1-2, and CNL 108 were identified to have good degree of submergence tolerance and yield potential.

Yield performance of varieties and lines were assessed in deep and medium-deep lowland flooding. Aquatic tillers contributed 34-88% of the final grain yield in the deepwater varieties.

In India, about 6 million ha of rice land suffer from excess water during the monsoonal (*kharif*) season. Of these, 2.3 million ha are planted to deepwater rices. Waterlogging is most acute in the northeastern Indian states of West Bengal, Bihar, and Orissa. Of 15 million ha of rice land in those states, at least 4 million ha are in stagnant and deepwater areas with water in the field until December.

In Bihar, about 2.0 million ha of winter (*aman*) rice is grown in ill-drained lowland and deepwater areas. Water depth varies from 40 to 400 cm. Deepwater rices are planted on 500,000 ha. An additional deepwater area of about 1,000 ha adjoins newly constructed irrigation canals and roads.

To develop suitable varieties and technology for deepwater areas, research started at Pusa in 1976. I present results of the following researches:

- Screening the materials in the field for deep lowland (60-70 cm) and deepwater areas,
- Variety trials, and
- Studies on the tillering pattern of deepwater varieties at two different water depths.

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FIELD SCREENING

Deep lowland seedling establishment and seedling mortality

Forty-day-old seedlings of 48 F_5s derived from Barogar/IR8//BR14, 7 F_5s from Barogar/IR8, and 45 mixed rices comprising local deepwater, lowland collections, and introduced materials were transplanted in a typical lowland field. Each entry had 6 rows of 22 plants each. Planting was at 1 seedling/hill (20 × 15 cm) at moderate fertilization (40 kg N, 17 kg P, and 17 kg K/ha). Two days after transplanting, water depth was increased to 40-45 cm and then drained after 10 days.

A week after drainage surviving plants were counted. Many entries appeared dead at the time of water removal but produced shoots later on. Varietal difference was clear-cut in seedling mortality, which ranged from 0 to 66%.

Of the 48 F_5s from the triple cross, 12 died and 10 had more than 20% survival. Of the 7 F_5s from Barogar/IR8 1 died and the others had survival percentage ranging from 27 to 47%.

Most of the deepwater collections, namely, Pichar, Jagar, Desaria, Barogar, Kobra, and Bajra had poor survival. Only Akalbir, Singhra, and Parwapankh had more than 20% survival. West Bengal introductions, namely, CN539, CN643, CN540, and OR103 also had poor survival.

In slightly submerged conditions, there were varietal differences in seedling mortality and in speed of establishment. Some entries established quickly, some took a week or more to establish. The survival of 66% plants in the entry 56-19-22, which was from a cross involving IR8 and had good plant type, is noteworthy. De Datta and Abilay (1975) reported that IR8 survived in 92-cm water depth, and its height increased 45 cm more than when it was grown with an increment of 5 cm increase in depth. Saran et al (1979) observed that IR8 had 1-week submergence tolerance in a flash flood. It appears that IR8 is a good combiner for submergence tolerance. Quick establishment of seedlings will help maintain population in lowland where flash flooding or stagnant flooding often damages the crop.

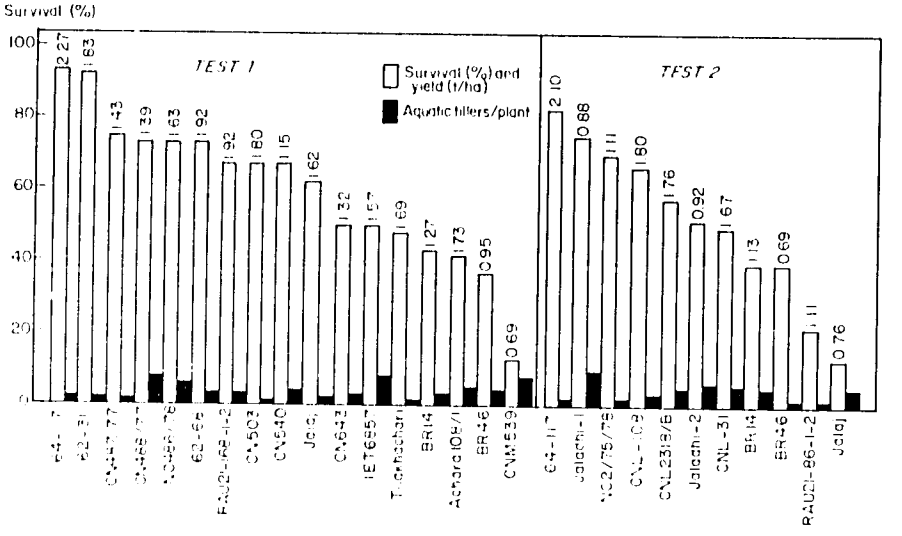
Medium deepwater submergence tests

Deepwater varieties from Bihar and West Bengal were transplanted in July for replicated trials in medium-deep water at 65-70 cm (17 entries) and 75-80 cm depth (11 entries). The plots were fertilized moderately (40 kg N, 17 kg P, and 17 kg K/ha). Seven days after transplanting, water depth was increased gradually to 45 cm in the first week, 55 cm in the second week, remained stagnant for a week, and then increased to the highest level.

Sampling in each replication of each variety was done for counting of survival rate. In the first trial six varieties — 64-117, 62-31, 62-68, CN487/77, CN488/77, and CN486/78 — survived well (Fig. 1). Highest yield (2.3 t/ha) was from 64-117.

In the second trial, 5 entries had survival scores less than 50%. 64-117 had 83% survival and Jaladhi-1 had 75% survival. Five entries were washed out. Highest yields were from 64-117 and CNL 108.

These trials were subjected to flood after establishment, in contrast to the earlier experiment. 64-117, 62-68, 62-31, RAU21-168-1-2, and CNL 108 performed well. Jaladhi-1, which had good survival, had low yield, probably because of late maturity



1. Percentage of survival yield (t/ha, and aquatic tillers/plant in 17 (left) and 11 (right) deepwater rice varieties subjected to flood 1 week after transplanting. Bihar, India, 1979.

(189 days). 64-117 was found promising in an earlier trial. This variety has good vegetative vigor and tolerance for submergence (Saran et al 1979).

VARIETAL TRIALS

Deep lowland

Thirteen tall-statured rices were tested in 1976-79 multisite replicated trials with BR8, BR34, and Mahsuri as local controls. Fertilizer rates were 40 kg N, 17 kg P, and 17 kg K/ha. The 2-year average yield of BIET1048 was 4 t/ha, compared to the 3-year average yield of 2.7 t/ha for BIET724 and 2.9 t/ha for BIET452 (Table 1).

Table 1. Comparative yield performance of varieties in deep (60-70 cm) lowland flooding, 1976-79.

Variety	Cross combination	Yield (t/ha)[a] 1976	1977	1978	1979	Av yield (t/ha)
BIET613	IR8/BR14	1.0	3.0	1.7	2.1	1.9
BIET599	IR8/BR34	0.7	2.9	2.9	2.3	2.2
BIET653	IR8/BR14	1.3	2.5	2.7	2.4	2.3
BIET943	IR8/Mahsuri	0.3	3.9	2.0	1.8	2.0
BIET724	IR8/BR14	1.2	3.5	3.3	-	2.7
BIET452	IR8/BR34	0.7	2.4	2.5	-	2.9
BIET927	IR8/Mahsuri	0.5	3.8	2.6	-	2.3
BIET1107	Jaya/Mahsuri	0.5	2.9	2.5	-	2.0
BIET600	IR8/BR34	0.4	4.0	2.5	-	2.3
BIET454	IR8/BR34	0.6	3.0	1.8	2.7	1.8
BIET720	IR8/BR14	0.6	3.2	2.4	3.3	2.1
BIET460	IR8/BR34	0.9	3.9	2.0	2.1	2.3
BIET1048	Jaya/Mahsuri	-	4.7	3.3	-	4.0
BR34 (C)		1.6	3.0	2.1	2.3	2.4
Mahsuri (C)		0.4	3.5	2.5	2.6	2.2
BR8 (C)		1.9	3.8	2.3	2.7	2.7
C.D. at 5%		0.6	1.0	0.6	0.9	

[a]Dash indicates no entry in trial.

Based on their performance in the multisite trials, BIET724 and BIET1048 were included in minikit trials. Except for BR8, no variety has been found suitable for fields with 60-70 cm water depth. BIET724 and BIET1048 may be popular among the farmers.

Medium-deep water

Fourteen lines, mostly from a BR8/BR14 cross, were tested in replicated variety trials for 3 years in medium-deep water. Water depths were 123 cm in 1976, 60 cm in 1977, and 110 cm in 1978. All lines had erect leaves and a nonlodging habit. Average yields of BIET820, BIET807, BIET763, Jalaj, and 64-117 were better than most of the controls (Table 2).

Twenty-five entries, mostly pureline selections, were tested in 1977-78 replicated varietal trials. Only 62-68 and 64-117 yielded more than 2 t/ha (Table 3). 62-68 had better grain quality than 64-117. In 1980-81, 62-68 was the top yielder (3.1 t/ha) and significantly outyielded 64-117.

Direct seeding of deepwater rices

Direct seeding is commonly practiced in deepwater areas. The performance of 26 lines (6 pureline selections, 8 lines from BR8/BR14, and 12 lines from IR8/BR14) were tested for direct seeding. BR14 and BR46 were used as controls. The trials were sown during April 1978 and 1979. Seven entries — 62-68, 64-117, 62-31, Pichar, BIET820, TCA4-12, and TCA4-13G — yielded more than 2 t/ha.

The results of a direct seeding trial during 1980 are not presented because severe rice tungro virus affected yields. However, the trial provided an opportunity to screen

Table 2. Comparative yield performance of lines in medium-deep water under transplanted condition, 1976-78.

Variety	Cross combination	Yield (t/ha) 1976	1977	1978	Av yield (t/ha)
BIET755	IR8/BR14	0.9	2.9	0.8	1.5
BIET747	IR8/BR14	1.8	2.8	0.7	1.8
BIET769	IR8/BR14	1.7	2.7	1.3	1.9
BIET820	IR8/BR14	1.6	2.7	1.4	1.9
BIET816	IR8/BR14	1.5	2.4	1.4	1.8
BIET601	IR8/BR14	0.8	2.4	1.2	1.4
BIET807	IR8/BR14	1.4	2.5	2.0	2.0
BIET763	IR8/BR14	2.0	2.8	1.1	2.0
BIET821	IR8/BR14	1.7	2.3	1.4	1.8
BIET758	IR8/BR14	1.6	2.6	1.0	1.7
BIET801	IR8/BR14	1.7	2.4	1.3	1.8
BIET799	IR8/BR14	1.4	2.5	1.7	1.8
Jalaj	IR8/BR14	1.7	3.0	1.3	2.0
64-117	Pureline	1.6	2.7	1.9	2.1
BR14 (C)		1.4	2.7	1.5	1.9
BR46 (C)		1.4	2.3	1.3	1.7
C.D. at 5%		0.5	N.S.	0.4	

Table 3. Comparative yield performance of deepwater lines under transplanted condition, 1977-78.

Variety	Yield (t/ha) 1977	Yield (t/ha) 1978	Av yield (t/ha)
Jaladhi-1	1.3	0.9	1.1
Jaladhi-2	1.6	1.6	1.6
64-18	1.9	0.5	1.2
108P	1.5	0.9	1.2
165P	1.4	0.3	0.9
161-F	2.0	0.7	1.3
Bhutani	2.0	0.8	1.4
Bajal	1.8	0.4	1.1
Parvaphankh	2.1	1.7	1.9
Pichar	2.6	1.3	1.9
191P	1.4	0.2	0.8
173P	1.6	1.2	1.4
62-2	2.3	1.2	1.7
62-31	2.1	0.7	1.4
62-68	2.5	1.8	2.1
146P	1.7	0.8	1.2
146-3P	1.5	0.5	0.9
62-10	1.6	1.7	1.7
64-117	2.0	2.1	2.1
Barogar	2.0	0.9	1.4
Lalsar	1.9	1.0	1.4
Jalaj	2.0	1.3	1.6
RR13A	1.6	0.7	1.2
BR14 (C)	2.1	1.4	1.8
BR46 (C)	2.1	0.9	1.5
CD at 5%	0.4	0.7	

entries for field resistance to tungro. 64-117 was observed to be resistant.

Several lines, either developed through hybridization involving local materials or selected from the local germplasm, performed well and may replace local varieties in due course.

TILLERING PATTERN IN DEEPWATER RICE

Many rice scientists have recommended that aquatic tillering ability be incorporated into deepwater hybrids but data to support the contention are lacking. Setabutara and Vergara (1979) reported morphological data on the aquatic tillers and found the contribution of aquatic tillers to single plant yield to be negligible in two deepwater rice varieties.

To study the tillering pattern and contribution of basal and aquatic tillers to yield, 6 locally adapted deepwater varieties — 64-117, BR14, Jagar, Kotahi, Akalbir, and Desaria — were studied in normal (6-10 cm) and deep (70 cm) water. The plants were uprooted intact and washed carefully. By making longitudinal sections of the base of the main tiller, the attachments of primary and secondary tillers were tagged and

studied in the laboratory. Data on four representative plants of each variety were taken at maturity. Plants affected by stem borer were not included.

Height of main tiller

The height of five varieties grown in deep water (70 cm) was less than that of those grown in normal (6-11 cm) depth. For example, 64-117 was 1.5 tall (including panicles) in deep water but as tall as 1.8 m in normal water. The variety Katahi, however, showed no marked difference in height in both regimes.

These varieties have the potential to grow up to 4 m in typical deep water but apparently because of environment (water depth) at an appropriate time the growth in the main tiller stopped and growth was diverted for aquatic tiller production.

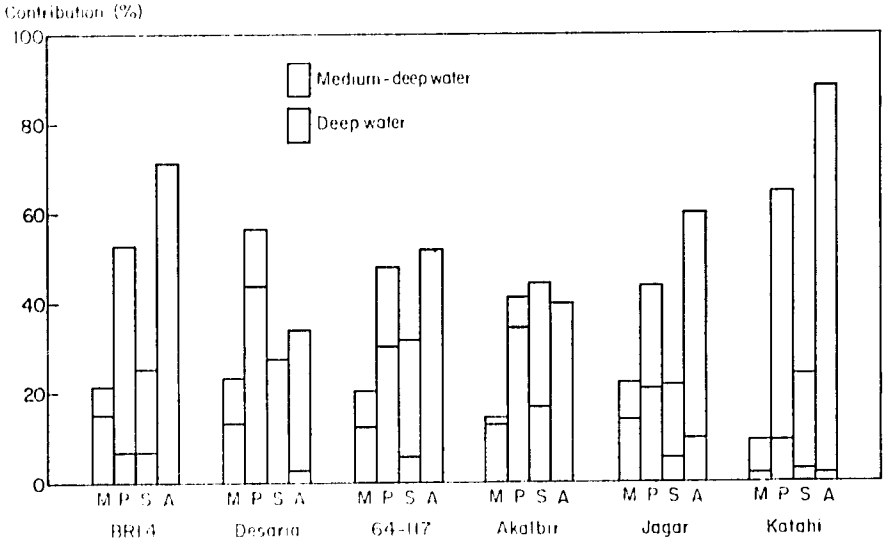
The number of internodes in deep water was higher than in normal water for all varieties except Jagar, which had 11 in both cases. 64-117 and Akalbir had 8 internodes in deep water and 7 in normal depth. Desaria, a typical deepwater variety, had 16 internodes in deep water and 11 in normal depth.

Shortening the height and increasing the number of internodes is desirable and will provide strength to the plant.

Spikelet fertility of individual tillers and contribution to yield

Average fertility was lower in deep water than in normal water depth. Individual tillers in normal water had generally more than 80% fertility. In deep water fertility varied. Fertility of BR14 varied from 50 to 65%. Aquatic tillers in Desaria showed 54% fertility. In other entries, fertility varied from 65 to 85%. This variation in spikelet fertility may account for low single-plant yield in deepwater rices.

The results of this investigation indicated that in deep water the major contribution to yield comes from the aquatic tillers (34-88%) whereas in normal water depth, primary tillers contribute about 50% (Fig. 2). The low contribution of aquatic tillers in



2. Contribution (%) to grain yield of the main (M), primary (P), secondary (S), and aquatic (A) tillers of six deepwater rice varieties. Bihar, India, 1979.

Desaria may be because of late maturity. The number of aquatic tillers per plant varied from 4.3 (Akalbir) to 13 (Katahi) in deep water.

Setabutara and Vergara (1979) did not find any appreciable contribution of aquatic tillers but speculated that aquatic tillers may be valuable in areas where water stagnates for a long period. In Bihar, direct seeding is done in March–April in deepwater areas. Water generally starts accumulating first week of July. In such cases aquatic tillers that emerge during that period get sufficient time to mature and bear fertile grains. Furthermore, as most of the older tillers are destroyed by stem borers, secondary and aquatic tillers contribute more toward yield. Generally, the deepwater rice is harvested by boat and the late aquatic tillers contribute something to yield. In addition, aquatic tillers provide essential buoyancy to the plant.

It is concluded that varieties capable of producing aquatic tillers at an early growth stage are desirable. Improvement of this trait should be intensified.

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DISCUSSION

DE DATTA: What yield are farmers getting with their local varieties and what yields are you getting with your modern varieties?

THAKUR: Farmers usually get yields ranging from 0.5 to 1 t/ha. However, yields as high as 3 t/ha are obtained when conditions are favorable. The improved deepwater rice yields are 10-30% more than yields of the local. Because environmental fluctuations are high in the deepwater areas, yield varies from year to year.

GRIFFIN: Has aquatic tillering been isolated as a specific varietal trait? Or is this an environmental response more or less common to all known deepwater varieties?

THAKUR: All deepwater rices are capable of producing aquatic tillers. However, there is variation in the number of aquatic tillers in different varieties grown in the same environment. Akalbir, for example, produced 4.3 aquatic tillers/plant, and Katabi produced 13. Aquatic tiller production is, therefore, a varietal characteristic.

HOQUE: In one of your slides, you showed a deepwater rice field without water but with erect tall plants (exceeding the height of a man standing near the field). This plant type is of great importance, particularly in areas where floodwater fluctuates over years. How many materials of this type do you have and what kind of grain yields have you acquired from these materials?

THAKUR: We have generated a number of cultivars that are doing well. Among them, BIET724 and BIET1948 are promising. With good management they give yields as high as

4 t/ha. They are especially suited to deeply flooded lowland fields.

KUPKANCHANAKUL: Under what conditions do aquatic tillers contribute a high percentage of the grain yield?

THAKUR: High contribution from aquatic tillers was obtained in medium deepwater plots (80-85 cm water depth). However, the same may be obtained in typical deep water. In typical deepwater, also, aquatic tillers are produced and contribute toward single plant yield. However, how much the aquatic tillers contribute toward single plant yield in the typical deepwater field is yet to be verified.

SARAN: C64-117 and BIET724 have good plant type with erect habit and deep green foliage. In medium deepwater plots (50-70 cm), these varieties yield 1.5 to 2.5 t/ha. They can be utilized as donor parents. Some scientists at IRRI and other places have already done that.

KUPKANCHANAKUL: When you say that with around 80-cm water depth aquatic tillers can contribute highly to grain yield, is it due to the fact that your treatment was limited to 80 cm? Do you think that a treatment of more than 80-cm water depth would not give such contribution of aquatic tillers to grain yield?

THAKUR: We have not studied this sytematically at depths greater than 80 cm. However, I presume aquatic tillers will contribute even more in typical deepwater fields.

OTHMAN: Are Mahsuri and Jaya the same as the ones with those names in Malaysia? Why is it that the 1976 yields (Table 1) are low, especially for Mahsuri?

THAKUR: Mahsuri and Jaya are different varieties. Mahsuri is a tall type and Jaya is semidwarf. Malinja is also a separate variety. The trial was in the deeply flooded lowland area, resulting in lower yields for Mahsuri.

ADAPTABILITY TESTING OF TRADITIONAL DEEPWATER RICES IN BANGLADESH

P. Francis and C. T. Brackney

SUMMARY

Crop-cut surveys and a limited number of trials in farmer fields have shown that a diverse range of agroclimatic and topographic factors affect deepwater rice yields. Widespread screening trials could evaluate a large number of potentially promising materials. Interchange of local varieties between different areas may prove a fast and inexpensive method of raising yields.

In a program of regional testing of promising local lines the few reliable results obtained confirmed the yield potential of some of the local lines and also showed how easy it is to lose completely those rices not suited to a particular flooding regime. Incorporation of common check varieties at all sites combined with a program of aggressive negative screening in extreme environments in farmer fields is proposed.

It is also proposed that studies be initiated in Bangladesh to determine the best methodology for winter seed production of photoperiod-sensitive, deepwater varieties because this could be of assistance in the rapid increase of seed supplies of varieties emerging from breeding programs.

The annual flooding and the variable topography over thousands of years in Bangladesh have resulted in the development of hundreds of plant types of deepwater rice, many of which are restricted to fairly narrow niches in the ecology of the great riverine habitat (Ahmed 1975). Research on those rices started in 1909 at the old Dacca Farm and in 1934 at the BRRI Habiganj Regional Experiment Station (Alim et al 1962). However, relatively little research was done in farmer fields to determine relative merits of the many varieties or the cultural practices used by farmers.

Seeking ways of improving yields of traditional varieties of deepwater rice (broadcast Aman) in farmer fields, using the farmers' technology as much as possible, has led to the development of research techniques especially adapted to the deepwater rice crop. The diverse range of environments in which the crop is grown also led to the

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development of a program of regional testing.

Yields of deepwater rice are remarkably stable. Despite severe weather, which completely destroys other types of rice (transplant aman, aus, and boro), deepwater rice yields, although often low compared to yields of modern varieties, are consistent over time.

The main factors affecting deepwater rice yield in Bangladesh are discussed in this paper.

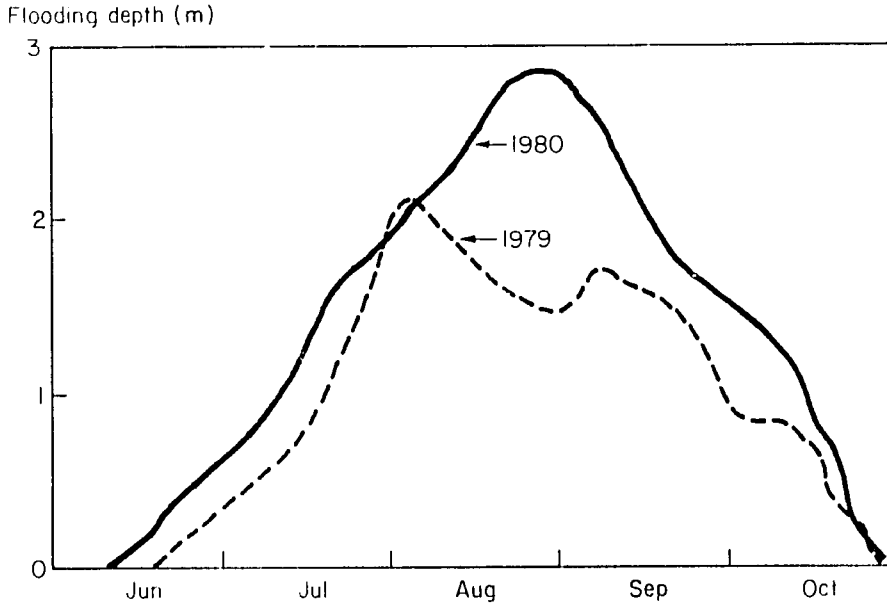
FLOOD LEVEL

Flood level has a direct effect on the yield of deepwater rice, and when there is insufficient time for the crop to establish before flooding, yields may be severely reduced.

Figure 1 shows that the rate of water rise at Manikganj in July 1979 and July 1980 followed a similar pattern. The August flooding patterns differed considerably. In 1979, the flood peak was 2.1 m in early August but in 1980 it was later and peaked at 2.8 m.

The 1980 water level rise at Manikganj 10-13 August was about 10 cm/day. Apparently the sudden water rise when water depth was already 2 m was too great to allow early-maturing local varieties to respond by elongation. Yields of Molladigha were severely affected. The mean yield of a nonreplicated trial with 9 treatments in 1979 was 2.3 t/ha; in 1980 mean yield from a similar trial at the same site was 1.8 t/ha.

At Agrakhola, Keraniganj, southwest of Dacca, where flooding followed a pattern similar to that at Manikganj, mean yield also dropped in 1980. In 1979, the mean yield from 12 treatments was 2 t/ha; this dropped to 1.88 t/ha in 1980 for a similar trial on the same site.



1. Flooding pattern at Manikganj in 1979 and 1980.

Because the Manikganj and Keraniganj sites were largely undamaged, varieties used were identical and treatments were similar, the yield loss may be attributed to different flooding patterns. However, early-maturing varieties adapted to flood levels of about 2 m were affected most in 1980; varieties adapted to deeper water were not unduly damaged. Catling et al (1980) reported that Puiatipari, which normally grows in water depths of 2.5-3 m, gave normal yields in 1980 (1.4-2.0 t/ha) despite an exceptional flooding depth of 3.4 m.

A severe yield loss (66%) with higher than normal flooding (1 m more than the normal depth) was reported for the Tangail variety Chamara. In a year when flood levels are moderate the highest yields appear to come from fields flooded between 1.5 and 1.8 m (Catling et al 1979).

MATURITY OF VARIETIES

The highest average yields of deepwater rice are usually obtained from varieties harvested during the first 2 weeks of November (Catling et al 1979, 1980). Yields were, however, highest for the period 16-30 November in 1979, a dry year. This was mainly due to a 0.4 t/ha decrease in yields on the Ganges floodplain (due to the late start of the rains) where many fields are harvested by 15 November. Because time of harvest and flooding depths are closely related (varieties harvested first have the least flooding depth) it is difficult to separate entirely the effect of flooding from that of crop duration. Multisite testing, preferably with controls at different water levels, would help clarify whether water depth or maturity date has the most effect on yield.

SUPERIOR LOCAL VARIETIES

As part of a process of natural selection farmers have selected superior local strains of deepwater rice and given them local names based on season of maturity, suitability for transplanting, cooking qualities, ability to elongate, etc. However, it is difficult to determine whether similar germplasm is given different names in different areas, or conversely whether varieties with identical names are, in fact, different. For example, in an observation trial at Bhanga, Faridpur district, the local variety Lakshmidigha had the same 50% flowering date as Bawalia in Manikganj, suggesting that the varieties, which have similar morphological characteristics, are identical. On the other hand, the variety known as Sarsari in Pabna and Manikganj appears to be, in fact, two different varieties.

There are several other group names of deepwater rice such as Khama, Digha, Boron, etc., from which one or two outstanding varieties have been identified. In crop-cut surveys, Pankaish, Khama, and Kartiksail gave consistently higher yields than other varieties. Another variety, Gilamyt, also grown on the Meghna floodplain at Narsingdi, performed consistently well at several sites and has regularly yielded more than 3 t/ha in crop-cuts and observation trials in farmer fields.

TRIALS ON FARMER FIELDS

The most reliable way to judge the performance of improved deepwater rices and new cultural practices is to try them in farmer-fields where natural variability is high.

Coefficients of variation of 30-40% are usual, however, and statistical differences between treatments are difficult to show unless a large number of replications are used. If variation is strongly localized, the use of large plots may give greater accuracy. Plant height creates another problem. After elongation the plant may be up to 10 times its height before flooding and lodge completely at harvest.

Because lodging is rarely uniform and large amounts of straw are produced only the panicles are harvested. It is difficult, however, to judge the point of origin of a panicle in tangled straw 3-4 m long. Hence, a minimum harvested area of 16 m^2 is necessary for accurate results. In cases where lodging direction varies extremely, it may be necessary to harvest the whole plot.

In 1979, some cooperative Overseas Development Administration/BRRI testing was done with local varieties at several sites. Trials were in farmer fields using, whenever possible, local practices. Local varieties were tried at each site in combination with a variety of establishment methods. Methods were laid out in strips with varieties randomized within strips. There was no replication of treatment at a site.

Table 1 gives the results for two of the varieties with two establishment methods at two sites. The highest yield was produced by Gilamyt at Rajabari, a shallow-water site. Gilamyt yields were affected by the deeper water at Manikganj suggesting that some varieties of deepwater rice are depth-specific. However, Gilamyt was still the superior variety at both sites.

An unusual result of the trial was that at equivalent seed rates, seeding by dibbiing gave higher yields than drilling due to the extremely dry conditions at the time of planting.

Flooding started at Manikganj in June but did not start at Rajabari until the first week of July. Rate of flood rise was similar at both sites.

Superimposed fertilizer trials in farmer fields were conducted at four sites in 1980 (Table 2). Response varied from 0.3 to 0.6 t/ha. We have observed that many deepwater-rice farmers use small amounts of fertilizer, applying phosphorus basally and urea at second hand weeding. Further on-farm trials, with a more sophisticated layout to overcome natural field variability, are needed to define benefits that may occur from the use of fertilizer on deepwater rice.

At Pabna, a varietal trial with a few local strains from other areas was planted in 1980 (Table 3). Fairly large differences in yield between varieties were not statistically significant because of insufficient replication. High flood levels of 1980 undoubtedly contributed to the rather poor performance of Molladigha and Kartiksail because as the tiller counts show, satisfactory establishment was achieved before flooding.

We could not demonstrate significance of results in the fertilizer and variety trials discussed in this section. There is a need to modify experimental procedures if convincing results are to be obtained from deepwater rice trials in farmer fields. Among other steps, layout design should allow for at least 20 degrees of freedom in the error term.

CROPPING PATTERNS

Although hydrologic characteristics of the environment and flowering dates are major determinants of varietal adaptability, other factors also influence farmers' choice of a

Table 1. Comparison of yield (t/ha) of deepwater rice varieties Sarsari and Gilamyt at two sites in Bangladesh, 1979.[a]

Establishment method	Sarsari		Gilamyt		Mean
	Manikganj	Rajabari	Manikganj	Rajabari	
Drilled	1.9	1.9	1.9	2.5	2.1
Dibbled	2.2	2.0	2.7	3.9	2.7

[a]Maximum flooding depth at Manikganj, 2.1 m; Rajabari, 1.8 m. Yields are means of fertilized and nonfertilized treatments.

Table 2. Grain yields of deepwater rice obtained at four Bangladesh sites by superimposed urea application, 1980.

Fertilizer rate	Yield (t/ha)			
	Bhanga	Lashkordia[a]	Nobogram[b]	Nandanpur
No fertilizer	2.29	2.09	1.65	1.61
30 kg N/ha	2.54	2.38	1.96	1.69
60 kg N/ha	2.89	-	-	1.68
30 kg P_2O_5	-	2.21	-	-
30 kg N/ha + 30 kg P_2O_5/ha	-	2.31	-	-

[a]Mixed stand of deepwater and nondeepwater rices. [b]Fertilizer applied at seeding, all others basal.

Table 3. Local variety trial of deepwater rice at Nandanpur, Pabna, 1980.

Variety	Tillers (no./m^2)[a]	Yield (t/ha)
Chamara	256	1.9
Sarsari	258	1.7
Habiganj Aman IV	237	1.1
Molladigha	233	1.0
Kartiksail (local check)	235	0.9
CV (%)	18	16.6

[a]Counts made before flooding.

deepwater variety. In areas of moderate water depth, it is common to see deepwater rices with a wide range of maturity dates. Where depths are uniform, variety is often determined by cropping pattern. Farmers who follow deepwater rice with a crop such as mustard, which must be planted by mid-October for best yields, often choose early varieties such as Ashwina or Bhadoia, which are weakly photoperiod sensitive. If wheat, which can be planted a month later than mustard, is to be planted, a

moderately late-maturing but higher-yielding variety may be chosen. Farmers who intend to fallow their fields are interested primarily in yield and are not highly concerned about harvest date. However, flowering must not be so late that low temperatures in November interfere with panicle exsertion and fertilization. Low yields of some late-maturing introductions in yield trials may be traced to this, even though initial floral emergence may occur at or about the same time as local varieties.

In areas with variable topography, such as the gradation from the tops of river levees toward the center of the extensive depressed water bodies (beels) in riverine areas, topography often dictates variety. The choice of crops that can follow deepwater rice in shallow areas is wider and frequently two or even three winter crops are possible whereas in deeper areas only one may be grown.

The great diversity of cropping and flooding patterns and establishment techniques make it necessary that priorities in any deepwater rice improvement program be established on a national basis. Even then, systematic testing is difficult because of the extremes of environment and the variations that occur from year to year.

About 800 deepwater rice accessions from Bangladesh have been placed in national and international germplasm banks and BRRI scientists estimate that about that number remains uncollected. Three years of sampling in farmer fields at harvesttime identified 46 varieties commonly grown by farmers in the most accessible areas of the Ganges, Jamuna, and Meghna floodplains (Catling and Alam 1981). This represents a small proportion even of the materials that have been collected. The task of sorting superior materials from the broad array of existing types is formidable.

Extreme variations in plant type of the parents of future high-yield potential deepwater rices result in widely segregating populations. The BRRI program already may contain the potential for plant types to fit the full array of environments from drought-resistant, direct-seeded dryland (aus) types to superior, very deep water types with rapid elongation ability. As with the traditional varieties already used by farmers, the task of identifying the needed types is demanding. Widespread screening of segregating materials in carefully selected environmental extremes of farmer fields should be considered.

REGIONAL TESTING PROGRAM

The results of performance testing and crop-cuts have shown that yields of several traditional varieties are equally as good as those of the most promising lines emerging from the BRRI deepwater rice breeding program (Kanter 1981). Thus, in 1979 BRRI initiated a program to determine whether superior local varieties could be moved from one floodplain to another, or even between regions within a given floodplain.

District extension officers of deepwater rice-producing districts were invited to a workshop and asked to bring 10 kg of seed of the 2 or 3 most popular deepwater rices grown by farmers. About 40 varieties were collected. These were redistributed at the workshop with each extension officer taking seed of 5 or 6 introduced varieties to plant in his home district. The varieties were distributed based on an informal classification of water depths for trials in farmer fields under farmer management. Checks were popular local varieties. BRRI issued a detailed pro forma to encourage uniform reporting of results.

Returns from 1979 trials were somewhat erratic and not amenable to statistical evaluation. However, at several sites the introduced varieties were equal to or better than local checks. The average yield for all sites (all varieties) was 1.9 t/ha. The average varietal yields across sites ranged from 1.2 to 2.4 t/ha for varieties grown at 2 or more sites. Water depths ranged from about 25 cm to 2.8 m.

The 1979 trials established the precedent for research and extension cooperation for deepwater rice applied research in farmer fields, but, technically, the results were not of much value in establishing yield potential of individual varieties. However, the general production trends tended to confirm the crop-cut results referred to earlier.

In 1980 nurseries were established at only a few sites in cooperation with extension personnel. The 1980 floods were early and destroyed some late-planted stands. Flood rise was normal until about mid-August when a sharp rise (Fig. 1) raised water levels to about 1 m more than those of 1979. Where deepwater rice survived easily in 1979 at 2.1 m in Rajshahi district, stands were completely destroyed in 1980. However, where planting (either transplanted or broadcast seeded) had taken place early enough for plants to survive the early flood, some outstanding deepwater rice yields were obtained. Table 4 shows that Sada Pankaish survived and produced a yield of 3.4 t/ha in 3.6 m of water at Rajabari. According to Catling and Alam (1981) this variety produced an average of 2.9 t/ha in 17 observations over a 3-year period. Kartiksail and Pathkhola also produced high yields at Rajabari.

Outstanding performance of native deepwater rice varieties was recorded at widely separated sites in 1980 (Table 4). These results, and others, confirm the yield potential

Table 4. Yields (t/ha) of several traditional Bangladesh deepwater rice varieties in three farmer fields. Plots at Rajabari and Hajiganj were broadcast seeded. The trial at Elliotganj was transplanted. Work at Rajabari was by BRRI Applied Research and Training Division (ARTD). Elliotganj and Hajiganj trials were by the Mennonite Central Committee and ARTD cooperating, 1980.

Variety	Site and water depth		
	Rajabari 3.5 m	Elliotganj 1.5 m	Hajiganj 0.9 m
Kartiksail	2.5	4.3	2.5
Habiganj Aman I	*a*	3.6	1.1
Habiganj Aman II	1.6	3.2	3.2
Early Sarsari	0.5	*b*	0.9
Sada Pankaish	3.4	3.2	*c*
Pathkhola	2.8	1.3	*c*
Chota Bawalia	0.8	1.3	*c*
Ashwina	*a*	0.8	*a*
Bhadoia	*a*	0.7	*a*
Lakshmidigha	*a*	0.8	*a*
Khama	1.9	*c*	*c*
Gilamyt	*c*	3.3	*c*
Kaira	*c*	*c*	2.8

[a] Indicates plots destroyed by floods. [b] Indicates plants survived but plots sustained severe physical damage from unknown source and were not sampled. [c] Indicates variety not included in trial.

standards that the new varieties emerging from breeding programs must meet. An ability to produce yields of 3.5-4.0 t/ha in highly adverse hydrologic conditions must be demonstrated before new rices will be useful to Bangladeshi farmers. In breeding for improved deepwater rices, breeders must select for the extremes of environmental adaptation, rather than for norms.

The 1980 experience caused further change in the testing program for 1981. Sada Pankaish, Habiganj Aman II, Kartiksail, and Gilamyt are recognized as varieties that seem capable of superior performance over a fairly wide environmental range. However, all of those are from the Meghna floodplain; their performance on the Lower Ganges and the Jamuna should be determined so that they may be used as cross check varieties. Because many varieties are floodplain-specific it will be difficult to determine the true effect of the hydrologic environment until more multisite trials with these as common checks can be completed. Such factors as soil type, silt deposition, rainfall pattern, water chemistry, and flooding pattern may all have significantly affected variety evolution.

The crop-cut surveys reported by Catling et al (1979, 1980) and Catling and Alam (1981) have shown consistently high yields on the Meghna floodplain. Pankaish (also Sada Pankaish) and Kartiksail, which consistently yielded more than 2.7 t/ha, originated there.

The Meghna floodplain also has a higher rainfall which commences earlier, and perhaps consequently, sowing is earlier and fertilizer use is higher.

In 1981, Sada Pankaish and Habiganj Aman II were included in 26 applied research trials to provide a common measuring standard. Kartiksail and Gilamyt were also placed in several nurseries with other good land races such as Baisbish, several Badal and Digha varieties, and other native deepwater rices. Thus, the 1981 approach is an attempt to determine how superior traditional rices compare with the best check varieties at specific sites and to learn how the introduced materials adapt to the new environments. Very shallow, early, and very deep, late sites were avoided. Trials are single replicates and under farmer management.

It is important to thoroughly describe environments, including cropping patterns in use. Perhaps the attempt to classify environments based on reaction of "indicator" varieties is too ambitious. However, material needing evaluation is so luminous and environmental variation so broad that it is impractical to replicate to the extent needed for statistical validity of yield and other data, at least during exploratory trials. However, tools are needed to help overcome the lack of precision caused by limited replication. Segregating breeding materials and local varieties might be tested at environmental extremes with "indicator" varieties to eliminate completely a high proportion of the test population.

SEED MULTIPLICATION PROGRAM

Bangladesh Rice Research Institute found early in its deepwater rice testing program that pure seed availability was often a limiting factor. A decision was made to produce seed of promising materials at BRRI. Two types of trials have been used:

- a replicated trial to determine seed production potential under shallow, wetland

Table 5. Yields, flowering dates, and approximate water depth adaptation of deepwater rice varieties grown in seed production trials under shallow water transplant conditions, BRRI, Joydebpur, 1980.[a]

Variety	Date of 50% flowering	Yield[b] (t/ha)	Approximate maximum water depth for maximum yield (m)
BR10 (check)	2 Nov	5.1 a	0.15-0.20
BR11 (check)	7 Nov	4.7 a	0.15-0.20
Nizersail (check)	9 Nov	2.8 b	0.20-0.30
Digha	1 Nov	2.7 bc	2.00-2.50
Chamara	2 Nov	2.5 bcd	1.50-2.00
Lakshmidigha	15 Oct	2.3 bcde	1.50-2.00
Sada Pankaish	30 Oct	2.2 bcdef	2.00-3.50
Habiganj Aman II	19 Oct	2.0 bcdefg	1.50-2.00
Pathkhola	20 Oct	2.0 bcdefg	2.00-3.50
Khama	15 Oct	2.0 bcdefg	2.00-3.00
Early Sarsari	15 Oct	1.9 bcdefg	2.00-2.50
Chota Bawalia	24 Oct	1.9 bcdefg	2.00-2.50
Kartiksail[c]	16 Oct	1.9 bcdefg	2.00-3.50
Ashwina	2 Oct	1.6 cdefg	1.00-1.50
Puiatipari	4 Nov	1.4 defg	3.00-4.00
Molladigha	12 Oct	1.3 fg	2.00-2.50
Bhadoia	2 Oct	1.1 fg	1.00-1.50

[a]Adapted from data collected by the BRRI Applied Research and Training Division. [b]Differences in yield followed by the same letters are not statistically significant at the 5% level. [c]There are at least 2 varieties called Kartiksail. The second, not referred to in this report, is used exclusively in river levees in 1 m of water or less in Pabna district.

conditions; and

- observational trials to determine flowering dates, basal tillering capability, and some disease reactions, and to produce a small quantity of seed for continuing trials.

Table 5 shows that the seed production potential of several traditional deepwater rices in shallow water is equal to that of Nizersail, a traditional nondeepwater variety (BRRI, Training and Applied Research Division 1981). Exceptions to this are the early varieties (Bhadoia, Ashwina) adapted to shallow water (maximum about 1.5 m) and very late varieties (Puiatipari) adapted to deep water (well adapted at 3.5 m). However, none of the deepwater materials approached the production potential of the BRRI modern varieties, BR10 and BR11.

Seed of many photoperiod-sensitive varieties can also be produced successfully in Bangladesh during the winter (boro) season. Experience with Nizersail has shown that maximum productive tillers are produced when seedbeds are sown between 12 and 20

November. Although few records of winter trials of deepwater rices are available in Bangladesh, it may be assumed that those may react in a similar way to Nizersail, provided that low temperatures in the vegetative stage, to which deepwater rices are not normally exposed, are not a limiting factor. Because flowering dates are variable (Table 5) the best planting date to produce a winter crop may vary among varieties.

It is suggested that winter screening of superior traditional deepwater varieties and new breeding lines would be productive because seed produced in the winter could be planted in any transplant aman area and many late-flooding, deepwater areas, dramatically increasing varietal spread.

Although low-temperature tolerance in the vegetative stage should not necessarily become a selection criterion in breeding programs for deepwater rice in subtropical areas such as Bangladesh, it might receive due consideration in parental or pedigree selection when convenient to do so.

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DISCUSSION

CHAUDHURY: What is the flowering duration of typical deepwater rice varieties when grown in the winter in Bangladesh?

FRANCIS: Once the basic vegetative phase is completed, initiation should take place. However, because of lower temperatures in November and December, this may be delayed. When winter sowing was done at Habiganj (sowing seedbeds in November, transplanted by mid-December) flowering took place the following May.

DE DATTA: Why do you say traditional varieties have greater adaptability than modern varieties? Your data do not support that comment.

FRANCIS: Modern varieties, when tried in farmers' fields, and subjected to cultural practices used by the Bangladesh farmers, particularly heavy hand weeding, have not performed as well as traditional varieties. Dr. Catling's data on crop-cuts, which were referred to, have statistical analyses of the effect of flooding depth and maturity date on yield. All trials discussed in the paper were laid out statistically and showed statistical differences.

PETPISIT: Is the different yield obtained in 1979 compared to 1980 due to early flooding or to deeper flooding?

FRANCIS: Lower yields obtained from early-maturing varieties in 1980 were almost certainly due to the late flooding in August (much later than usual) together with the fact that the levels of flood in 1980 averaged 0.8-1.0 m higher than mean levels.

JUGSUJINDA: The yields in your fertilizer nitrogen response study were low. Did you correct the sulfur phosphorus-deficiencies beforehand?

FRANCIS: Even when sulfur is adequate, the response to nitrogen by traditional varieties is usually of an order of 0.3 to 0.6 t/ha. Sulfur deficiency is not common in deepwater rice areas of Bangladesh. Phosphorus deficiency is not common where there is heavy silt deposition. The trial at Lashkandia had a phosphorus treatment and showed no response.

AWAKUL: You show that planting by dibbling gives more yield than drilling. Why?

FRANCIS: The year of this trial was very dry. Dibbling places the seed deeper than drilling. The deeper seed had more moisture. Better germination occurred and higher yields resulted.

YIELD PERFORMANCE OF DEEPWATER RICE IN A THAILAND NETWORK

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SUMMARY

The Thai Yield Trial Network consists primarily of four deepwater rice stations where uniform sets of photoperiod-sensitive and insensitive breeding materials are grown in interstation yield tests. Generally, 2 to 4 trials are planted at each station, an average of 14 to 22 entries/trial. Entries that perform poorly across all sites are discarded after 1 year and replaced by new promising lines from the breeding program. The procedures can identify stable, high-yielding lines quickly and efficiently. Results to date suggest that semidwarf rices with elongation ability grown in semideep water have the potential to outproduce tall, native types.

Large environmental variations over an ecological region for rice production require that breeding materials be tested in the various environments to identify stable, high-yielding genotypes that will gain farmer acceptance. For Thailand, we believe such tests can be most efficient if first made at rice experiment stations and then the most promising entries grown in farmer fields.

Another paper deals specifically with farmer field trials (Prechachat et al, this volume). Our paper covers Thai Yield Trial Network results at four rice experiment stations where floodwater is relatively deep and not controlled. The sites are Huntra and Prajinburi, designated floating rice stations, and Pisanulok and Klong Luang, areas where water depths may range from 50 to 85 cm depending on the year.

Generally, 2 to 4 interstation yield tests, containing 14-22 entries/trial, are planted each monsoon season at each major deepwater experiment station. Entries that perform poorly at most sites are usually discarded at the end of the first year and new breeding lines evolving from observational and preliminary yield trials are used as replacements. Emphasis is placed on an experimental line's ability to elongate in up to 1 m of water but lines must also exhibit good plant type and other important characteristics. Although semidwarf types are generally desired we also include tall types if they are promising in other respects. Due to their ease in handling, some

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photoperiod-insensitive lines are retained for our tests but these are not deemed as important as those possessing sensitivity and are grown in separate experiments.

Our check varieties usually consist of a popular floating rice variety. Recently we have included RD19 because it represents a new concept in rice breeding for semideep-water areas.

We discuss the scope of our deepwater rice yield trials and present data on the performance of a few selected lines in comparison with standard check varieties.

METHODS OF CONDUCTING THAI NETWORK EXPERIMENTS

An annual meeting of all technicians from the deepwater stations reviews the performance of the deepwater yield trials and other related research. After an agreement on the entries and the number of tests to be planted the next season, planting plans and seed are distributed to each station.

At planting time 25- to 30-day-old seedlings are transplanted into the field in a randomized complete block design with 4 replications. A 1 m × 5 m plot (5 × 21 hills) is used for the photoperiod-sensitive entries with 3 plants/hill spaced 25 cm × 25 cm apart. Fertilizer at 37-37-37 kg NPK/ha is used as basal application and 37 kg N/ha is applied 60 days after seeding as a topdressing. Grain yields are obtained from the three center rows with one border hill left for each end.

For the photoperiod-insensitive lines we used a 13 m × 13 m hill plot and harvested the 9 center rows with 2 border hills left at each end.

After threshing, the seeds from each plot are sun-dried for about 1 week before weighing. A sample is taken for moisture determination and weight correction is made to the standard 14% moisture for each plot.

RESULTS AND DISCUSSSION

Table 1 gives the number of sites, entries, and tests for the 1979 and 1980 wet seasons. In 1979 about 2/3 of the entries planted were photoperiod sensitive but this was reduced to about 50% in 1980. Most of the testing stations are in the Central Plain where deep water is a common problem.

In 1979, no serious flooding or pest damage occurred, and all sites were successfully evaluated for yield and other characters. No data could be collected at 3 of the sites in

Table 1. Number of lines and varieties in deepwater tests in Thailand, 1979 and 1980 wet season yield trials.

	1979				1980			
	Sites (no.)	Entries (no.) Short	Entries (no.) Tall	Experiments (no.)	Sites (no.)	Entries (no.) Short	Entries (no.) Tall	Experiments (no.)
Photoperiod-sensitive	5	17	61	6	7	10	48	4
Photoperiod-insensitive	6	38	2	3	6	39	21	3

Table 2. Yield performance of selected photoperiod-sensitive varieties and experimental lines grown in semideep water in multisite trials, Thailand, 1979 and 1980.

Entry	Parents	1979[a] yield (t/ha)	1980[b] yield (t/ha)	Av plant height (cm)	Av flowering date	Av elongation score
RD19	IR262-Pin Gaew	3.2	2.7	155	14 Nov	6
Leb Mue Nahng 111	Pure Line	2.1	2.2	233	18 Nov	1
SPT6984-40	Khao Puang 32/ Sigadis	2.5	2.9	220	18 Nov	6
SPR7276-18	Khao Nahng Nuey/ C4-63	3.0	2.5	194	17 Nov	7
SPR7233-44	Leb Mue Nahng/ C4/63	2.5	2.3	214	20 Nov	5
HTA7205-11	RD1/Wild Rice	2.2	2.6	228	11 Nov	3
SPR7297-343	Pin Gaew/IR648	3.4	2.5	140	15 Nov	8
SPR7299-2	Huntra 1646/ Nakorn Sri Tamarat 6517-17	2.6	2.2	149	22 Nov	7

[a]Four sites. [b]One site (Prajinburi); other site's crop destroyed by flood or ragged stunt virus.

1980 because of damage by flood or pests.

The 1979 trials had 55 semidwarf entries. The 1980 trials had considerably more tall type than semidwarfs because many of the semidwarf selections in the breeding program failed to elongate enough to justify advancing them to deepwater yield trials.

Table 2 shows the yield performance of eight common entries grown at the sites in the 1979 and 1980 wet seasons. All were photoperiod sensitive. Average maximum water depth at the various sites was about 65 cm and ranged from about 50 cm at Klong Luang to about 1 m at Prajinburi.

The data in Table 2 illustrate the magnitude of yield differences. In 1979, RD19 and a semidwarf line, SPR7297-343, produced the highest average yield for the 4 sites; the traditional floating variety Leb Mue Nahng 111 produced the lowest yield. In 1980, with data from only 1 site, RD19 produced 0.2 t/ha less than the most productive entry but 0.5 t/ha higher than Leb Mue Nahng 111.

Considering the 8 entries in Table 2, there appeared to be no strong relationship between yield and either elongation ability or plant height because two of the best entries (SPR7297-343 and RD19) did not attain a height of more than 155 cm even when grown in relatively deep water.

The yield results from the Thai network suggest that yields can be improved through breeding and even though the production levels presented here are not high, research aimed at better methods of nitrogen application in deepwater fields along with improved varieties could contribute to greater productivity.

Because water regimes, soils, and other environmental conditions vary greatly we

believe it is important to continue to conduct multisite tests such as those reported here to identify those genotypes with strong yield stability to gain farmer acceptance.

Dry season tests with photoperiod-insensitive rices were planted in shallow water but are not reported here. The results reveal that their performance is generally similar to that of ordinary high-yielding varieties but their use in the dry season when water depths are shallow makes their use irrelevant to this paper. Sirikant et al (1977) reported that the yield potential of rices with elongation genes (in shallow water fields) was not reduced compared to high yielding RD7. Our results, although not reported here, tend to support that observation.

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DISCUSSION

CHAUDHURY How do you determine the photoperiod sensitivity of varieties?

CHAROENDHUM: We plant the lines in April when days are long. If there is no flowering until September or later (at least 180 days after seeding), we consider a variety sensitive.

FARMER FIELD YIELD TRIALS FOR DEEPWATER RICE IN THAILAND

C. Prechachat, N. Supapoj, W. Limkanchanapon, and B. R. Jackson

SUMMARY

Tests in farmer fields have changed from small replicated plots with about 20 entries to large plots with 5-6 lines and check varieties. Testing has also changed from transplanting to broadcast seeding to more nearly conform to farmer practices. In addition to the standard yield trial, several special tests were made in farmer fields to obtain more precise information on performance of one or two newly developed hybrids in comparison to popular traditional floating and nonfloating varieties. The modifications appear satisfactory and enable identification of promising new lines with more confidence. When grown in water 1 m deep, or slightly more, some of the new semidwarf hybrids show a positive response to fertilizer and are considerably superior to the type varieties in yield potential.

Trials in farmer fields in 1979-81 examined the degree of wide adaptability of promising lines that had been tested in uniform variety trials for 2-3 years and obtained farmer reaction to the promising lines before their release as new varieties. The trials were divided into two phases.

FARMER FIELD TRIALS — PHASE I

Yield trials in farmer fields (regional trials) have been conducted continuously for more than 20 years at several sites in the different provinces where the deepwater rice is grown. The experimental design has gradually changed. For example, 10 years ago the tests were on 3-row, 4.5-m-long plots, with 4 replications in a randomized complete block design with 20 or more entries. This experiment was small and when grown in a farmer field any potentially outstanding lines were obscured by adjacent farmer varieties. The design was recently modified — the number of replications is reduced to 2, the plots are enlarged to 10 m × 10 m, and only 5-6 promising lines are

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used. The plant spacing is 25 × 25 cm and yield measurements are taken on 2 3 × 3-m^2 samples from each basic plot after eliminating border rows.

Fertilizer is applied as a basal dose of nitrogen and phosphorus at 19-19 kg/ha, and a topdressing of nitrogen at 19 kg/ha. Water depth varies from 50 to 180 cm depending on the site.

During the 1981 wet season, broadcast seeding on dry soil replaced transplanting to more nearly conform with farmer practices.

Trials are planted at 9 sites: 2 in Ayudhaya, 2 in Patumtani, 2 in Prajinburi, 1 in Pitsanulok, 1 in Chainat, and 1 in Suphanburi provinces.

Yield data for the 1979 wet season were obtained from 7 of the 9 sites. Plots in 2 sites were damaged by flood and rats. BKN6986-28-1 was the best adapted line, and consistently produced grain yields at least equivalent to those of Pin Gaew 56 (PG56) and Leb Mue Nahng 111 (LMN 111) at 4 sites and outyielded Leb Mue Nahng 111 at 3 sites. The lines BKN6986-147-2 (RD19), SPT6849-77, and HTA7205-11 also showed good adaptability. Yield performance and other characteristics are shown in Table 1.

The advantages of RD19 are that it remains short in shallow water and produces yields of 4-5 t/ha. But when water depth gradually increases RD19 elongates and produces fairly good yields. Besides high yield potential it has acceptable grain length, and drought and submergence tolerance. Its major disadvantages are that it has chalky grain and it matures too early for some areas.

In the 1980 wet season, the promising new lines SPT6849-77, SPR7233-44, SPR7270-18, SPR7292-6, and SPR7292-343 replaced the undesirable lines in the trials. RD19 replaced PG56 as a check variety. Results were obtained from 6 sites. Plots in three sites were damaged by flood. RD19 and SPR7297-343 showed good adaptability, even in some sites with plots damaged by flood and diseases. Yield performance and other characteristics are shown in Table 2.

In the 1981 wet season BKN6986-28-1, SPT6969-77, SPR7233-44, and SPR7292-6 were discarded due to their poor characteristics. Four promising new lines —

Table 1. Yield performance and agronomic characteristics of deepwater rice yield trials in farmer fields at 7 sites in Thailand, 1979 wet season.

Line	Cross	Grain yield (t/ha)	Grain length (mm)	Height (cm)	Flowering date
BKN6986-28-1	IR262/PG56	2.9	7.2	158	16 Nov
BKN6986-81-5	IR262/PG56	2.3	7.1	181	11 Nov
BKN6986-147-2[a]	IR262/PG56	2.8	7.4	145	16 Nov
BKN6988-21	IR262/LMN 111	2.1	7.4	181	12 Nov
HTA7205-11	RD1/wild rice	2.6	7.4	186	15 Nov
SPT6849-77	PG56/Sigadis	2.7	7.4	192	19 Nov
PG56 (check)	-	2.4	7.4	211	6 Nov
LMN 111 (check)	-	2.5	7.4	199	20 Nov

[a]Named as RD19 in 1979.

Table 2. Yield performance and agronomic characteristics of deepwater rice yield trials in farmer fields at 6 sites in Thailand, 1980 wet season.

Line	Cross	Grain yield (t/ha)	Grain length (mm)	Height (cm)	Flowering date
BKN9686-28-1	IR362/PG56	2.9	6.9	158	27 Nov
SPT6849-77	PG56/Sigadis	2.2	7.3	204	28 Nov
SPR7233-44	LMN 111/C4-63	2.3	7.1	196	23 Nov
SPR7270-18	KNN 11/C4-63	2.4	7.3	165	26 Nov
SPR7292-6	NKG/IR648	2.6	7.3	164	25 Nov
SPR7297-343	PG56/IR648	3.1	7.4	138	26 Nov
RD19 (check)	-	2.8	7.5	160	28 Nov
LMN 111 (check)	-	2.1	7.6	228	26 Nov

HTA7205-11, HTA7421-8-1-0, SPR7233-32-1-6-1, and SPR7299-2 — were added to form the new trial.

FARMER FIELD TRIALS — PHASE II

When new improved varieties for semideep water were named in 1979 research on cultural practices for deepwater rice was given increased attention. The Phase II studies were to:

- Determine if drilling deepwater rice seed is better than broadcast seeding;
- Compare the performance of RD19, a newly released variety, with that of the traditional LMN 111 or PG56, and
- Assess fertilizer response under farmer conditions.

Two sets of split-plot design experiments with 2 replications were planted in farmer fields at Phu Khaw Thong and Bang Pahan in Ayudhaya Province. Three combinations of cultural practices — broadcasting without fertilizer, broadcasting plus fertilizer, and drilling plus fertilizer — were assigned to main plots with varieties as subplots.

Phu Khaw Thong trials, 1979

In 1979 trials at Phu Khaw Thong, BKN6986-81-5 replaced RD19 and PG56 represented the traditional deepwater rice. Maximum water depth was slightly more than 1 m. Analysis of variance indicated no significant yield difference between cultural practices, but a difference was found between varieties (P = .05), with PG56 superior to BKN6986-81-5 in most cases.

The poor performance of BKN6986-81-5 was due mainly to:

- High weed density, which caused poor stands,
- Its maturity was too early for the site;
- Upper panicles were lost to people or pests just before harvest, and
- Severe drought in the vegetative stage (before flooding).

The drilling treatment, which consisted of using only alternate rows of the drill (25

Table 3. Yield results of Pin Gaew 56 in farmer fields at Phu Khaw Thong, 1979 wet season.

Treatment	Yield (t/ha)
Broadcasting with fertilizer	2.1
Broadcasting without fertilizer (farmer practice)	3.7
Drilling every hole[a]	3.4
Drilling every other hole	2.5

[a]Distance between holes is 12.5 cm.

cm between rows), may have contributed to failure to obtain a significant difference among cultural practices. One guard strip of PG56 was seeded using every drill row and gave higher yields on the basis of 3 6-m² samples. A summary of the yield results of PG56 is given in Table 3.

The results indicated that the usual farmer practice gave the best yield. The experiment was repeated in 1980 to confirm findings, but unfortunately the experiment was damaged by flood.

Bang Pahan trials, 1979

The 1979 trial at Bang Pahan was seeded in a farmer field using treatments similar to those at Phu Khaw Thong except RD19 was used instead of BKN6986-81-5. The results were disappointing because of extreme soil variability, poor germination, and excessive weed competition, especially barnyardgrass. Water depth was slightly more than 1 m but the plots suffered severe drought stress before flooding.

The data did not show differences due to treatments and did not appear meaningful.

Lad Krabang test, 1979

RD19 was developed to replace the tall traditional varieties in areas where ordinary modern varieties cannot be grown in the wet season due to deep water. At Lad Krabang and nearby areas, Khao Tah Haeng 17 has been popular with the farmers for many years. The area was not considered appropriate for modern varieties because water depth may reach 1 m.

A 1979 trial was planted at Lad Krabang Agricultural College to determine if RD19 would yield more than Khao Tah Haeng 17 with high fertilizer rates and to find the appropriate level of fertilizer for RD19 in a farmer field. Khao tah Haeng 17 is one of the most popular tall traditional varieties grown in the Central Plain.

The maximum water depth was 60 cm. A split-plot design with 3 replications was used. Nitrogen and phosphorus rates applied to the main plots were: 0-0-0, 19-19-0, 38-38-0, 75-38-0, and 112-38-0/ha. RD19 and Khao Tah Haeng 17 were transplanted in early July and treated as 5 × 4 m subplots. The plots were severely damaged by rats prior to harvesting and grain yield was taken from only a few square meters of the undamaged part of each plot. From the analysis of variance, differences between the two varieties were highly significant. RD19 outyielded Khao Tah Haeng 17 at all

Table 4. Yield of RD19 and Khao Tah Haeng 17 in a farmer field at Lad Krabang, 1980.

Fertilizer (kg NPK/ha)	Yield (t/ha)	
	RD 19	Khao Tah Haeng 17
0-0-0	4.0	3.3
37-37-37	4.3	3.1
75-37-37	4.0	2.7
112-37-37	4.8	3.2

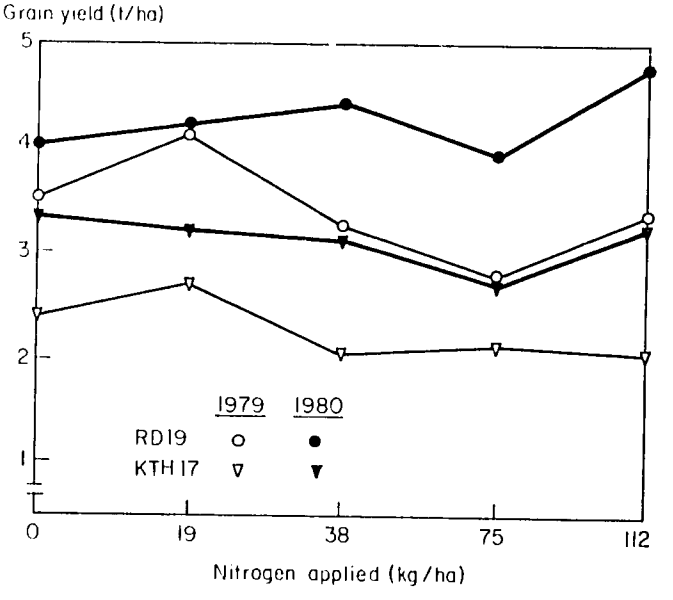
fertility levels. The yield advantage of RD19 was about 31% at the 0-0-0 level, and about 35% at the 19-19-0 level. Khao Tah Haeng 17 showed little response to nitrogen regardless of the fertilizer level and consistently produced lower yields.

Lad Krabang trial, 1980

In the 1980 trial at Lad Krabang, a split design with 3 replications had nitrogen and phosphorus applied to main plots as 0-0-0, 37-37-37, 75-37-37, and 112-37-37 kg/ha. The soil was puddled and pregerminated seeds were sown on the mud following the farmer method.

The water level was not controlled and water depth was slightly more than 1 m in early November. Yield results are given in Table 4.

The natural fertility of the Lad Krabang soil was high, which was reflected in the high yield of the nonfertilized plot. No positive yield response to fertilizer was observed with Khao Tah Haeng 17. RD19 generally produced the most panicles/m^2



1. Yield of RD19 and Khao Tah Haeng (KTH 17) at Lad Krabang, 1979 and 1980 wet seasons.

at the highest nitrogen fertilizer level, but this was not evident for Khao Tah Haeng 17.

These 1980 data confirm those obtained at the same site in 1979 and suggest that RD19 can outyield one of the most popular tall traditional varieties, even without fertilizer, at water depths of less than 1 m. A summary of the 1979 and 1980 results is shown in Figure 1.

DISCUSSION

CHAUDHURY: What is the amylose content and other grain qualities of RD19?

PRECHACHAT: The amylose content of RD19 is high, about 27-28%. The poorest quality of RD19 is its high chalkiness, which causes low milling outturn. Cooking quality is acceptable for our people.

JUGSUJINDA: Your data show it is almost impossible to increase yield with the application of fertilizer to deepwater rice. With the 1979 results at Lad Krabang, transplanted rice was eaten by rats. In Phu Khaw Thong, rice was affected by high weed density, panicles lost, and severe drought at the vegetative stage. I believe that if all yield constraints were removed, we could increase the present yields to a higher level especially with modern deepwater rice and proper fertilizer management. Experiments on fertilizer management for deepwater soils are under way and the progress is reported in this workshop.

TOURE: I notice that HTA7201-11 is a cross between RD1 and wild rice. My general concept is that crosses between wild rice and cultivated rice usually give high sterility.

JACKSON: The wild rice we used is a floating type that has long awns and red pericarp. It belongs to *Oryza sativa* and gave no indication of high sterility in the cross. We did find elongation much greater than what you find in the cultivated floating rices. We tend to define wild rice as anything that has long awns and tends to shatter. You will see these wild rices on the field trip. They grow in the floating rice fields.

DURVASULA: Crosses between cultivated and wild rice need not necessarily produce sterility. We have used *Oryza nivara* successfully.

SARAN: What is the reaction of RD9 to photoperiod? Does it possess seed dormancy?

PRECHACHAT: RD19 is photoperiod sensitive. Its seed dormancy is 3-4 weeks.

STAND DENSITY IN DEEPWATER RICE AND ITS RELATION TO YIELDING ABILITY IN FARMERS' FIELDS IN BANGLADESH

H. D. Catling, Z. Islam, and B. Alam

SUMMARY

The seasonal fluctuation and dynamics of deepwater rice plant stands, and the relation of stand density to eventual yield were studied in 1977-80 in farmers' fields in Bangladesh. Maximum stand densities of about 220 tillers/m^2 were recorded before flooding in June or early July. Advanced breeding lines usually recovered poorly from a rigorous farmer weeding practice whereas indigenous varieties recovered well. A marked decrease in stand density occurred during the stem elongation stage to average densities of 160-180 tillers/m^2 mainly due to loss of secondary basal tillers and to tillers damaged by stem borer. There was an overall stand reduction of more than 50% from preflood to harvest. Aquatic tillering, which was particularly active in fields with poor stands and which tended to compensate directly for the loss of basal tillers, offset the decrease in tiller density somewhat in the mid-flooding period. A decrease in density in the reproductive phase reduced average densities to 90-100 panicles/m^2 near harvest. Losses in stand from the end of the elongation stage to harvest were mainly due to stem borer attack, and to tiller and panicle cutting by rats; also some tillers probably remained unproductive.

Because several factors cause tiller losses during the long growing period and the indigenous deepwater rices possess strong tillering ability, preflood stand densities were sometimes poorly related to grain yield. From the end of the elongation stage this relationship improved and panicle density was found to be strongly correlated with yield. For most Bangladesh varieties 120-130 panicles/m^2 was associated with a 3 t/ha yield; this yield level required about 200 tillers/m^2 in the late elongation stage and 300-320 tillers/m^2 before flooding.

Stand density, which has an important bearing on eventual grain yield, is of basic interest to agronomists and plant breeders concerned with improving the yield of

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deepwater rice. Unfortunately, there is a dearth of information on the dynamics of deepwater rice plant stands and their relation to yield. Apart from the work of Francis (1980), which is unpublished, and Kupkanchanakul (1981), much of the available data are derived from studies in experimental tanks where growth conditions differ from those in farmers' fields.

The data we present here were collected from 1977 to 1980 during pest management studies, during which assessments of stand density were made at regular intervals in farmers' fields in several of the principal deepwater rice areas of Bangladesh. Relevant data were also taken from a series of yield assessments and from several varietal screening experiments.

METHODS

The main study site was a typical field at Agrakhola village (10 km west southwest of Dacca) where the variety Chota Bawalia was broadcast at 95 kg/ha from 1977 to 1980. Stand density was assessed at 1-2 week intervals from germination in April to flowering in early October. During the heading and ripening stages the sampling interval was sometimes increased to 3 weeks to avoid crop damage. A second field was sampled at less frequent intervals near Bastia village (8 km west of Manikganj) from 1977 to 1980 where the varieties Raja Mondal or Digha were grown. In 1978 regular density assessments were made near Manikganj in two fields of different water depths planted to mixed stands of deepwater rice and a short-duration aus rice.

Stand densities were also measured during routine pest surveys during the flooding period of 1979 and 1980. Those surveys included 15 different deepwater rice varieties. Fluctuations in stand density were recorded for several indigenous varieties and advanced breeding lines in varietal screening experiments in fields at Agrakhola, Manikganj, and the Habiganj Rice Experiment Station in 1978 and 1979 (Catling and Islam, this vol.). Lastly, panicle density and yield were assessed in a series of crop-cuts from 1977 to 1980 (Catling and Alam 1981).

Stand density, including panicle counts at harvest, was assessed from twenty 0.25-m^2 quadrats sampled along the diagonals of each field. A floating wooden quadrat was used in flooded fields. (Deepwater rice fields area usually 0.2-0.4 ha in Bangladesh.) In the varietal screening experiments, preflood stands were assessed 50-60 days after sowing by taking 6 quadrat samples in each plot; at flowering the stand was rated into 5 categories by observation from a boat.

The relation between panicle density and yield was investigated by first drawing scatter diagrams for those individual varieties sampled frequently in the crop-cut series. The data for most varieties were then grouped for analysis into 9 categories of panicle density — < 50 with increasing increments of 10, to > 120 panicles/m^2. Varieties with very light (< 2g) and very heavy (> 4g) panicles were omitted.

RESULTS

Stand density in preflood period

Agrakhola. Farmers weeded from the end of April to early May with a simple cattle-drawn implement, called an *ashra* in Bengali, which temporarily reduced plant

stands as much as 28% in 1978. The one or two hand weedings carried out in May also reduced plant stands temporarily. In 1977, 1978, and 1980 preflood growth conditions were favorable and the mean stand density increased from 145 tillers/m² in early to mid-May, to 219 tillers/m² in mid-June. From May to early June there were usually 1-2 tillers/plant. Early tiller populations were considerably lower in the drought year of 1979. Average stand density was 49 tillers/m² in early to mid-May and 99 tillers/m² in mid-June. But vigorous basal tillering, stimulated by heavy June rains and later than usual flood inundation, led to a good preflood stand (Table 1). There was an average of 6 tillers/plant in early July but many late tillers did not survive the July flooding. Maximum stand densities of 196-323 tillers/m² were recorded before flooding (Table 1).

Bastia. Maximum preflood stand densities at Bastia were not unlike those recorded at Agrakhola in 1977 and 1979 (Table 1); no assessments were made in 1980. Stand density was low in 1978 because of extremely late planting. In 1977 a 46% reduction in stand was recorded in April, shortly after a weeding cultivation.

Stand density in flood period

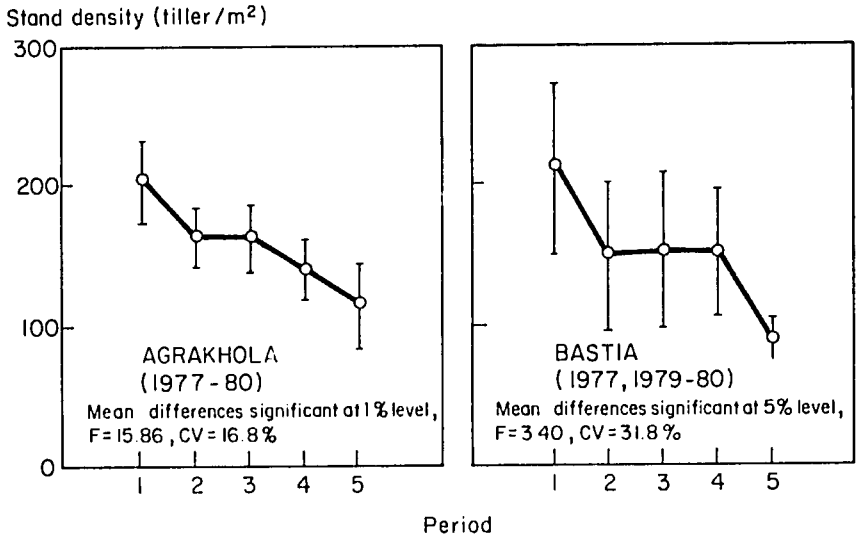
Agrakhola and Bastia. The individual records for each year at the two main study sites showed a fairly consistent trend in the decrease in stand density during the flooding period. When all observations at Agrakhola were considered for 5 periods, the average preflood density of 204 tillers/m² decreased to 164 tillers/m² during the elongation phase of deepwater rice (Fig. 1). Another marked decrease occurred at heading and ripening to reach an average density of 118 panicles/m² near harvest. A similar decrease in tiller density was recorded at Bastia (Fig. 1), with a greater level of variation among fewer observations. When both fields were taken together there was an overall 54% reduction in stand from flood inundation to harvest.

Stem samples removed from the two study fields during the late elongation and early heading stages revealed a strong negative correlation between aquatic tiller production (tillers originating from the floating, elongated stem) and stand density (r

Table 1. Stand densities and yields in deepwater rice fields at Agrakhola and Bastia, Bangladesh, 1977-80.

Site	Year	Stand density (tillers/m²) Preflood maximum	Late elongation stage	Panicles at harvest	Yield (t/ha)
Agrakhola	1977	196	149	103	2.4
	1978	323	153	98	2.9
	1979	213	120	110	2.4
	1980	253	163	123	2.1
Bastia	1977	195	100	70	1.7
	1978	105	10		0.5[a]
	1979	280	190	103	2.8
	1980		167	107	1.2

[a]Yield estimated.



1. Mean stand densities of deepwater rice in a farmer's field at Agrakhola and at Bastia. Period 1 = 1 week before flooding to a water depth of 50 cm; 2 = 50-cm water depth to end July (early elongation stage); 3 = August (late elongation and aquatic tillering stage); 4 = September to early October (heading and early ripening); and 5 = at and near harvest (panicles only). Standard deviation is shown for each point.

$= -0.919^{**}, n = 9$). At stand densities of more than 170 tillers/m², less than 10% of the total were aquatic tillers, whereas at densities of less than 100 tillers/m², the aquatic tillers comprised more than 30% of the population.

Manikganj, 1978. In the shallow flooded Manikganj field the average stand density was 82 tillers/m² from July to October and 66 panicles/m² at harvest. A deeper flooded field had an average of 44 tillers/m² from July to October and 20 panicles/m² at harvest.

Pest survey fields. For 7 pure stands of flooded deepwater rice in early August 1979 a mean density of 179 tillers/m² was recorded, whereas stands of deepwater rice mixed with aus rice averaged only 93 tillers/m² ($t_9 = 3.12^*$).

Twenty-three fields were sampled from July to early October in 1980. On the Meghna and Ganges floodplains the mean stand density decreased from 197 tillers/m² before mid-August, to 149 tillers/m² for the period from mid-September to early October ($t_{10} = 2.81^*$). Mean stand density was significantly lower (99/m²) on the severely flooded Jamuna floodplain (Table 2).

Varietal screening experiments. At Agrakhola in 1978, plant stands of 3 BR (Bangladesh Rice Research Institute) and 2 BKN (Bangkhen, Thailand) advanced breeding lines failed to recover from 2 hand weedings followed by normal flooding, whereas all of the 10 Bangladesh indigenous varieties produced good stands.

Four advanced breeding lines and 17 indigenous varieties (16 BR and Yodaya from Burma) were screened at 2 deeply flooded sites in 1979. At Habiganj, despite high stand densities (>300 tillers/m²) and weeding, subsequent flooding (95 cm in the first 10 days, 190 cm after 28 days) severely reduced the plant stands of the advanced breeding lines (Table 3). Only 3 of the indigenous varieties (Balam, Bunajota, Yodaya)

Table 2. Mean stand density, water depth, panicle density, and yield of deepwater rice on three floodplains, Bangladesh, 1980. Data presented for the last three characteristics are from Catling and Islam, this volume.

Floodplain	Fields sampled (no.)	Stand density[a] Jul to Sep (m^2)	Maximum water depth (m)	Panicle density[b] (m^2)	Yield[c] (t/ha)
Meghna	7	179 a	2.01	119 a	2.6 a
Ganges	11	158 ab	2.46	109 ab	2.0 b
Jamuna	5	99 c	2.74	82 b	1.4 c

[a]Means followed by a common letter are not significantly different at the 1% level (F = 6.35, CV = 27.2%). [b]Means followed by a common letter are not significantly different at the 5% level (F = 8.51, CV = 24.4%). [c]Means followed by a common letter are not significantly different at the 1% level (F = 14.85, CV = 30.3%).

Table 3. Effect of hand weeding and flooding on the density of advanced breeding lines and indigenous varieties of deepwater rice in the fields at Habiganj, Bangladesh, 1979.

Preflood stand (tillers/m^2)[a]				Rating of stand at flowering
50-100	100-200	200-300	300-400	
			Shulpan	Good
		Chamara		Very good
		Habiganj Aman II		Very good
		Khama		Good
		Chota Bawalia		Good
		Mura Bajal		Good
	Sarsari			Good
	Lakshmidigha			Good
	Kartiksail			Good
	Pankaish			Good
	Puiatipari			Medium
	Badal 106			Medium
Habiganj Aman VIII				Good
Raja Mondal				Good
			BR222-B-358	Poor
			BR222-B-323	Very poor
			BR117-3B-37	Very poor
			BR116-3B-28	Very poor
		Balam		Poor
		Bunajota		Very poor
	Yodaya			Very poor

[a]Mean densities significant at the 1% level (F = 5.03).

were seriously affected. Habiganj Aman VIII (on its home ground) and Raja Mondal, with less than 100 tillers/m^2 50 days after sowing, developed good stands. Entries rated poor or very poor produced four times more aquatic tillers than those rated good or very good at flowering (t_{17} = 7.02**). Advanced breeding lines also produced poor stands in an identical experiment at Manikganj but the results were partly confounded by mealybug attack.

Another varietal screening in 1979 at Agrakhola was subjected to normal hand weeding, severe drought stress, and a floodwater rise of 5 cm/day up to a depth of 184 cm. Seventy-five percent of the 20 advanced breeding lines in the trial were severely affected but only 15% of the 61 Bangladesh indigenous varieties included showed poor stands at flowering. Eight non-Bangladesh indigenous varieties were intermediate.

Stand density and yield

Data relating maximum preflood stand density to eventual grain yield were limited to four observations at Agrakhola and two observations at Bastia. There was some indication that a preflood stand of 260 tillers/m^2 is required for a 2.5 t/ha yield, and 320 tillers/m^2 for a 3 t/ha yield. However, it was sometimes observed that vigorous varieties with preflood stands of less than 100 tillers/m^2 went on to produce good stands at flowering and thus satisfactory yields.

More data were available for relating stand density in the late elongation stage (August to early September) to grain yield. There was a significant correlation (r = 0.798**, n = 13) between stand density and yield for the combined data from the two main study sites (Table 1), the two Manikganj fields in 1978, and the means for the three floodplains in the 1980 surveys (Table 2). Regression analysis indicated that at the late elongation stage, 190 tillers/m^2 is associated with a 2.5 t/ha yield and 220 tillers/m^2 with 3 t/ha.

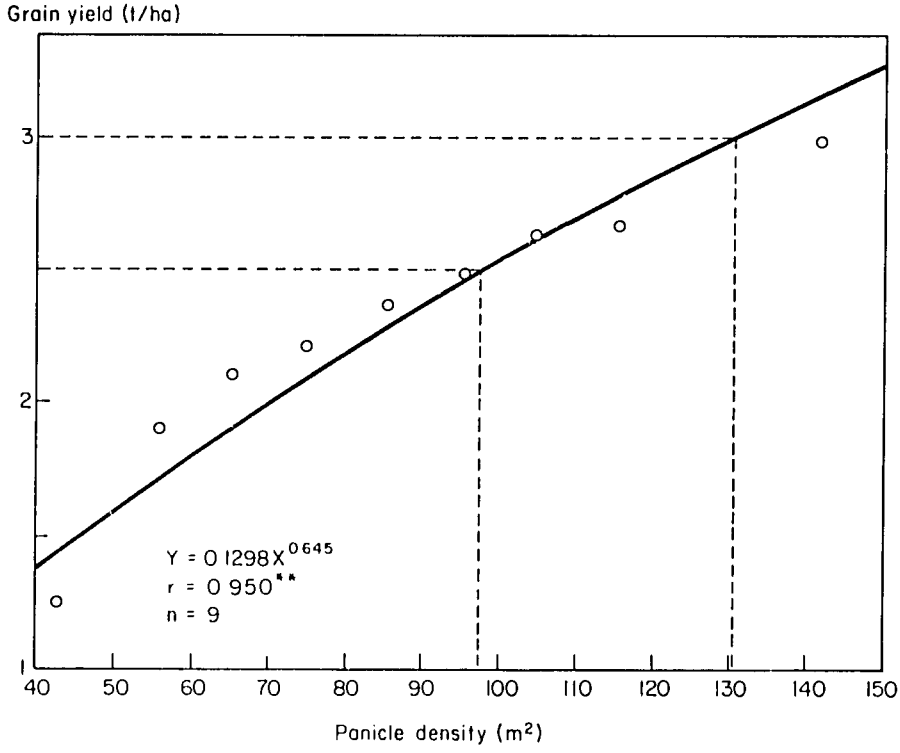
As expected, the best correlation was between panicle density at harvest and grain yield. This was evident for varieties such as Chota Bawalia, Gabura, and Sail Kotha when plotted individually. When data were taken from 202 fields sampled from 1977 to 1980, which included all varieties (24) with medium panicle weight, the mean yield differences within 9 categories of panicle density were significant. The mean values for panicle density and yield were strongly correlated (Fig. 2); 95-100 panicles/m^2 was required for a 2.5 t/ha yield, and 130 panicles/m^2 was associated with 3 t/ha. In 38 fields yielding >3 t/ha (taking all varieties) the mean density was 109 panicles/m^2.

DISCUSSION AND CONCLUSIONS

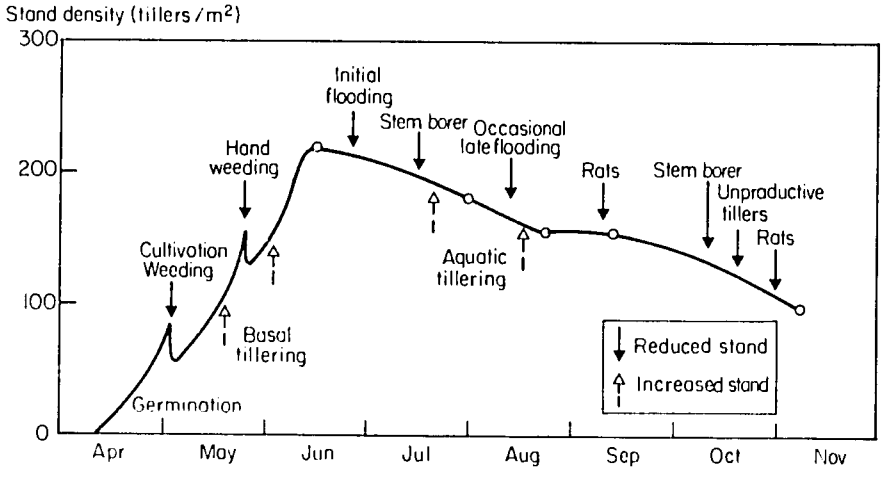
Seasonal fluctuation in stand density

Maximum stand densities were recorded in Bangladesh each year immediately before flood inundation — from mid-June to early July. At Agrakhola inundation was at a mean of 65 days after sowing (53-89 days). During the preflood period the tillering stands were temporarily reduced several times by vigorous weeding practices but the indigenous varieties always recovered strongly from those setbacks. The mean maximum stand density for *all Bangladesh study sites* was about 220 tillers/m^2 (100-320/m^2). In Thailand, maximum stand densities were recorded 40 days after seedling emergence. A marked decline in density, probably caused by drought and competition within the stand, occurred during the preflood period (Kupkanchanakul 1981).

Plant stand during the early elongation stage from the end of June to the end of July decreased to mean densities of 180 tillers/m^2 (165-200/m^2) for all sites (Fig. 3). Many stems with poor elongation ability such as secondary basal tillers (Setabutara and Vergara 1970) and stems damaged by yellow rice borer (Catling 1981) do not survive the rise in floodwater. Except in 1980, the water rise was more gradual in August and



2. Panicle density and yield of deepwater rice in farmers' fields in Bangladesh based on 202 observations in 202 fields, 1977-80.



3. Seasonal fluctuation of indigenous deepwater rice stands in Bangladesh with major factors affecting stand density. Based on the results from all study sites from 1977 to 1980.

early September and the level remained static or even subsided for short periods. Most aquatic tillers were produced at this time and partly compensated for the earlier loss of main stems and basal tillers. Thus, aquatic tillering, which was more active at low stand densities, tended to dampen the decrease in stand so that there was a smaller decrease during this period to a mean of 150 tillers/m^2 for all sites (Fig. 3). Losses from yellow rice borer continued in August and September and stem cutting at the water surface by rats begins in July or August (Catling and Yasin 1981).

Stand assessments were less reliable during the reproductive phase from the end of September to October-November because of the difficulty of counting the dense mat of floating tillers and the need for increasing the sampling interval to avoid excessive plant damage. However, a sharp decrease in plant stand to mean densities of 90-100 panicles/m^2 was evident before harvest (Fig. 3). Losses to borers and rats continued. It is also likely that some stems are unproductive due to a shading effect and because some aquatic tillers are still in an early reproductive stage when the main crop is ripe (Kupkanchanakul, T., Rice Division, Thailand, pers. comm., 1981).

Comparing the mean maximum preflood stand density with the mean density of panicles at harvest at the 2 study sites, we found a 54% loss of stand for years 1977 to 1980. In another Bangladesh field study, based on 3 varieties at 3 sites, plant stand decreased from 285 tillers/m^2 before flooding to 123 panicles/m^2 or 57% (Francis 1980). In Thailand the stands of most varieties decreased during the flooding period in a field study at Ayudhaya (Kupkanchanakul 1981). This decrease in stand density, which is a regular feature of flooded deepwater rice, represents a serious obstacle to yield improvement.

Weakness of breeding lines

Many of the advanced breeding lines showed poor growth and survival when grown in farmers' fields. Normal weeding practices followed by a typical rise of floodwater resulted in poor stands at flowering and thus low yields. It is possible that the normal method of generation advance by transplanting in deepwater ponds with little or no growth stress is partly responsible for this dangerous loss of vigor. Strong seedling vigor is essential in deepwater rice varieties for Bangladesh where farmers weed rigorously.

Relation of stand density to yield

Many diverse factors affect the stand density of deepwater rice throughout its long growing period. Thus, it is not surprising that stand density in the early growth stages may sometimes give a poor indication of eventual yield. Varietal differences and the vagaries of flooding are particularly important in the vegetative phase. Hardy varieties may overcome poor early stands by vigorous tillering when flooding conditions are favorable. For example, deepwater rice varieties mixed with aus rice, with stands of less than 100 tillers/m^2 after the aus harvest in July, often yield about 2 t/ha in November (Catling et al 1980).

Stand density at the elongation stage and counts of panicles near harvest were fairly reliable predictors of grain yield. However, another set of factors influencing panicle weight has a bearing on the accuracy of panicle counts. Large varietal differences were found in the panicle weight of Bangladesh indigenous varieties: from <2 g (variety

Gabura) to >4 g (Boron group). Average panicle weight also varied between seasons. The lighter panicles produced by the severe flooding in 1980 may be seen by comparing the mean panicle densities and yields of the 3 floodplains shown in Table 2 with the regression in Figure 2. Yields were 0.3-0.8 t/ha lower than the predicted values; the widest gap was recorded for the Jamuna floodplain where flooding was most severe. Although the stand density was not affected, the yields of several individual varieties were depressed in 1980 (see Chota Bawalia at Agrakhola, and Digha at Bastia in Table 1). Yield is also influenced by the relative proportion of main stems, basal tillers, and aquatic tillers at harvest, because panicle weight varies with tiller type. Heaviest panicles are borne by basal tillers whereas aquatic tillers, especially those developing late, bear lighter panicles (Setabutara and Vergara 1979, Francis 1980, Catling 1981). Panicle weight is reduced by yellow rice stem borer attack (Catling and Islam 1979).

Given the fact that most Bangladesh varieties require a density of 120-130 panicles/m^2 to ensure a 3 t/ha yield and assuming average growing conditions, the 3 t/ha yield will reouire about 200 tillers/m^2 in the late elongation stage, 240 tillers/m^2 in the early elongation stage, and about 300 tillers/m^2 before flood inundation.

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DISCUSSION

FRANCIS Could a refinement be made of your recommendations for different cultural practices such as growing aus-aman mixes, transplanting, and fertilizer use, which may result in changed panicle weights of the same variety?

CATLING: This could well be done for some factors after another examination of the field data.

HOQUE: You showed a panicle density of 90/m^2 in mix-cropped field and 170 panicles/m^2 in pure stand. Could you please give an idea as to how many panicles of aus rice you found per square meter in aus and deepwater rice yields from the two stand types?

CATLING: The panicle densities of aus rice were not measured separately.

OITA: Mixing of early- and late-maturing varieties can be an insurance for farmers to ensure a harvest. In other words, it is the wisdom of farmers. In such a situation, you should include both types in your countings until final yields.

CATLING: Both pure stands of deepwater rice and mixed stands of deepwater rice plus aus rice were included in the data presented, but not separately.

BIOLOGICAL NITROGEN FIXATION AND SCREENING RICES FOR DROUGHT TOLERANCE

POTENTIAL OF BIOLOGICAL NITROGEN FIXATION IN DEEPWATER RICE

I. Watanabe, W. Ventura, W. Cholitkul, P. A. Roger, and S. A. Kulasooriya

SUMMARY

Aquatic roots, leaf sheaths and, to a lesser extent, culms of deepwater rice under water are colonized by epiphytic N_2-fixing blue-green algae (BGA). BGA were also within the air cavities of decaying leaf tissues. Rice was grown in pots containing ^{15}N-labeled ammonium sulfate in shallow and deep (<110 cm) water in fields in the Philippines and Thailand. Rice plants in deep water had lower ^{15}N enrichment, suggesting that nitrogen in floodwater either as molecular nitrogen or combined nitrogen, or both, contributes to nutrition of deepwater rice. Submerged leaf sheaths and roots shaded by black cloth had higher ^{15}N content than nonshaded ones, suggesting also epiphytic N_2-fixation by BGA.

Direct evidence of N_2-fixation associated with deepwater rice was obtained by exposing deepwater rice to $^{15}N_2$ gas for 9 days. Higher enrichment of ^{15}N from molecular nitrogen was found in the aquatic root and leaf sheath where blue-green algae grow epiphytically. Eight mg N/plant was fixed during this period and about 40% of fixed nitrogen was found at maturity in the portions not directly exposed to $^{15}N_2$.

For many years, deepwater rice has been grown without the benefit of fertilizer nitrogen but with good biomass production. Little is known about the sources of nitrogen for deepwater rice. The submerged stems produce clusters of aquatic roots, which grow freely and may absorb nutrients from the floodwater. However, the extent to which deepwater rice can absorb nitrogen directly from the floodwater is not known; neither is the contribution of biological nitrogen fixation to its nitrogen nutrition.

We studied the algal biomass attached on the surface of the submerged and floating parts of deepwater rice and used ^{15}N to see if nitrogen fixation by epiphytic blue-green algae (BGA) contributes to the nitrogen nutrition of deepwater rice.

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EPIPHYTIC NITROGEN FIXATION ON DEEPWATER RICE

Studies of epiphytic N_2-fixation in rice and weeds in a shallow-water rice field by Roger et al (1981) and Kulasooriya et al (1981b) have indicated that epiphytic microorganisms make a limited contribution of nitrogen in this ecosystem. This was related to a limited biomass offered to epiphytism. In deepwater rice, on the other hand, a large part of the deepwater rice plant remains under water and offers greater biomass for colonization by aquatic microorganisms. Surveys of the BGA population and N_2-fixing (acetylene reduction) activity were made for the deepwater rice. The results were published by Kulasooriya et al (1981a).

Methods

A deepwater rice (DW6255) was grown in pots and transferred to an IRRI deepwater plot (14 × 38 m) 30 days after planting. Water depth was increased 10 cm every other day to a final depth of 110 cm, which was maintained. Epiphytic microorganisms in the plot were examined microscopically every 3 weeks. Algae and bacteria were counted and measurements of acetylene-reducing activity (ARA) were made at rice heading and maturity.

At heading, 7 plants were removed from the plot, their aerial parts and roots cut off, and the remainder of the material was used for measuring ARA and enumerating the epiphytic algae. ARA was measured on 4 replications (30 g fresh weight) randomly taken and incubated with 10% acetylene in air (in 900-ml plastic cylinders) at room temperature (30-32°C), either in light (800 lx) or in darkness (wrapped in aluminum foil). Gas samples were removed after 30 and 90 minutes of incubation for chromatographic analysis. Algal enumerations were as described by Roger et al (1981).

At maturity, the lower part of the plant grew vertically in water (submerged part) followed by the upper part growing horizontally just beneath the water surface (floating part). Aerial tillers grew upward from the floating parts.

After removing the aerial tillers and roots, each plant was separated into floating and submerged parts. Fresh weights of aerial tillers, floating parts, submerged parts, and roots were obtained from 8 separate plants. Light and dark ARA measurements were made for randomly selected triplicate samples (100 g fresh weight) of intact floating and submerged parts. The exposed roots, leaf sheaths, inner roots (enclosed by leaf sheaths), and culm portions were separated from each of the floating and submerged parts of one plant. Aliquot triplicate samples were taken randomly from each of these separated parts for ARA measurement and algal enumerations.

Distribution of epiphytic microorganisms

Microscopic examination for epiphytic algae revealed the presence of BGA, green algae, and diatoms attached to the surface of exposed roots, leaf sheaths, inner roots, and culm. The predominant BGA were N_2-fixing ones, notably *Nostoc*, *Anabaena*, *Calothrix*, and *Gloeotrichia*. These epiphytic species were seen on submerged and floating parts. *Nostoc* was frequently present at the points of lateral branches of roots, whereas *Calothrix* did not show any such preference. *Gloeotrichia* was more common on the decaying leaf blades and sheaths than on other parts. Observations on dissected parts and sections indicated that:

- species of *Nostoc* and *Calothrix* were present on the leaf sheaths,
- the algae were also present inside the air cavities of the leaf sheaths, but not within the host cells, and
- this *endophytism* was common within senescent or dead material but absent in living tissues.

Within the limit of accuracy of the method of algal enumeration used (Roger and Reynaud 1978), no significant difference in the population size of BGA was found among submerged and floating parts. Among the different components of the plant, the culm supported the lowest number of BGA (Kulasooriya et al 1981a). Integrated algal densities on the different components corresponded to an N_2-fixing population of 33×10^4 colonies per gram fresh plant material available for epiphytism. The value was of the same order as that obtained with intact host material at heading (23×10^4 colonies/g fresh weight), possibly indicating that algal colonization had not changed between heading and maturity of the crop. It should be noted, however, that the enumeration method does not distinguish between propagules and active cells.

Nitrogenase activity

ARA measurements at heading and maturity revealed that activity in the light was 3 times more at heading and more than 13 times higher at maturity than in darkness, indicating that photodependent N_2-fixation, probably by BGA, was more active than heterotrophic N_2-fixation (Table 1). Relating the specific activities to the rice plant biomass, total photodependent activity per plant was 3.9 and 4.6 μmol C_2H_2/hour at heading and maturity. These were equivalent to 1.2 and 1.4 μmol C_2H_2/m^2 per day when extrapolated to the field on the basis of 12/12 hours day-night cycle, and a

Table 1. Acetylene-reducing activity in the component parts of a deep-water rice plant at maturity (Kulasooriya et al 1981a).

Component parts of plants	Biomass (g fresh weight/ plant)	Light: Specific ARA (nmol C_2H_4/g fresh weight per h)	Light: ARA[a] (nmol C_2H_4/h)	Dark: Specific ARA (nmol C_2H_4/g fresh weight per h)	Dark: ARA (nmol C_2H_4/h)
Floating					
Exposed roots	2.5	24	61	0.06	0.15
Leaf sheath[b]	62	54	3,348	1.5	93
Inner roots	0.25	69	17	0.03	0.01
Culm	98	2.5	245	0.5	49
Submerged					
Exposed roots	64	0.5	35	0.08	5
Leaf sheath[b]	15	12	180	0.1	1.5
Inner roots	1.3	3	4	0.05	0.06
Culm	100	0.3	30	0.02	2

[a]Specific ARA x component biomass. [b]Covered by leaf sheath.

planting density of 25 plants/m^2.

This level of activities (more than 1 μmol C_2H_2/m^2 per day) was observed in the field when algal biomass was visible in the floodwater (Watanabe et al 1978). ARA measurements associated with separated parts of the plants (Table 1) clearly demonstrated that activity in the light was always higher than that in darkness and that specific activities associated with the floating parts were higher than the corresponding activities on the submerged parts. Among the different components, highest specific activity was associated with the inner root on the floating part followed by the leaf sheath, exposed root, and culm. However, the total activity of each part of the plant (specific ARA × fresh weight) was clearly highest in the leaf sheath, followed by the culm and exposed root.

SOURCES OF NITROGEN TO DEEPWATER RICE OTHER THAN SOIL

To estimate the contribution of nitrogen from the floodwater, DW6255 was grown in pots containing a small amount of ^{15}N ammonium sulfate. Rice was grown either by shallow flooding of the pots or by putting the pots in a deepwater plot. The experiments were at IRRI and in Thailand.

Methods

Maahas clay soil (7 kg dry weight/pot) was mixed with ^{15}N-labeled (6.948 atom % excess) ammonium sulfate at 500 mg/pot during the 1979 wet season and 600 mg N/pot (17.21 atom % excess) during the 1980 wet season. DW6255 seedlings were transplanted at 1 seedling/pot. When rice was 49 days old, one series of pots was placed on the bottom of a 19 × 38 m deepwater plot at IRRI and water depth was increased 10 cm every other day to a final depth of 110 cm, which was maintained until maturity. Other pots were placed on an elevated platform built in the deepwater plot, which gave 5-cm flooding on the pot surface. A black cloth covered the surface of half of the shallow-water pots to prevent algal growth on the soil surface. In deep water a round metal support of 20 cm diameter and 90 cm height was placed on top of the pots. The outside of the support was covered with black cloth to prevent algal growth on the portion of deepwater rice below water.

In a similar experiment in Thailand, soil from a field at Bangkhen was mixed with ^{15}N-labeled ammonium sulfate at 200 mg N/pot (12.538 atom % excess). Pots in shallow water were placed in a greenhouse at Bangkhen. Pots for the deepwater test were put in a plot at Huntra, which was flooded to 50 cm or less. Other pots were placed in a farmer's field at Ongkarak, which was flooded to about 120 cm.

There were 5 replicated pots in every site. At maturity, the plant parts were separated as in ARA assays described earlier. The dried materials were analyzed for total nitrogen by micro-Kjeldahl and for ^{15}N by emission spectrometry.

^{15}N dilution as affected by water depth

The black cloth covering the submerged portions of the rice plant adversely affected the growth of deepwater rice, resulting in less tillers and panicles than the nonshaded plants (data are not presented).

Total N and dilution of ^{15}N in plants are shown in Table 2. Content of ^{15}N in plant

Table 2. Total nitrogen and ^{15}N contents and dilution of ^{15}N in total plant portions in experiments in shallow and deep water. Philippines and Thailand.

Site	Season[a]	Water depth (cm)	Shading	Total N (mg/plant) A	Total N (mg/plant) B	Dilution A/B
Philippines						
IRRI	1979 wet	5	Yes	923 ± 31[b]	273 ± 10	3.4
		5	No	879 ± 47	235 ± 11	3.7
		110	Yes	618 ± 31	114 ± 13	5.4
		110	No	983 ± 67	212 ± 17	4.6
	1980 wet[a]	5	No	939 ± 13	380 ± 1	2.5
		110	No	777 ± 31	283 ± 10	2.7
Thailand						
Bangkhen	1979 wet	5	No	829 ± 65	112 ± 8	7.4
Huntra		<50	No	1,030 ± 115	74 ± 5	13.9
Ongkarak		120	No	988 ± 79	98 ± 11	10.1

[a]Atom % excess was 6.948, 17.210, and 12.538 in 1979, 1980 at IRRI, and 1979 in Thailand respectively. [b]Mean ± standard error.

was clearly lower in the deep than in the shallow water.

If the contribution of soil nitrogen in pots was not affected by the floodwater depth, lower atom % ^{15}N in deepwater rice would mean that nitrogen was absorbed from floodwater. If the nitrogen in the plant comes partly from biological N_2 fixation by epiphytic BGA, the deepwater rice of which the submerged parts were covered by black cloth must have higher atom % ^{15}N. The analysis of the plant, however, did not prove the expectation. Because the growth and nutrient uptake of deepwater rice was adversely affected by the black cloth, the result must be interpreted with some reservation. Atom % excess of various parts of deepwater rice showed that exposed root, inner root, and leaf sheath below water had lower ^{15}N when not shaded than when shaded (Table 3). In trials in Thailand (Table 4), the leaf sheath and root under water showed lower enrichment of ^{15}N than other plant parts. These sites showed higher specific ARA as shown in Table 1 and, hence, were the major sites of epiphytism by BGA. Therefore, it is reasonable to attribute lower ^{15}N contents in the parts under water to ^{15}N-fixation by epiphytic BGA.

In shallow water, the plant parts under water also showed lower ^{15}N content (data are not presented) and shading of those parts increased ^{15}N enrichment, indicating that even in shallow water, epiphytic N_2 fixation is associated with shoots under water.

Nitrogen derived from the floodwater (including both combined and molecular nitrogen) is estimated by the equation

$$\text{Estimated N absorbed from floodwater} = \left(1 - \frac{\text{atom \% excess in deepwater rice}}{\text{atom \% excess in shallow water rice}}\right) \times \text{Total N of deepwater rice}$$

Table 3. Total N and ^{15}N atom % excess in various parts of rice grown in deep water, IRRI, 1979 wet season.

Parts	Submerged portions not shaded		Submerged portions shaded	
	Total N (mg/pot)	Atom % excess	Total N (mg/pot)	Atom %[a] excess
Aerial parts				
Grain	346 ± 32	1.68 ± 0.08*	234 ± 29	1.41 ± 0.14
Leaf blade	122 ± 23	1.60 ± 0.08*	65 ± 7	1.39 ± 0.08
Culm and leaf sheath	116 ± 9	1.67 ± 0.04*	105 ± 3	1.33 ± 0.11
Upper submerged parts				
Leaf sheath	58 ± 8	0.93 ± 0.07	21 ± 1	1.01 ± 0.09*
Culm	75 ± 14	1.71 ± 0.06*	43 ± 3	1.42 ± 0.11
Exposed root	20 ± 5	0.60 ± 0.33	27 ± 5	0.80 ± 0.10*
Inner root	4 ± 1	0.67 ± 0.06	3 ± 1	0.89 ± 0.09*
Lower submerged parts				
Culms	67 ± 10	1.94 ± 0.05*	15 ± 2	1.24 ± 0.07
Exposed root	130 ± 9	0.81 ± 0.06	97 ± 9	0.94 ± 0.10*
Root in soil	45 ± 7	1.58 ± 0.10*	7 ± 1	0.98 ± 0.07
Whole plant		1.84 ± 0.09		1.47 ± 0.11

[a]Shows that atom % excess indicated with * was significantly higher than that of the other treatment.

This equation is similar to the estimation of N_2-fixation by measuring ^{15}N abundance in non-N_2-fixing and N_2-fixing plant (Rennie et al 1978).

The estimates of nitrogen absorbed from floodwater were 178 and 80 mg N/pot at IRRI in 1979 and 1980 trials. These accounted for 18 and 10% of the total nitrogen in the plant. In Thailand, the values were 479 and 264 mg N/pot in Huntra and Ongkarak, corresponding to 46 and 27% of the total N in the plant. But because the shallow-water pots in Thailand were not at the same sites and some roots were attached to the soil after the water receded, the results must be considered with some reservation.

Assuming that the shaded submerged plant parts are non-N_2-fixing (photodependent) ones, photodependent N_2-fixation associated with deepwater rice was calculated by an equation similar to equation 1. In shallow water, this value was 84 mg N/plant. But in deep water, the calculation was impossible for total plant part because of higher atom % excess in nonshaded condition.

But such a calculation is possible in each part where atom % excess was higher in shaded than in nonshaded condition. The total for estimates of photodependent N_2-fixation in the leaf sheath, the exposed root, and the inner root of the upper submerged part and the exposed root of the lower submerged part was 58 mg N/plant.

Table 4. Atom % excess in different parts of deepwater rice plants grown in Thailand, 1979. Rice variety was Leb Mue Nahng 111.

Site	Water depth (cm)	Parts	Atom % excess
Bangkhen	Shallow (5)	Panicles	1.48 ± 0.10
		Leaf blade	1.82 ± 0.17
		Leaf sheath	1.87 ± 0.09
		Culm	1.53 ± 0.11
Huntra	Semideep (<50)	Panicle	1.01 ± 0.08
		Leaf blade	1.06 ± 0.07
		Leaf sheath	0.77 ± 0.04
		Culm	0.94 ± 0.08
Ongkarak	Deep (120)	Panicle	1.36 ± 0.21
		Leaf blade	1.31 ± 0.09
		Upper leaf sheath	1.36 ± 0.08
		Upper culm	1.38 ± 0.19
		Lower leaf sheath	1.07 ± 0.12
		Lower culm	1.27 ± 0.14
		Root in water	1.02 ± 0.16

$^{15}N_2$ INCORPORATION BY DEEPWATER RICE

The experiments described strongly suggest that N_2-fixation takes place in association with aquatic parts of deepwater rice. $^{15}N_2$-feeding experiments were conducted to get direct evidence of N_2-fixation and to see to what extent the fixed nitrogen is transferred to aerial parts.

Method

DW6255 was grown in IRRI's deepwater plot in the same way as in the ^{15}N dilution experiment except that 600 mg N/pot of the nonlabeled ammonium salt was added to the soil. At heading, the entire submerged portion, plus about 15 cm of the aerial part of the rice culms, was enclosed in plastic bags such as those used in ARA assays of wetland rice soil (Watanabe et al 1978). The bag opening around the culm was sealed by modeling clay. The plastic bag was completely filled with floodwater and assay chambers were submerged in deepwater plot.

^{15}N-labeled N_2 gas (Monsanto Research Corporation USA, 98 atom %) was washed by potassium permanganate solution and acidic sodium sulfate. One liter of ambient air and 1 liter of $^{15}N_2$ gas were introduced into the plastic bag, and the air was circulated through the assay chamber for 5 minutes to solubilize the introduced gas in the floodwater. Labeled N_2 in the chamber was changed every 2 or 3 days (4 changes) for 9 days. Control plants were grown beside the $^{15}N_2$-fed rice plant. Each treatment had 4 replications.

Analysis of $^{15}N_2$ in the plastic bag just after introduction and before changing gas

phase was by emission spectrometry. After 2 or 3 days, atom % ^{15}N in N_2 gas decreased to about 23, and the average of ^{15}N abundance during the 9 days was 48%.

After the assay chamber was removed, the rice plants were grown to maturity. At maturity, aerial, floating, and submerged portions were removed and ^{15}N abundance of the different parts was determined by mass spectrometer (VG Micromass 622). ^{15}N abundance in the control plant parts was also analyzed.

Results

^{15}N enrichment was found in all parts of the plant exposed to ^{15}N (Table 5). Among the parts under water, leaf sheath had the highest ^{15}N enrichment, followed by aquatic root, culm, and root in the soil.

These results agree with those of the earlier ARA and ^{15}N dilution experiment, indicating that leaf sheaths and aquatic roots and, to a lesser extent, culms were the sites of N_2-fixation in association with deepwater rice.

Labeled nitrogen was also found in aerial parts not exposed to $^{15}N_2$. About 40% of fixed nitrogen was found in the aerial parts, the leaf blade acting as sink.

Eight mg N was fixed during 9 days. This value was higher than those reported by Ito et al (1980) and Yoshida and Yoneyama (1980) by heterotrophic bacteria in association with shallow-water wetland rice.

Table 5. N_2-fixation by deepwater rice exposed to $^{15}N_2$ for 9 days. IRRI, 1980 wet season.

Plant parts	Total N (mg N/pot)	Atom % excess	Fixed N (µg N/plant)[a]
Aerial parts			
Grain	184 ± 33	0.04 ± 0.02	149
Leaf blade	75 ± 17	1.77 ± 0.88	2780
Leaf sheath	28 ± 3	0.30 ± 0.21	208
Culm	26 ± 4	0.11 ± 0.07	57
Upper parts			
Leaf sheath	36 ± 3	3.12 ± 1.14	2310
Culm	27 ± 1	0.48 ± 0.15	264
Root	6 ± 3	2.01 ± 0.77	267
Lower part			
Leaf sheath	29 ± 3	1.37 ± 0.46	831
Culm	28 ± 4	0.27 ± 0.07	153
Root	35 ± 3	0.66 ± 0.28	625
Root in soil	68 ± 6	0.23 ± 0.11	329
Whole part	542 ± 51		7973
Submerged weed	41 ± 12	0.97 ± 0.48	823

[a]Assuming an average of 48.1 % excess of $^{15}N_2$ during 9 days exposure.

DISCUSSION

Molecular nitrogen is fixed in deepwater rice by both photodependent and heterotrophic N_2-fixing microorganisms. The role of N_2-fixation in nitrogen nutrition of deepwater rice was proven by ^{15}N dilution technique and direct exposure of deepwater rice with $^{15}N_2$. Greater contribution by BGA was indicated by greater ARA in light than in darkness and by greater ^{15}N dilution in the submerged tissues not shaded. Although $^{15}N_2$ feeding experiments were not conducted with shaded plants, the assumption that $^{15}N_2$ was fixed more by photodependent N_2-fixing microorganisms than by heterotrophic microorganisms is in agreement with data obtained by ARA and ^{15}N dilution techniques.

Previous observations had been that epiphytic BGA preferentially developed on the submerged decaying tissues of the host (Kulasooriya et al 1981a). The idea that N_2 fixation by epiphytic microorganisms results in the accumulation of nitrogen in decaying tissues and this fixed nitrogen is not directly available by host plant is not supported by the results we describe here. In the $^{15}N_2$-feeding experiment, the contribution of phototrophic N_2-fixing microorganisms to the transferred nitrogen was not directly assessed. It is reasonable, however, to assume that the transferred nitrogen came partly from photodependent N_2-fixation, because ARA values associated with submerged parts were much greater in the light than in darkness and the total amount of N fixed during the $^{15}N_2$ exposure appeared to be much higher than the reported heterotrophic N_2-fixing rates associated with wetland rice (Ito et al 1980, Yoshida and Yoneyama 1980).

Extrapolating the observed N_2-fixing activity for 9 days to 100 days, which is assumed as the submerged growth period of deepwater rice, N_2-fixation explains about 10% of total nitrogen in deepwater rice at maturity (80 mg N over 800 mg N in total biomass of the host). Because BGA on deepwater rice grown in IRRI's deepwater plot grew much less profusely than BGA associated with deepwater rice in Thailand (visual observation by authors), the role of BGA in nitrogen nutrition of deepwater rice field could be much greater than those found at IRRI.

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DISCUSSION

DE DATTA: Is epiphytic nitrogen fixation greater in deepwater rice than in shallow-water wetland rice?

WATANABE: N_2-fixing activity per rice plant was much higher in deep water than in shallow water. This is due to highly photodependent N_2-fixing activity (as shown in Table 1) and to higher biomass under water.

GOMOSTA: How is the $^{15}N_2$ fixed by epiphytic algae absorbed and transported to aerial parts?

WATANABE: The possibility of nitrogen fixation by aerial plant parts is ruled out because of negligible acetylene reduction activities of the aerial parts. I suspect that $^{15}N_2$ is fixed in algae cells and released to the plant after their disintegration or decomposition. We need to determine the mechanism.

TOWNSEND: Do you see any great potential for this?

WATANABE: Our ^{15}N data show 9 mg N fixed/plant in 9 days. Assuming 90-100 days as the effective period when nitrogen fixation is going on, it becomes about 10% of the total nitrogen in the plant. I point out that our experiment at IRRI was in a shallow deepwater pond. We grow much less algae there than can be grown on farms in deepwater rice areas. Thus, I suspect the contribution in a deepwater rice area will be much higher, but I cannot say how much.

KARIM: Considering the fact that nitrogen is fixed by microorganisms in deepwater rice, what conditions would enhance or optimize the fixation rate? Do blue-green algae have preferential association with particular varieties of rice?

WATANABE: Water quality and plant morphology may affect the epiphytic growth of blue-green algae. There must be a kind of association but I have not studied varietal differences.

CATLIN: Is the high amount of nitrogen fixation in deepwater rice due to a high daily rate of fixation and the large biomass of deepwater rice?

WATANABE: It is due to the large biomass of deepwater rice. But, as shown in Table 1, photodependent nitrogen fixation in aquatic roots and leaf sheaths was much higher than heterotrophic N_2 fixation. Therefore, I suspect the daily rate was also much higher in deep water than in shallow water.

CONTRIBUTION OF ALGAE TO THE NUTRITION OF DEEPWATER RICE

M. R. Martinez and H. D. Catling

SUMMARY

One hundred and ninety-one species of algae were identified in rice and water samples from deepwater rice fields of Bangladesh and Mali. These were distributed among 6 divisions, which were dominated by Cyanophyta (blue green-algae), Chlorophyta (green algae), and Bacillariophyta (diatoms) in terms of biomass and species composition. Their habitats and some factors affecting their distribution are presented.

The contributions of these algae to the nutritional needs of deepwater rice include nutrients that become available upon the death of the algal cells and from the extracellular products or degradation products excreted by the living cells.

Attention has been focused recently on the presence of a variety of algae in deepwater rice (DWR) fields of Bangladesh (Catling et al 1982) and Mali (Martinez and Catling 1980). One hundred ninety-one species of algae were identified, of which 27 species are heterocystous types of blue-green algae (BGA) that are presumably capable of fixing atmospheric nitrogen. The estimated amount of nitrogen contributed by epiphytic algae on deepwater rice plants set up in artificial fields at IRRI was 10-20 kg N/ha (Kulasooriya et al 1981) that is almost 6 times the value obtained from epiphytic algae on shallow-water wetland experimental rice fields at IRRI (Roger et al 1981).

This paper includes a summary of a paper to be published in Phycologia (Catling et al 1982).

TAXONOMY AND ECOLOGY

Algal surveys were done in the DWR fields of Bangladesh in 1977 and 1978, and a field was sampled in Mali in 1978. The first algae samples from DWR were collected from stalks of floating rice plants in Agrakhola, Keraniganj, Bangladesh, in 1977. This was followed by a more detailed sampling in the 1978 DWR cropping season on the

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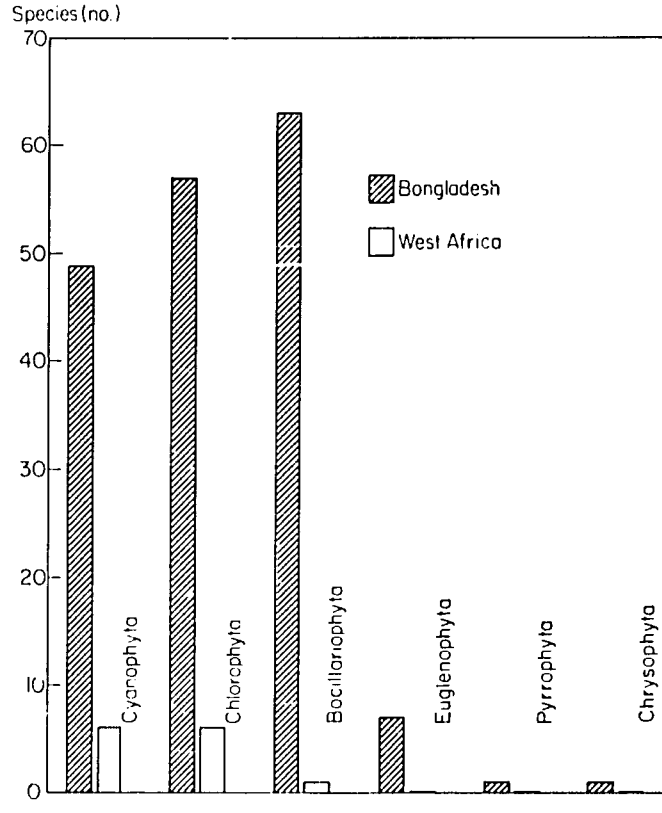
floodplains of Ganges, Meghna, and Jamuna rivers. A sequential series of samples was taken in a farmer's field at Agrakhola for determining the density of the algae on DWR plants and at 10 cm above the field's bottom.

A single collection of algae was done in DWR (160 cm deep) near Mopti, Mali, 10 October 1978. Stem sections of the variety Mogo (*Oryza glaberrima*), including aquatic roots and leaf sheaths, were collected and preserved.

The algae collected from sedimented samples and various parts of the rice plant were examined from temporary mounts prepared in lactophenol blue or glycerine jelly from 2-3 mm^2 pieces of leaf sheaths and leaf blades, and from pieces of aquatic roots 1-2 mm long. The mounts were later sealed and placed in the herbarium of the College of Agriculture, University of the Philippines at Los Banos (UPLB). When possible, identifications were to the species level but in some cases it was only feasible to identify the genus.

Enumeration of the algae was done with a compound microscope and the haemacytometer as described by Martinez et al (1975). Algal concentration was expressed as units per milliliter with a unit consisting of a colony, a filament, or a single cell.

The 191 species identified belonged to 96 genera distributed in 6 divisions: Cyanophyta (BGA), Chlorophyta (green algae), Bacillariophyta (diatoms), Euglenophyta (euglenoids), Pyrrophyta (dinoflagellates), and Chrysophyta. Numbers of species identified are seen in Figure 1.



1. Total number of species identified between groups of algae in the deepwater rice fields of Bangladesh and Mali, 1977-78.

Bangladesh

The 1977 samples yielded 24 species that included 12 cyanophytes, 4 chlorophytes, and 8 bacillariophytes (Martinez and Catling 1978). The BGA included 6 presumed nitrogen fixers: *Anabaena unispora* Gard., *Nodularia* sp., *Scytonema coactile* Montagne *ex* Born. *et* Flah., *Stigonema mesentericum* Geitl., *Calothrix marchica* Lemm., and *Microchaete robusta* Setch. *et* Gard.

In the 1978 survey, sampling began in June 1978, shortly after flooding, and continued through the crop's elongation, aquatic tillering, and maturity phases. One hundred and seventy-eight species were identified to the species level (Fig. 1).

Algae, particularly the BGA and green algae, were observed to colonize DWR immediately after crop inundation. The aquatic roots, culms, and the leaf sheaths were equally colonized. The highest density of epiphytic and planktonic types were observed in July and high densities continued until the end of September. With the exception of the diatoms, the number of algae declined markedly with flood recession in October. The late predominance of diatoms may be due to their greater tolerance for cloudy, oxygen-poor water which develops at this time.

No differences in the incidence of algae among the three main floodplains were noted. The more abundant species were represented in all areas (Catling et al 1982).

Cyanophyta. The 49 species of BGA identified comprised 28% of all algal forms taken. They were particularly abundant on the culms (32 species) and were present in every culm sample until harvest. In general abundance and number of species identified, the genus *Anabaena* was most common followed by *Gloeotrichia*, *Oscillatoria*, *Chroococcus*, *Nostoc*, *Lyngbya*, and *Microchaete*.

This group of organisms is important because it includes the heterocyst-containing filamentous forms that are capable of fixing atmospheric nitrogen. Twenty-one species of this type were identified in the Bangladesh samples (Table 1). However, there are also some nonheterocystous types containing nitrogenase, which are also capable of fixing nitrogen. Of these types 8 genera were identified in these fields: *Aphanothece*, *Gloeocapsa* (*Gloeothece*), *Synechococcus*, *Lyngbya*, *Oscillatoria*, *Phormidium*, *Plectonema*, and *Xenococcus*.

There were more species attached to plant parts (33) than found in sedimented samples (10) (Fig. 2). The attached forms were represented mostly by the species *Anabaena*, *Gloeotrichia*, and *Oscillatoria* and the sedimented samples were mostly *Gloeotrichia* and *Oscillatoria* species.

Dense colonies of *Anabaena* were observed on the culms on 23 June 1978 when floodwater was only 50 cm deep (Catling et al 1982). BGA continued to colonize the elongating plants. Among the abundant and frequently occurring epiphytic genera were *Gloeotrichia* and *Lyngbya* on aquatic roots and leaf sheaths, *Anabaena* and *Plectonema* mainly on leaf sheaths, and *Nostoc* on the culms (Fig. 3). BGA decreased when floodwater receded rapidly from mid-September to October. At that time only six BGA were recorded on the culm and in water samples, and the population density had decreased (Catling et al 1982).

Chlorophyta. The 57 identified Chlorophyta species comprised about 32% of the algal species identified (Fig. 2). Most of them were epiphytic. The most abundant were *Oedogonium*, *Cosmarium*, *Tetraedron*, *Chlorella*, *Scenedesmus*, *Staurastrum*, *Spirogyra*, *Bulbochaete*, and *Ulothrix* (Catling et al 1982). *Oedogonium*, *Spirogyra*, *Bulbo-*

Table 1. Heterocystous blue-green algae capable of nitrogen fixation identified in deepwater rice areas of Bangladesh and West Africa, 1977-79.

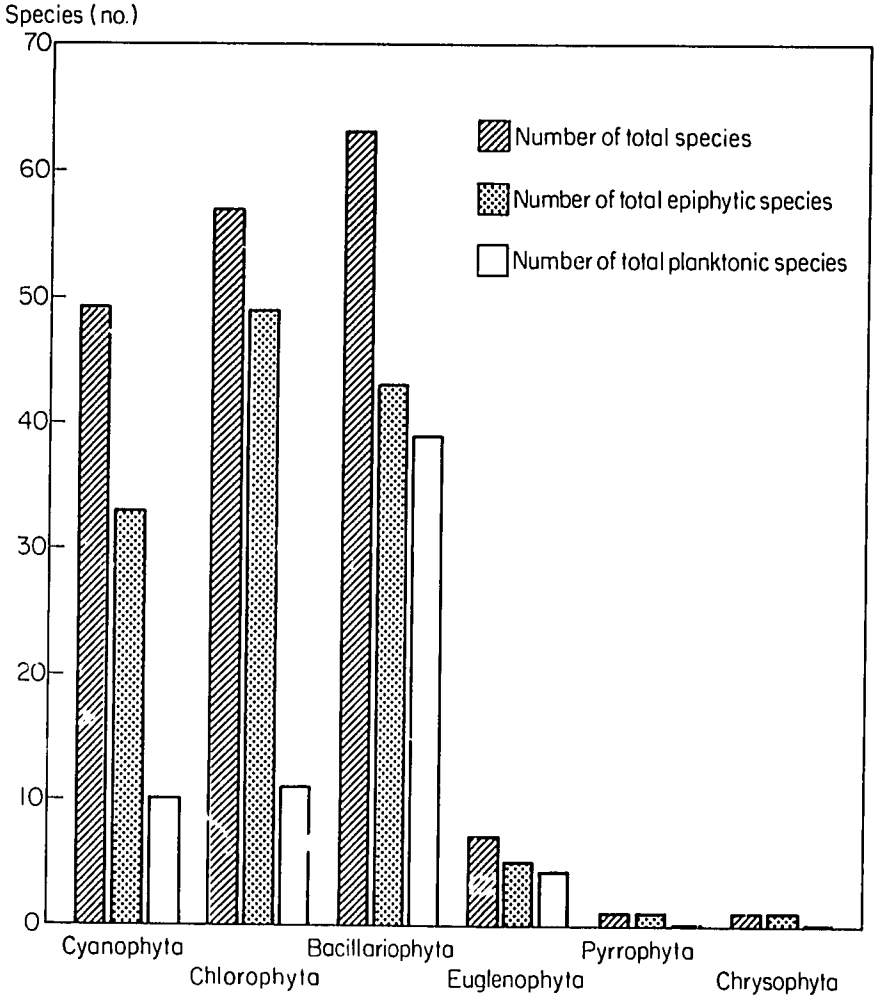
Species identified in	
Bangladesh	West Africa
Anabaena oscillarioides Bory *ex* Born. *et* Flah.	*Anabaena torulosa* (Carm.) Lag.
A. planctonica Brumthaler	*A. vaginicola* Fritsch *et* Rich
A. sphaerica Born *et* Flah.	*Cylindrospermum licheniforme* (Bory) Kuetz.
A. unispora Gard.	*Gloeotrichia natans* (Hedw.) Rabh.
Anabaena sp.	*Hapalosiphon stuhlmannii* Hieron.
Calothrix marchica Lemm.	*Nostoc* sp.
Cylindrospermum stagnale (Kuetz.) Born. *et* Flah.	
Cylindrospermum sp.	
Gloeotrichia echinulata (J.E. Sm.) P. Richter	
G. natans Rabh. *ex* Born. *et* Flah.	
Gloeotrichia sp.	
Microchaete robusta Setch. *et* Gard.	
Microchaete tenera Thuret *ex* Born.	
Microchaete sp.	
Nodularia sp.	
Nostoc commune Vauch. *ex* Born. *et* Flah.	
N. linckia (Roth) Born. Born. *et* Flah.	
Nostoc sp.	
Scytonema coactile Montagne *ex* Born. *et* Flah.	
Scytonema sp.	
Stigonema mesenteriform Geitl.	

chaete, and *Ulothrix* are filamentous and, except for *Spirogyra*, are epiphytes with a distinct holdfast and a basal-distal differentiation of the filaments. A large number of *Oedogonium* species were observed on the culm samples, (they comprised as much as 92%) and also on leaf sheaths and aquatic roots, but were not detected in the water sample.

Only 7 genera and 11 species were recorded from the water samples in the Agrakhola field. *Ulothrix* was present in about 33% of the samples and *Tetraedron* in 20% of them. Large numbers of *Ulothrix chaetales* occurred in the water sample in July (16,800 units/ml).

Like the BGA, the green algae, especially the *Oedogonium* species, rapidly colonized the flooded DWR. But their numbers declined in October in the Agrakhola field (Fig. 4).

Bacillariophyta. Sixty-three diatom species comprised 35% of the total identified

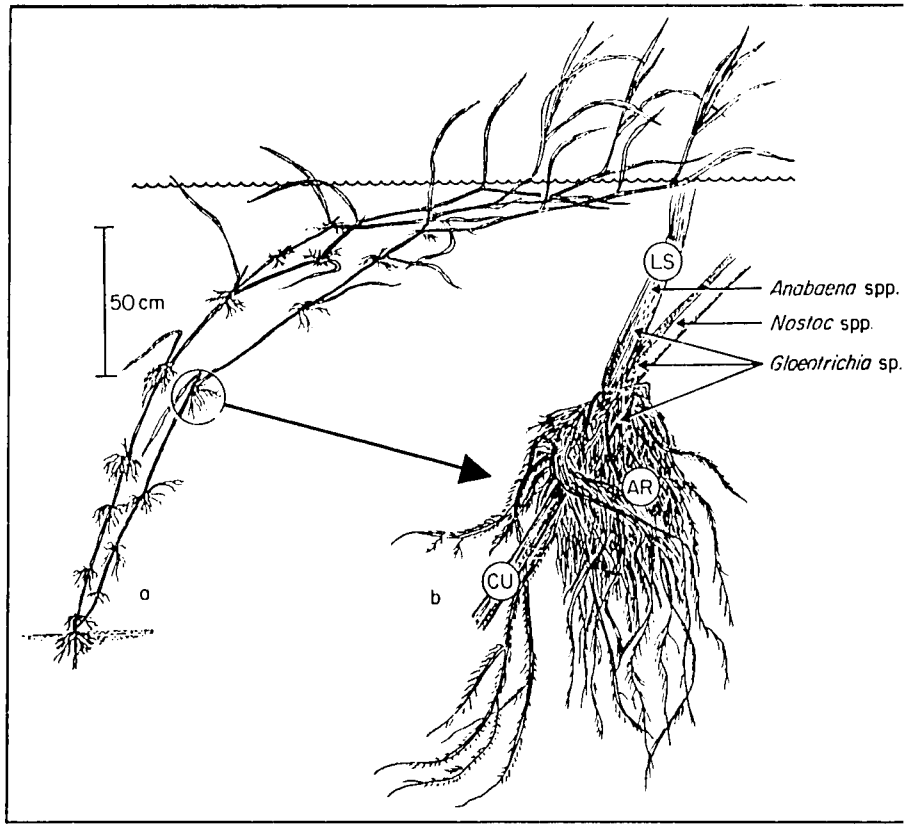


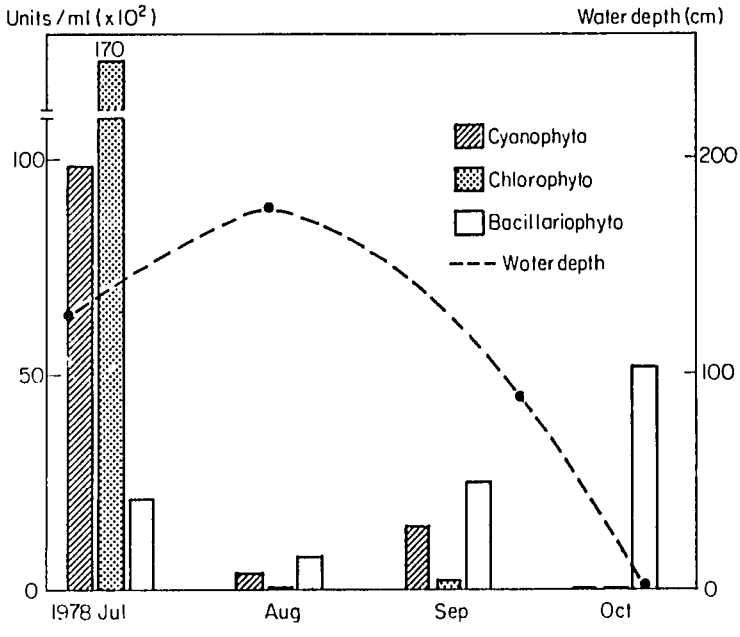
2. Relationship of the number of total species identified to the number of species observed attached on the rice plant (epiphytic) and to those found on the sediment (planktonic) in the deepwater rice fields of Bangladesh, 1978.

algae. There were almost the same number of planktonic and epiphytic types. In the floodwater at Agrakhola, 24 diatom species were recorded in significant concentration as compared to only 2 species each for the other groups. The concentration of diatoms was as high as 2,100 units/ml in July but represented only 7% of the total number of algae. As the rice plant matured and the water started receding, the diatoms became predominant.

The centric species, *Cyclotella kuetzingiana* Thw., was consistently present in significant numbers, reaching a peak in July; pennate *Synedra ulna* var. *danica* reached its maximum number in September. Other genera included: *Nitzschia*, *Melosira*, *Navicula*, *Synedra*, *Fragilaria*, *Gomphonema*, *Pinnularia*, and *Rhopalodia*. Those recorded most commonly on culms were *Coscinodiscus*, *Fragilaria*, *Nitzschia*, *Navicula*, and *Synedra*. Some were also epiphytic on leaf sheaths and roots.

Other algae. Seven species of euglenoids were recorded, comprising 4% of the total





▲ 3. Chota Bawalia, a typical Bangladesh deepwater rice variety. a) The entire plant in mid-September at the end of elongation stage; floodwater receding. b) Fully developed aquatic root system (AR) showing part of the culm (CU), leaf sheath (LS), and the typical habitat of the common N_2-fixing algae (adapted from Catling et al. 1981).

◀ 4. Relation of water depth to density of algae sampled 10-20 cm from the bottom of deepwater rice fields, Agrakhola, Bangladesh, 1978.

algae (Fig. 1). *Trachelomonas* species were present both on the culms and in the water samples. The euglenophytes and a single species each of Pyrrophyta and Chrysophyta were rare.

West Africa

Twenty-six species of algae were recorded on culm samples of the variety Mogo (*Oryza glaberrima*) obtained in 165-cm-deep water at Mopti, Mali (Martinez and Catling 1980). The 26 species consisted of 8 BGA, 13 green algae, 3 diatoms, and 2 euglenophytes (Table 2). The BGA were dominant in abundance in total species

Table 2. Some commonly occurring algae observed on the deepwater rice Mogo in Mopti, Mali. October 1978.

Species	Abundance on[a]		
	Leaves or leaf sheaths	Aquatic roots	Sediments
Cyanophyta			
Anabaena torulosa (Carm.) Lag.			A
A. vaginicola Fritsch *et* Rich	M	M	M
Chroococcus limneticus Lemm.	R	R	R
Cylindrospermum licheniforme (Bory) Kuetz.	M	R	R
Gloeocapsa quaternata (Breb.) Kuetz.	VR		VR
Gloeotrichia natans (Hedw.) Rabh.	A	M	A
Hapalosiphon stuhlmannii Hieron.	A	M	A
Nostoc sp.	A		R
Chlorophyta			
Asterionella formosa Hassal.			VR
Bulbochaetae sp.	A	R	A
Cosmarium nitidulum De Notaris			M
C. reniforme (Ralfs) Arch.			VR
C. speciosum Lundel.			VR
Cosmarium sp.			VR
Crucigenia sp.			VR
Draparnaldia sp.			VR
Oedogonium sp.	A	M	A
Pleurotaenium truncata (Breb.) Naeg.			VR
Scenedesmus obliquus (Turp.) Kuetz.			VR
Spirogyra sp.	VR		VR
Xanthidium cristatum var. *uncinatum* Breb.			VR
Bacillariophyta			
Gomphonema semiapertum Grun.	VR		VR
Pinnularia sp.			VR
Synedra ulna var. *indica* (Kuetz.) V.H.	VR		VR
Euglenophyta			
Trachelomonas crebea (Kell.) Defl.			VR
T. volvocina Ehr.	VR		VR

[a] A = abundant, M = moderate, R = rare, VR = very rare.

recorded. All, except *Chroococcus limneticus* and *Gloeocapsa quaternata*, were heterocystous-filamentous types. BGA *Hapalosiphon* and the greens *Asterionella*, *Draparnaldia*, and *Xanthidium* were recorded only in Mali.

AVAILABILITY OF ALGAL NUTRIENTS TO DEEPWATER RICE

Only one study has so far attempted to investigate the contribution of algae to the nutrition of the DWR plant. Kulasooriya et al (1981) found a high rate of nitrogen fixation (10-20 kg N/ha per crop) by *Nostoc*, *Anabaena*, *Calothrix*, and *Gloeotrichia* on submerged, decaying DWR tissue in artificial ponds at IRRI, Philippines.

Besides nitrogen, phosphorus, potassium, magnesium, silicon, and other substances are important in the nutrition of rice. Those elements or compounds are also important components of algae. Generally, artificially cultured algae contain, on a dry weight basis, 37-56% carbon, 6.9-8% nitrogen, and 1.1-3% phosphorus (Round 1973, Tirol 1981).

Nutrients from algae become available to the rice plants by:

- the release of the nutrients stored in the algae and other algal grazers upon their death, which adds to the accumulated detritus and crop residues. These nutrients are usually available only in the succeeding seasons.
- direct supply from living algal cells as extracellular or degradation products.

Intracellular nutrients

Biological degradation of algae may be due to viruses (Safferman 1973), bacteria (Daft and Stewart 1971, Shilo 1970), fungi (Canter 1972, Whitton 1973), and indirectly by a number of algal grazers that were noted in the collecting areas — aquatic insects, crustaceans, and snails (Catling et al 1982). The decomposition rate depends on the environment and the species, including its physiological properties (Gunnison and Alexander 1975, Verma and Martin 1976).

Generally, the lower the carbon-nitrogen (C-N) ratio, the higher the mineralization rate. And this ratio is partly dependent on the chemical nature of the cell walls. Thus, BGA, which contain more low-molecular-weight, water-soluble carbohydrates in their cell walls (Jones et al 1952, Kreger 1962), have lower C:N and higher mineralization rates than other groups of algae (Verma and Martin 1976).

The euglenoids generally possess only a bounding plasmalemma known as the pellicle that probably makes them easily susceptible to degradation. However, in the case of the *Trachelomonas* species there is a shell (lorica) around the pellicle that is cellulose and highly impregnated with iron.

The physiological state of the algae cells at the time of death partly determines their decomposition rate. Based on the hypothesized model on the regeneration of nitrogen and phosphorus it has been noted that there is a greater regeneration of nutrients when there is a greater organic decomposition from higher initial nutrient-containing cells (Foree et al 1970).

In a rice field ecosystem, algal decomposition is usually charaterized by drying of the field at the end of the crop cycle (Roger and Kulasooriya 1980). This can also be the case in DWR areas.

Due to the high volume of submersion water and the high quantity of plant material

made available for colonization by the epiphytes, the extracellular products of algae may also be important as we will show later in this paper.

Nitrogen

Nitrogen accumulates in different amounts and in various forms in different algae. The green algae, especially those in Chlorococcales which are unicellular colonial types and multiply only asexually, can concentrate from as much as 6.5 to 8.5% N in their body (Prescott 1968). This group was well represented in the surveys and about 36% of the total number of identified green algae is worth considering. Other algae that contain significantly high amounts of nitrogen in their bodies are the diatoms and the euglenophytes.

In laboratory cultures at UPLB, *Navicula* (diatom) contained as much as 5% nitrogen (Martinez 1976); *Euglena* can have as much as 8%. The diatoms were well represented in the DWR areas studied (Fig. 1).

These groups of algae obtain nitrogen from the environment mostly in the form of combined nitrogen. On the other hand, some BGA can fix elemental nitrogen from the air and water. This is usually associated with heterocyst-forming filamentous types which include the following genera observed in the DWR areas: *Anabaena*, *Aulosira*, *Calothrix*, *Cylindrospermum*, *Gloeotrichia*, *Hapalosiphon*, *Microchaete*, *Nostoc*, *Nodularia*, *Scytonema*, and *Stigonema* (Table 1). However, nitrogen fixation is also known to occur in the nonheterocystous BGA, including the unicellular, colonial types (*Chroococcacean*, *Pleurocapsalean*) and other filamentous forms (Stewart et al 1979). Some of these types were also observed in the study areas, like, *Aphanothece*, *Gloeocapsa* (*Gloeothece*), *Synechococcus*, *Xenococcus*, *Lyngbya*, *Phormidium*, and *Plectonema*.

Two Philippine species cultured in vitro in the absence of nitrogen accumulated as much as 4.79% nitrogen for bacterized *Gloeotrichia* and 7.37% nitrogen for *Nostoc* (Tirol 1981). In experiments at IRRI the epiphytic BGA in DWR were extrapolated to yield 10-20 kg N/ha per crop (Kulasooriya et al 1981). This value does not include nitrogen that can be obtained from the free-floating N_2-fixers, which was estimated to be 11-28 kg N/ha per crop (dry season) in wetland rice fields (Alimagno and Yoshida 1975, Watanabe et al 1978, Martinez et al 1981).

Phosphorus

A major source of phosphorus compounds in soil is the vast quantity of plant material, including algae, that decays. Phosphorus usually ranks third in abundance in the algae cell (Round 1973). The phosphorus levels in the cells may fluctuate widely depending on species and environment.

Some algae can concentrate phosphates as much as 850,000 times than in surrounding water, as with *Spirogyra* (Round 1973). The excess phosphorus can be stored as polyphosphate granules that are generally found in the cytoplasm of some BGA (Fig. 5). Their number and size vary in different cells but they generally disappear where there is phosphorus deficiency. A greater amount of this immobilized phosphorus can be made available after death of the cell.

Phosphorus availability also seems to be correlated with flooding of soil, which results in decreased Eh and increased pH. This may be the case in Bangladesh DWR.

5. Cells of *Anabaena cylindrica* showing cyanophycin granules (C), polyphosphate bodies (P), photosynthetic thylakoids (T), and polyhedral body (PB). Line mark = 1 μm (adapted from Lang et al 1972).

Six flooded areas showed an increasing trend of phosphorus in the water from a mean of 0.67 ppm to a maximum of 5.5 ppm after 9 weeks (Islam et al 1975). One possible reason is the reduction of ferric phosphate to ferrous phosphate. This was demonstrated by Chang (1965) who measured the absorbance of each chemical form of inorganic phosphorus in the rice plant.

Silicon

Next to carbon, silicon has the highest content in the rice plant ranging to 14% of the total dry weight of rice straw (Clawson et al 1970). A possible source of this element is decaying rice tissues (Espada 1965, Gines 1966). Another possible source is decaying diatoms that may contain as much as 50% silicon on a dry weight basis (Vinogradov 1953). These constituted the greatest number of species (34%) and the highest population in the DWR areas studied. Their values in recycling silicon lie in their abundance in nature, although only about 50% of the silicate material appears soluble (Round 1973).

The availability of silicon from diatoms to the rice plant has not yet been studied but in nature there is indirect evidence that the fluctuation of silicon is inversely related to the diatom population. A greater amount of silicon in nature is associated with the death of some cells (Prescott 1968) implying a dissolution of the element.

There are other elements found in algae that are also needed for the optimal growth of the DWR plant but so far there are limited reports on the availability of these elements to the rice plant even in paddy fields (Roger and Kulasooriya 1980).

Extracellular/degradation products

Among these products liberated during algae growth are carbohydrates, nitrogen- and phosphorus-containing compounds, vitamins, enzymes, growth-promoting and growth-inhibiting substances, and other products associated with algae.

Glycolic acid, a by-product of ribulose diphosphate in the photosynthetic cycle, is the most commonly liberated organic acid by algae (Hellebust 1974). As much as 90% of the total carbon fixed was liberated in freshwater lakes when diatoms and BGA were the predominant organisms. In natural waters these acids constituted as much as 1 ppm (Fogg 1962). In the laboratory they seemed to be excreted when levels of carbon dioxide and oxygen were low (Hellebust 1974).

Other organic compounds noted to be secreted by algae are galactose and arabinose (Lewin 1956), sucrose (Tolbert and Zill 1956), and rhamnoside (Wangersky 1952). The extracellular nitrogenous materials released by BGA may be in the form of polypeptides and a small amount of free amino acids (Jones and Wilson 1978). About 5-40% of the assimilated nitrogen was in extracellular form among the BGA investigated (Magee and Burris 1954, Fogg et al 1973). There was direct evidence that these extracellular products were directly assimilated by higher plants (Stewart 1970) and by a moss species (Jones and Wilson 1978).

Free phosphatase was found in the epilimnion rich in phytoplankton (Reichardt et al 1967) and phosphomonesterase activity was found greatest at 5-m depth in the Pluss See (Germany) corresponding also to the chief zone of mineralization of the phytoplanktons.

Vitamins, although not totally extracellular products but mostly degradation products of algae, have been detected in some bodies of water. Dissolved thiamine was detected to be as much as 350 ng/liter in freshwater (Provasoli and Carlucci 1974). Cobalmin was detected to occur as much as 63 ng/liter in Lake Ikeda (Japan) at 20 m depth (Kashiwada et al 1960). This vitamin is believed to be one of the factors that trigger blooms of the BGA, which may be due to presence of cobalt that is essential in the process of nitrogen fixation. In fact, this has been extracted from BGA as *Tolypothrix tenuis* (Okuda and Yamaguchi 1960) and *Cylindrospermum muscicola* (Venkataraman 1968).

On the other hand biotin was observed to occur in Lake Tsukuri (Japan) ranging from 8 to 80 ng/liter (Ohwada et al 1972). This vitamin is reported to be required and synthesized by a much smaller group of algae (Provasoli and Carlucci 1974).

Roger and Kulasooriya (1980) reported a number of studies indicating the presence of growth-promoting substances in BGA. For example, extracts from *Phormidium* accelerated the germination of rice seed (Gupta and Lata 1964) and promoted root elongation of rice and increased the weight and protein content of the rice grain (Gupta and Shukla 1969). Some of the free amino acids from algae have rhizogenous effect on rice (Venkataraman and Neelakanthan 1967). In most of the reports the action was gibberellin-like.

There are some inhibiting substances reported in algae (Pratt 1944, Bishop et al 1959). Some of these excretory products from BGA could inhibit the growth of a bacterium (Telitchenko and Federov 1962) and a phycomycete (Bautista and Martinez 1980), and could cause physiological disorder in man (Schwimmer and Schwimmer 1968).

CONCLUSION

A large number and a great variety of algae were found in the DWR fields of Bangladesh and Mali. About 14% of the identified species had heterocyst presumably

containing nitrogenase in their filaments — aside from the fact that there were also some nonheterocyst containing BGA observed — and were capable of fixing atmospheric nitrogen.

The possible contribution of algae to the nutrition of DWR appears to be immense. They are potential sources of fertilizers. The intracellular nutrients in the algal cells are released on death of the cells and made available in the latter stage. Living algae cells are also sources of nutrients, through excretion of extracellular degradation products that may directly or indirectly benefit the rice plant.

The importance of algae lies in their capacity to grow well in deep water where there is a great mass of submerged rice plants available for epiphytism, a greater volume of water for planktonic growth, a longer period of submersion, and less mechanical disturbances of the field.

Thus, where fertilizer application may not be feasible, these biofertilizers, which grow luxuriantly, should be studied to measure their actual contribution to the nutrition of the rice plant. More surveys should be done to assess the abundance and species composition of algae in different deepwater-rice regions. They should be artificially cultivated to tap their full potential as a nutrient source and also as sources of basic food in the food chain.

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DISCUSSION

FRANCIS: This year in Bangladesh we observed that distribution of blue-green algae populations was very localized. There seemed to be some relationship between the buildup of the algae populations and the high levels of decaying organic material in the water. Could organic phosphorus be the cause?

MARTINEZ: Yes, it is possible that the phosphorus coming from decaying organic material is an element needed for good growth of algae, especially of the blue-green algae.

CATLING: A possible explanation for some of the variation in algal activity between fields is the fact that some farmers burn rice stubble thoroughly and others burn it partly or not at all. Burning presumably kills many overwintering algae.

OITA: You showed many different kinds of blue-green and green algae. For nitrogen fixation have you found any cooperation or competition among them?

MARTINEZ: There are insufficient data regarding that aspect. It is an interesting area of study for the future.

SCREENING OF DEEPWATER RICES FOR DROUGHT TOLERANCE IN THAILAND

N. Supapoj, C. Boonwite, J. C. O'Toole, S. K. De Datta, and B. R. Jackson

SUMMARY

Erratic early rainfall causes severe drought stress of young rice seedlings in Thailand's rainfed areas. In 1977, the Rice Division started screening local varieties and hybrid lines for drought tolerance. The screening procedure is outlined. Drought stress was greater in 1978 and 1979 than in 1980. In 1980 tests, crosses with BKN6986 as a common parent were outstanding. Problems of soil variability were offset by adjustment of scores based on scores of nearby tolerant and susceptible checks.

Somrith and Awakul (1979) estimate that about 6.5 million ha or 77% of Thailand's total rice area is rainfed. The rainfed area has about 90,000 ha of dryland, 5.78 million ha of wetland, and 510,000 ha of deepwater rice. Because most rainfed rice areas are in northeastern and Central Plain of Thailand, some background information may be useful.

NORTHEASTERN THAILAND RAINFED RICE

In northeastern Thailand, soils tend to be sandy (Table 1). In addition, organic matter content is low and aggravates drought stress, which commonly occurs for 2-week intervals in some years. The topography of the region is undulating and farmers still plant rice on the upper terraces, which frequently lack sufficient moisture for transplanting. The result is high abandonment of the rice crop in drought years.

Figure 1 demonstrates the need for drought tolerance during the vegetative stage of the rice crop at Nakornratchasima (Korat) in northeastern Thailand, especially while rice is in the early vegetative growth stage. Transplanting is usually during May to July depending on the availability of rainfall. The probability of 25 mm or more precipitation per week in May through August is generally less than 50%. Thus, drought periods of 1 or more weeks during the early growing period are common.

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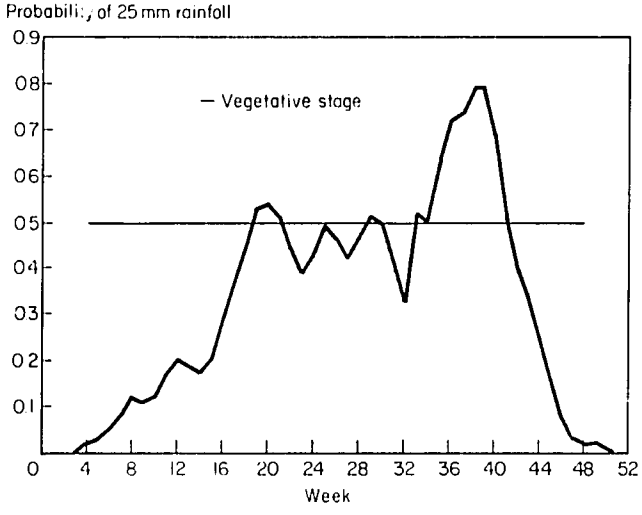
Table 1. Soil physical and chemical characteristics of the Mahasarakam region in the rice growing area of northeastern Thailand.

Soil depth (cm)	Particle size (%)				WHC[c] (%)	Organic matter (%)	P (ppm)	K (meq/100 g)
	COS[a]	FS[b]	Silt	Clay				
0-10	14	37	37	12	31	0.66	44	0.44
10-25	26	47	18	9	32	0.29	44	0.06

[a]Coarse sand. [b]Fine sand. [c]Water-holding capacity.



1. Probability of 25 mm or more weekly precipitation falling at Nakornratchasima, Thailand, based on the 26-year average (1951-77).

RAINFED RICE AREAS OF CENTRAL PLAIN

The Central Plain immediately north of Bangkok is a large flat alluvial area characterized by a heavy soil (Table 2), treeless plains with depressions that fill with water to a depth of 3 meters in certain areas during the monsoon.

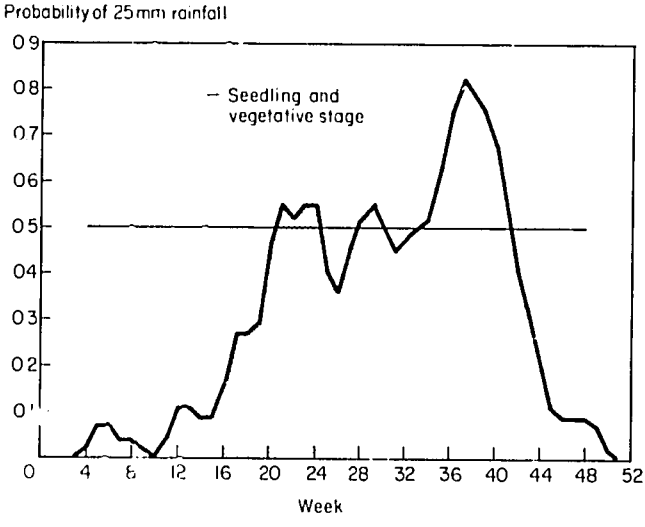
The parts of the Central Plain that are likely to collect water more than 1 m deep during maximum flood are broadcast-seeded to floating rice during the premonsoon rains in May and June. This permits early establishment of the rice plants, which tiller and elongate when floodwater reaches the area in August through November. During the premonsoon period and beginning of the monsoon, rainfall is erratic and causes severe drought stress of the young rice seedlings for periods of 2 or more weeks in some years. This stress comes when the seedlings are attempting to become established and weeds provide serious competition for moisture and sunlight.

Rainfall probabilities for the Ayuthaya area of the Central Plain (Fig. 2) clearly indicate that rainfall is sometimes critical from April to July when the floating rice is becoming established. Generally, after August, floodwater arrives and water depth continues to increase until flowering in mid-November.

Table 2. Soil physical and chemical characteristics of the Angthong, floating rice area in the Central Plain, Thailand.

Soil depth (cm)	Particle size (%)				WHC[c] (%)	Organic matter (%)	P (ppm)	K (meq/100 g)
	COS[a]	FS[b]	Silt	Clay				
0-10	1	15	39	45	57	2.74	349	0.72
10-25	2	34	35	30	50	1.24	305	0.63

[a]Coarse sand. [b]Fine sand. [c]Water-holding capacity.



2. Probability of 25 mm or more weekly precipitation falling in the Ayuthaya area of the Central Plain, Thailand, based on the 11-year average (1970-80).

EARLY FIELD SCREENING

Most of past efforts in breeding for drought tolerance involved local selection of drought-tolerant types in the Northeast and Central Plain floating rice areas by farmers. Examples of land varieties that exhibit drought tolerance are Khao Dawk Mali 105 from the Northeast and Leb Mue Nahng 111, a floating variety from the Central Plain.

In 1977, the Rice Division began screening local varieties and experimental hybrid lines at the Klong Luang Rice Experiment Station. The screening, with short rows on raised beds, was during the dry season to get the desired level of drought stress. Results of the 1977 test are not in this report but they were sufficiently encouraging to merit further screening.

Testing procedures

In general, 5 g dry seed/entry are hand drilled in a 1.25-m row on raised beds 25 cm apart. Generally, three check varieties — Leb Mue Nahng 111, BKN6986-108-3, and IR20 — are planted every 3-10 rows depending on the experimental design and

objectives. The soil is saturated by daily watering until the seedlings are 30 days old. The soil is then permitted to dry to induce plants to undergo drought stress. Drought scores are recorded when the susceptible check, IR20, appears severely stressed. The scoring system is on a 1-9 scale (IRRI 1975): 1 = none or only slight effect of stress, 5 = 25-50% of all leaves fully dried, and 9 = all plants apparently dead.

The field is then watered to relieve soil moisture stress and each entry is scored after about 7 days, also using the 1-9 scale: 1 = at least 90% of plants fully recovered, 5 = 40-50% of plants fully recovered, and 9 = all plants dead or nearly dead.

FIELD SCREENING

In the 1978 and 1979 dry seasons, 135 and 343 lines and varieties, respectively, were seeded in 2 replications for screening at the Huntra Rice Experiment Station. In the 1978 test, BKN6986-108-3, Khao Dawk Mali 105, and Leb Mue Nahng 111 were check varieties and planted alternately every 20 rows. In 1979, three checks, including Leb Mue Nahng 111, BKN6986-108-3, and RD7 were planted alternately every three rows.

In the 1980 dry season, 1,092 rices from the 1980 IRDWON and the 1979 Deep Water Rice Observational Nursery were screened. Three check varieties, Leb Mue Nahng 111 (resistant), BKN6986-108-3 (intermediate), and IR20 (susceptible), were planted alternately every 3 rows. A systematic design was assigned with one replication. Tables 3-5 show only entries with the lowest stre. s scores in 1978-80.

Table 3. The 20 best lines or varieties in screening fo" drought tolerance at the Huntra Rice Experiment Station, Thailand, 1978.

Line or variety	Average score[a]		Parent
	Drought	Recovery	
FR13A	3.0	4.0	
SPR7295-86-1-2-0	4.0	7.0	HTA1649/IR648
Salumpikit	5.0	6.5	
KU 276	5.5	7.0	
BKN6986-27-8-35	5.5	5.5	IR262/PG56
SPR7292-138-2-3-0	5.5	7.0	Nakorn GAN/IR648
SPR7323-9-0	5.5	6.5	PG56/Sigadis//Daw Luang 88
Bao Vista	6.0	7.0	
IR442-2-58	6.0	2.5	IR95/LMN111
BKN6986-68-14	6.0	6.5	IR262/PG56
BKN6986-114-9	6.0	6.5	IR262/PG56
SPR7297-479-2-1-0	6.0	8.0	PG56/IR648
HTA7406-111-0	6.0	8.0	SPR6726/RD1//KP32
SPR7233-1-40-1-3-0	6.0	7.5	LMN111/C4-63
SPR7233-1-40-1-4-0	6.0	8.0	LMN111/C4-63
LMN111	6.5	7.0	
SPR7224-137-1-7-0	6.5	5.5	HTA1645/IR648
HTA7406-110-0	6.5	8.0	RD7//RD1/KP32
KDML 105	6.5	5.5	
BKN6986-27-8	6.5	5.5	IR262/PG56

[a]Based on Standard Evaluation System for Rice (IRRI 1975).

Table 4. The 20 best lines or varieties in screening for drought tolerance at the Huntra Rice Experiment Station, Thailand, 1979.

Line or variety	Average score[a] Drought	Recovery	Parent
B922C-Mr-91-2-1	4.5	5.0	Pelita I-1/B60B-242-4
DWCT-25-1-0-2	4.5	4.0	
B922C-Mr-91-4-0	5.0	3.5	Pelita I-1/B60B-242-4
BKNFR76061-15-1	5.0	4.0	
CNL 319	5.0	3.5	
BKN6986-81-5	5.5	5.5	IR262/PG56
Yodaya	5.5	5.0	
CNL 241	5.5	4.5	
IR4971-KLG-101-4-0	5.5	5.0	IR2035/IR95/LMN111
BKN6988-52-1-1-0-8	5.5	5.0	IR262/LMN111
BKN6988-52-1-3-0-0	5.5	5.5	IR262/LMN111
BKNFR76035-97-2	5.5	6.0	IR4427/RD19//BKN6987-52-1
SPR7275-4-3	5.5	5.5	HTA1646/C4-63
BKN6987-68-7	5.5	5.5	IR262/KNN 11
BR223-B-38	6.0	6.0	TKM6/Habiganj Aman II
SPR7224-1-2-1-0-1	6.0	6.5	HTA1645/IR648
SPR7273-0-0-12	6.0	5.5	HTA1629/Sigadis
DWCT134-3-1-0	6.0	6.0	
HTA7406-110-1-0	6.0	6.0	SPR6726-134-2-24//RD 1/IR1416
ARC5955	6.0	7.0	

[a]Based on Standard Evaluation System for Rice (IRRI 1975).

Table 5. The 40 best lines in screening for drought tolerance at Huntra Rice Experiment Station, Thailand, 1980. Average score for IR20 was 6.7.

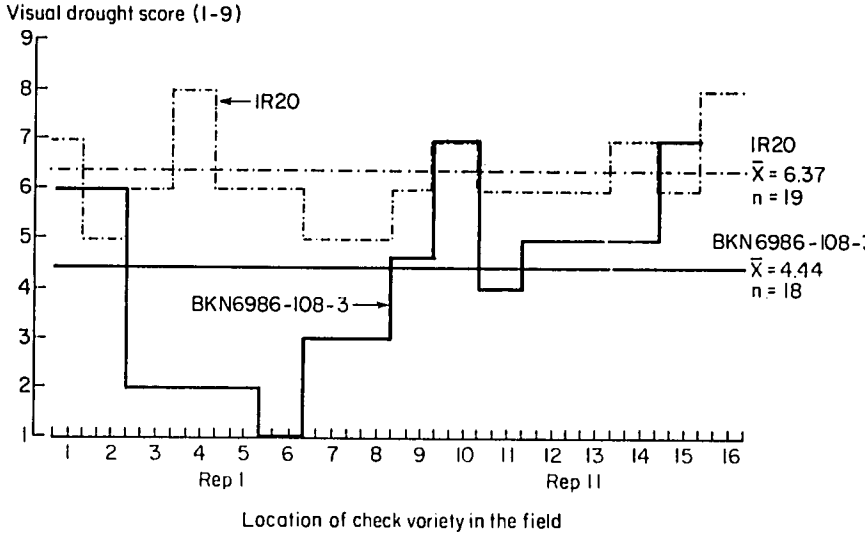
Line	Av score[a] for drought	Parents
BKNFR76011-9-1-3-1	1	IR28/BKN6986-81
BKNFR76011-24-3-1-1	1	"
BKNFR76012-47-3-1-3	1	IR20/BKN6986-167
BKNFR76012-47-3-7-1	1	"
BKNFR76014-77-2-0	1	IR28/BKN6986-81-5
BKNFR76014-116-1-2-1	1	"
BKNFR76026-37-3-2-2	1	IR4427-70-4/RD19
BKNFR76020-7-2-3-1	1	IR4427-70-6/RD19
BKNFR76029-7-2-3-2	1	"
BKNFR76043-95-1-1	1	BKN6986-71/LMN111
BKNFR76004-53-6-2-1	1.3	IR30/BKN6986-81-5
BKNFR76005-14-2-4-1	1.3	IR30/BKN6986-167
BKNFR76005-53-3-2-1	1.3	RD19/IR29
BKNFR76012-47-3-1-1	1.3	IR20/BKN6986-167
BKNFR76012-47-3-1-2	1.3	"
BKNFR76014-77-3-1	1.3	IR28/BKN6986-81-5
BKNFR76026-29-2-1-1	1.3	IR4427-70-4/RD19
BKNFR76014-1-9-1	1.5	IR28/BKN6986-81-5
BKNFR76014-1-9-2	1.5	"
BKNFR76014-1-9-3	1.5	"
BKNFR76020-10-2-3-1	1.5	BKN6986-108/IR28
BKNFR76026-3-2-2-3	1.5	IR4427-70-4/RD19
BKNFR76028-70-1-4-2	1.5	IR4427-70-2/RD19

Continued on next page

Table 5 continued

BKNFR76028-70-1-4-3	1.5	IR4427-70-2/RD19
BKNFR76028-136-3-3-1	1.5	"
BKNFR76029-7-2-5-1	1.5	IR4427-70-6/RD19
BKNFR76010-66-1-1	1.8	RD19/IR29
BKNFR6014-24-2-2-1	1.8	IR28/BKN6986-81-5
BKNFR76014-24-2-3-1	1.8	"
BKNFR76014-44-1-2-1	1.8	"
BKNFR76025-182-1-1-1	1.8	IR4427-70-5/RD19
BKNFR76025-182-1-2-1	1.8	"
BKNFR76025-182-1-2-2	1.8	"
BKNFR76026-193-1-2-2	1.8	IR4427-70-4/RD19
BKNFR76027-16-2-1-1	1.8	IR4427-70-5/RD19
BKNFR76028-182-0-2-1	1.8	"
BKNFR76037-6-2-3	1.8	RD19/BKN6986-81-5
BKNFR76011-47-3-7-1	2.0	IR28/BKN6986-81
BKNFR76011-47-3-7-2	2.0	"
BKNFR76011-47-1-2-2	2.0	"

[a]Scores for recovery not made because the field was used for other experiments.



3. Variation across the field illustrated by the change in responses of IR20 (susceptible check) and BKN6986-108-3 (resistant check). Huntra Experiment Station, Thailand, 1980.

The data clearly show that drought stress was much greater in 1978 and 1979 than in 1980. We believe this was due to the absence of IR20, the susceptible check, in 1978 and 1979 because subsequent tests showed that the check varieties used in 1978 and 1979 had good tolerance for drought.

The 40 best lines shown in Table 5 were derived from crosses with BKN6986 line as a common parent. This line originated from a cross between Pin Gaew 56, a floating variety, and IR62, an experimental semidwarf from IRRI.

De Datta and O'Toole (1977) pointed out that deepwater rices generally encounter drought problems at the seedling stage and have, therefore, evolved through natural selection for tolerance in the vegetative stage. However, Pin Gaew 56 itself showed a relative susceptible reaction to drought in the 1980 test (4.6). Possibly the gene(s) for tolerance in this variety is in a hypostatic condition but could be expressed after recombination with other parents.

Our greatest difficulty has been soil variability and how to measure genetic differences resulting from the extreme variation that occurs under drought stress. Figure 3 provides an example of the variability noted in the 1980 experiment in the Huntra plots. Under such conditions, the validity of the test scores logically comes into question. However, we have attempted to adjust the scores based on nearby tolerant and susceptible checks and believe this gives a fairly reliable estimate. Furthermore, two replications are used to reduce some of the inconsistencies.

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DISCUSSION

KUPKANCHANAKUL: How much yield loss due to drought at seedling stage do you expect in deepwater conditions?

SUPAROJ: In Thailand we have not had any specific information about yield loss caused by drought during the seedling stage.

JACKSON: Why can't we institute an IRTP drought tolerance test as we have done with other stresses? Drought is important in deepwater rice.

DURVASULA: Presently the upland and deepwater observational nurseries are being screened for drought stress. There is also an ongoing collaborative project on drought participated in by a limited number of countries. I fully agree with Dr. Jackson's suggestion for a separate drought tolerance test. We may initiate such a test under IRTP.

EVALUATION OF RICES FOR DROUGHT TOLERANCE FOR DEEPWATER AREAS

S. K. De Datta, J. A. Malabuyoc, and E. L. Aragon

SUMMARY

Frequent soil moisture stress during the seedling and vegetative stages of early-seeded crops dictates a need for drought tolerance in modern deepwater varieties. Greenhouse and field screening at IRRI have identified the traditional varieties Khao Dawk Mali 105, Leb Mue Nahng 111, and Nam Sagui 19 as drought tolerant. Those rices are used extensively as parents in breeding for drought tolerance for all types of rainfed rices including modern deepwater rices. Drought-tolerant progenies crossed with semidwarfs are now either recommended varieties, such as Nam Sagui 19 derivatives, for shallow-water rainfed wetland, or are under test in observational nurseries for rainfed and deepwater areas.

Nam Sagui 19 is a known excellent donor parent for drought tolerance, because of its numerous drought-tolerant descendants. Two selections from BKN6986, a cross between semidwarf IR262 line and the deepwater rice variety Pin Gaew 56, showed consistent drought tolerance in at least 4 years of field testing.

Ironically, the deepwater-rice farmer also faces the threat of drought. Drought damage to rice seedlings occurs between seeding which is generally done on dry soil, and the start of monsoonal rains — a period when deepwater rice grows as dryland rice. Drought in deepwater areas can occur in Bangladesh (Choudhury and Zaman 1970), West Bengal, India, and Thailand (De Datta 1981), Mali (Bidaux 1970), and Vietnam (Xuan and Kanter 1975). Over a period of 126 years in Thailand (1831-1957) drought was experienced in 60 years (Chang et al 1979).

Because modern deepwater varieties may not have the early elongation ability of traditional deepwater rices early seeding is advocated. This ensures rapid stand establishment and reduces the risk of seedling destruction by fast rising floodwater (De Datta and O'Toole 1977, Vergara and Mazaredo 1979). It is the early-seeded rice,

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however, that more frequently experiences soil moisture stress. Thus, there is a need for breeding deepwater rices for drought tolerance at the seedling and early vegetative stages (De Datta and O'Toole 1977).

It is, therefore, imperative that a screening technique for drought tolerance be developed to identify rices suitable for deepwater areas and to use those as parents in hybridization programs to incorporate drought tolerance into modern deepwater rices.

SCREENING TECHNIQUES

Various techniques for screening rices for drought tolerance at the vegetative stage were summarized by De Datta and O'Toole (1977). A greenhouse drought-screening technique earlier reported by Sarkar and De Datta (1975) provided simulation of limited rooting depth that represented dryland field conditions with a hardpan at shallow depth. The deepwater varieties Leb Mue Nahng 111 and Khao Dawk Mali 105 were identified for drought tolerance by the technique (De Datta et al 1978). In the greenhouse, however, limited space restricts the number of test materials.

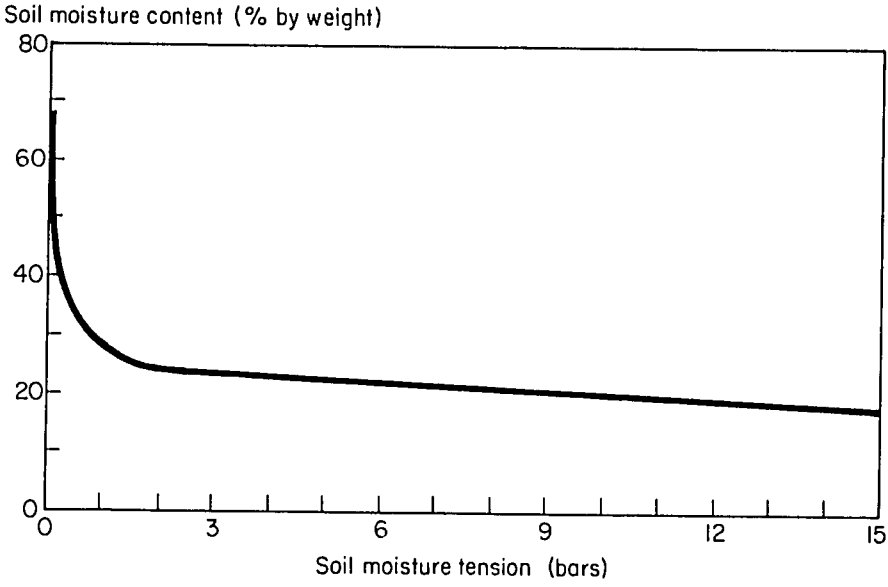
A field screening technique developed at IRRI in 1975 (De Datta and Vicencio 1976, De Datta et al 1979) allowed the testing of thousands of rices at one time. Rices were seeded on dry soil for field screening during the dry season and sprinkler-irrigated at 4-6 day intervals until the seedlings were 30 days old. The soil was then allowed to dry naturally. Reactions to soil moisture stress were determined when 2, 5, and 10 bars soil moisture tensions (SMT) were reached using the SES 1-9 scale (IRRI 1975) where 1 = no to negligible effects of soil moisture stress and 9 = all plants apparently dead. After drought scoring at 10 bars SMT, soil moisture stress was relieved by sprinkler irrigation. Recovery scoring was done 7 to 10 days later also using the SES 1-9 scale, where 1 = 90% and above of the plants fully recovered and 9 = no plants fully recovered.

Recovery from drought stress is more important for a deepwater rice crop than for a shallow-water wetland crop. Failure to fully recover before the rise of floodwaters may mean a total crop loss.

The result from 3 years of greenhouse tests and 4 years of field tests at IRRI are summarized in this paper.

GREENHOUSE SCREENING

A greenhouse study on improved drought tolerance at shallow rooting depth was initiated in 1975 and continued through 1980. A total of 105 entries each season (elite lines and selected varieties and lines) were evaluated for drought tolerance and ability to recover from stress. A different set of entries, including the promising lines in the previous season's test, was tested the following season. All entries (including Moro-berekan as an indicator plant in 1978, and Leb Mue Nahng 111 in 1979 and 1980) were seeded into dry soil in steel drums. The effective rooting depth was 45 cm. The soil in the drums was watered regularly until 30 days from seeding and then allowed to dry naturally. As soon as the indicator plant was apparently dead from moisture stress the entries were scored for drought tolerance, the soil sampled for moisture content,



1. Desorption curve for soil from the new IRRI farm used in the greenhouse experiments. IRRI, 1976.

the plants rewatered, and recovery ability scored at a desired growth stage.

In all tests, the average soil moisture content just before relieving stress was about 8.2% at the 20-cm soil depth and 11.4% at the 30-cm depth, values well above 15 bars of SMT (Fig. 1).

Promising lines for deepwater areas

Among the deepwater rices reported earlier to have good drought tolerance were Khao Dawk Mali 105, Nam Sagui 19, and Leb Mue Nahng 111 (De Datta et al 1978). In the 1978-80 studies those varieties continued to perform fairly well.

Table 1 shows the drought-tolerant lines with a deepwater rice parent or progenitor. IR442-2-58, with Leb Mue Nahng 111, a deepwater rice from Thailand, as

Table 1. Drought-tolerant lines with deepwater rice parent or progenitor from IRRI greenhouse tests, 1978-80.

Line	Female parent	Male parent
IR5825-44-3-P_1	IR2061-213-2-16	Nam Sagui 19/IR1416-131-5
IR442-2-58	IR95-31-4	Leb Mue Nahng 111
IR5853-118-5 (IR52)	Nam Sagui 19/IR2071-88	IR2061-214-3-6-20
IR9814-6-3	IR2070-423-2-5/Nam Sagui 19	IR2070-423-2-5-6
IR3839-1	Pelita I-2/IR1529-680-3	IR442-2-58/Rikuto Norin 1
IR9411-5-3-3	IR442-2-58/IR1545-213-2-16	IR2058-78-1-3-3-3

parent, has been consistently drought tolerant in many greenhouse studies. IR5825-44-3P$_4$, which has also been reported to have good submergence tolerance, has had good drought tolerance. These and other promising lines should be further evaluated for other plant characters desirable for deepwater rice culture.

FIELD SCREENING

The number of rices involved in each year of field screening from 1978 to 1981 is shown in Table 2. The materials include deepwater varieties from the IRRI germplasm bank (GB) and entries to the International Deep Water Observational Nursery (IRDWON) of the International Rice Testing Program (IRTP). Of the 4,358 entries in the 1981 dry season, 68 were deepwater GB accessions from Bangladesh, India, and Sri Lanka and 65 were entries from the 1980 IRDWON. An undetermined number was from the IRRI hybridization nursery and observational yield trial. The 1980 entries also included IRDWON materials, among which were 30 selections from 1976 to 1978 IRDWONs for various desirable agronomic and physiologic characteristics.

Promising deepwater varieties

In the 1981 dry season, 6 deepwater rice accessions from Bangladesh and 1 from Sri Lanka had the same drought score (5 at 10 bars SMT) as Salumpikit, a Philippine traditional dryland variety, which was used as a tolerant check (Table 3). Only Horhoria/Sarsari had a recovery score as good as that of Salumpikit. Bhabani (Jabain), Hijal Digha, and Tilbazal, all from Bangladesh, had a recovery score similar to that of IR442-2-58, another drought-tolerant check.

Promising IRDWON materials

Most of the 1980 IRDWON entries were products of hybridization and selection at IRRI, Philippines, and Thailand, and had a modern (semidwarf) and a traditional deepwater variety as parents in most cases. Earlier IRDWONs included traditional varieties from different countries with deepwater rice areas.

Table 2. Number of entries and outstanding selections in field screening of rices for drought tolerance at the vegetative stage. IRRI, 1978-81 dry seasons.

Year	Entries (no.)	Outstanding selections[a]
1978	4757	43
1979	3897	145
1980	4540	169
1981	4358	87

[a]Drought tolerance score as good as or better than IR442-2-58 and Salumpikit at 10 bars SMT, except 1979 test which was at 5 bars SMT.

Table 3. Deepwater rices from the IRRI germplasm bank with promising drought tolerance in field drought screening at the vegetative stage. IRRI, 1981 dry season.

Accession	Accession no.	Origin	Drought score[a] at 5 bars SMT[c]	Drought score[a] at 10 bars SMT	Recovery score[b] at 10 bars SMT
Bhabani (Jabain)	49266	Bangladesh	4	5	3
Hijal Digha	49276	Bangladesh	4	5	3
Horhoria/Sarsari	49277	Bangladesh	4	5	2
Koitor Moni/Kalakari	49281	Bangladesh	3	5	4
Nai Handiran	40852	Sri Lanka	5	5	4
Nap Tosha	49287	Bangladesh	3	5	4
Tilbazal	49296	Bangladesh	4	5	3
Salumpikit (tolerant check)	5423	Philippines	3	5	2
IR442-2-58 (tolerant check)		IRRI	5	6	3
IRAT 9 (susceptible check)	28206	Ivory Coast	6	8	8
IR20 (susceptible check)		IRRI	7	8	5

[a]SES 1-9 scale, where: 1 = no to slight effects of soil moisture stress and 9 = all plants apparently dead. [b]SES 1-9 scale, where: 1 = 90% or above of the plants fully recovered and 9 = no plants fully recovered. [c]SMT = soil moisture tension.

Among the 1980 IRDWON entries selected from 1976 to 1978 IRDWON sets, two BKN6986 lines (IR262-43-8-11/Pin Gaew 56) and SPR7292 (NKG/IR648) from Thailand had drought tolerance similar to or better than those of the tolerant checks Salumpikit and IR442-2-58 in 2 years of field tests (Table 4). Madhukar from India was as drought tolerant as the checks.

In 1979 BKN6986-66-2 and BKN6986-147-2 (Table 4) were released as RD17 and RD19 by Thailand's Department of Agriculture as drought-tolerant deepwater (0.5-1 m depth) rice varieties. These were the first high yielding varieties developed especially for flood-prone deepwater areas.

DEEPWATER RICES AS PARENTS IN IRRI HYBRIDIZATION PROGRAM

Earlier the objective of using deepwater rices as parents in developing high yielding varieties for flood-prone areas was to incorporate such characteristics as elongation ability, as when Leb Mue Nahng 111 was crossed with four high yielding varieties in 1965, out of which T442-57 was selected at the Klong Luang Experiment Station in

Table 4. Promising selections from IRDWON for drought tolerance at the vegetative stage from field screening at IRRI, 1980 and 1981 seasons.

Entry	Origin	1980 Drought score[a] at 5 bars SMT[c]	1980 Drought score[a] at 10 bars SMT	1980 Recovery score[b] at 10 bars SMT	1981 Drought score[a] at 5 bars SMT	1981 Drought score[a] at 10 bars SMT	1981 Recovery score[b] at 10 bars SMT
1980 IRDWON entries, selected earlier from 1976-78							
BKN6986-66-2 (RD17)	Thailand	4	5	3	3	4	3
BKN6986-147-2 (RD19)	Thailand	3	4	4	3	4	3
Madhukar	India	3	5	5	5	6	4
SPR7233-1-24-2-2-2-3	Thailand	3	5	3	5	7	5
SPR7292-151-2-1-B-B	Thailand	4	5	3	3	4	3
SPR7292-206-1-3-B	Thailand	3	5	3	5	5	4
A 1980 new IRDWON entry							
Khama	Bangladesh	4	5	5	3	5	3
Other 1976-78 IRDWON selections							
BKN6986-81-5	Thailand	4	5	5	4	5	3
CR1009	India	4	5	3	4	6	4
Checks							
Salumpikit (tolerant)	Philippines	4	5	4	3	5	2
IR442-2-58 (tolerant)	IRRI	4	6	3	5	6	3
IRAT 9 (susceptible)	Ivory Coast	7	8	8	6	8	8
IR20 (susceptible)	IRRI	6	8	5	7	8	5

[a]SES 1-9 scale, where: 1 = no to slight effects of soil moisture stress and 9 = all plants apparently dead. [b]SES 1-9 scale, where: 1 = 90% or above of the plants fully recovered and 9 = no plants fully recovered. [c]SMT = soil moisture tension.

Table 5. Drought-tolerant deepwater rices and the number of IRRI crosses each one was involved in as direct parent or ancestor, IRRI, 1980.

Parent or ancestor	Crosses (no.)
BKN6986-108-2	43
RD19	115
Khao Dawk Mali 105	1,888
Leb Mue Nahng 111	1,255
Nam Sagui 19	1,694

Thailand (HilleRisLambers 1978). In such crosses, drought tolerance was one of the characteristics incorporated. IR442-2-58, a sister line of T442-57, was identified as a drought-tolerant rice with moderate elongation capacity (IRRI 1973).

IRRI had made 33,898 crosses as of the 1980 dry season. Three deepwater rice varieties identified as drought tolerant were involved as direct parent or progenitors of a large number of crosses (Table 5). RD19 and BKN6986-108-2 were used extensively in the 1979-80 crosses.

Drought tolerance in deepwater rices at the vegetative stage is believed to be a product of natural selection because of the high frequency of severe drought stress the deepwater rice seedling encounters as it grows in dry soil.

Tables 6-8 show that Nam Sagui 19 is one of the best gene donors for drought tolerance. Among five drought-tolerant IRRI lines from five crosses involving a deepwater rice parent or progenitor, four descended from Nam Sagui 19 and one from Khao Dawk Mali 105. Among these was IR5853-118-5 (Nam Sagui 19/IR2071-88//IR2061-214-3-6-20), named in the Philippines as IR52, for rainfed wetland areas. Leb Mue Nahng 111 was a parent of IR442-2-58, one of the two drought-tolerant checks.

The most consistent deepwater rice in the field tests from 1978 to 1981 has been BKN6986-108-2. It had the best scores for drought tolerance and recovery from drought stress in 1981. Its use has been suggested for breeding drought tolerance into rices to be grown in dryland, shallow rainfed wetland, and deepwater areas.

Promising rices for drought in 1981 field screening and selected from 17 crosses are shown in Table 8. Of the 17 crosses, 13 were descendants of Nam Sagui 19, 2 of KLG6986 lines, and 1 each of Khao Dawk Mali 105 and Leb Mue Nahng 111.

In field screening, Nam Sagui 19, earlier cited as an excellent donor parent for drought tolerance (De Datta et al 1979, De Datta and Seshu 1982), had good tolerance at 2 and 5 bars SMT but was moderately susceptible at 10 bars SMT (Tables 6-8). It is likely that due to recombination of gene(s) released from possible hypostatic condition, or due to complementary gene action, a number of progenies involving this variety were more drought tolerant than the parent (De Datta and Seshu 1982).

Table 6. Outstanding deepwater rices and progenies of crosses involving a deepwater rice in field drought screening at IRRI, 1978 and 1979.

Entry	Deepwater parent	1978			1979	
		Drought score[a] at 5 bars SMT[c]	Drought score[a] at 10 bars SMT	Recovery[b] at 10 bars SMT	Drought score[a] at 5 bars SMT	Recovery[b] at 10 bars SMT
IR5624-110-2	Khao Dawk Mali 105	1	3	3	3	1
IR5853-118-5 (IR52)	Nam Sagui 19	2	3	3	3	1
IR8235-194	Nam Sagui 19	2	4	3	3	1
IR9266-124	Nam Sagui 19	2	4	3	3	1
IR9995-96-2	Nam Sagui 19	1	3	1	3	1
BKN6986-108-2	Pin Gaew 56	2	3	2	3	1
BKN6986-147-2 (RD19)	Pin Gaew 56	1	2	3	-	-
Khao Dawk Mali 105		3	6	3	2	1
KLG6986-165-P		1	3	1	3	1
Leb Mue Nahng 111		2	4	3	3	1
Nam Sagui 19		3	7	5	4	1
IR442-2-58 (tolerant check)	Leb Mue Nahng 111	3	5	3	3	1
Salumpikit (tolerant check)		1	4	1	3	1
IR20 (susceptible check)		5	8	7	5	3
IRAT 9 (susceptible check)		6	9	9	7	5

[a]SES 1-9 scale, where: 1 = no to negligible effects of soil moisture stress and 9 = all plants apparently dead. [b]SES 1-9 scale, where: 1 = 90% or above of the plants fully recovered and 9 = no plants fully recovered. [c]SMT = soil moisture tension.

Table 7. Outstanding deepwater rices and progenies of crosses involving a deepwater rice in field drought screening at IRRI, 1980 and 1981.

Entry	Deepwater parent	1980			1981		
		Drought score[a] at		Recovery[b] at	Drought score[a] at		Recovery[b] at
		5 bars SMT[c]	10 bars SMT	10 bars SMT	5 bars SMT	10 bars SMT	10 bars SMT
IR5624-110-2	Khao Dawk Mali 105	3	3	1	4	5	3
IR5853-118-5 (IR52)	Nam Sagui 19	4	5	2	5	7	3
IR8235-194	Nam Sagui 19	3	3	3	4	5	3
IR9266-124	Nam Sagui 19	3	3	3	4	6	3
IR9995-96-2	Nam Sagui 19		5	3	4	6	4
BKN6986-108-2	Pin Gaew 56	2	4	3	3	4	2
BKN6986-147-2 (RD19)	Pin Gaew 56	3	4	4	3	4	3
Khao Dawk Mali 105		5	7	3	5	7	4
KLG6986-165-P		3	4	3	3	4	3
Leb Mue Nahng 111		4	6	5	–	–	–
Nam Sagui 19		6	7	3	5	6	3
IR442-2-58 (tolerant check)	Leb Mue Nahng 111	4	6	3	5	6	3
Salumpikit (tolerant check)		4	5	4	3	5	2
IR20 (susceptible check)		6	8	5	7	8	5
IRAT 9 (susceptible check)		7	8	8	6	8	8

[a]SES 1-9 scale, where: 1 = no to negligible effects of soil moisture stress and 9 = all plants apparently dead. [b]SES 1-9 scale, where: 1 = 90% or above of the plants fully recovered and 9 = no plants fully recovered. [c]SMT = soil moisture tension.

Table 8. Drought-tolerant progenies in field screening of multiple crosses inovlving a drought-tolerant deepwater rice variety as parent. IRRI, 1981 dry season.

Designation	Deepwater parent	Drought score[a] at 5 bars SMT[c]	Drought score[a] at 10 bars SMT	Recovery score[b] at 10 bars SMT
IR5853-213-6-1	Nam Sagui 19	2	3	2
IR8235-194	Nam Sagui 19	3	4	3
IR9830-27-2-3	Nam Sagui 19	3	4	3
IR11288-B-B-65-1	Leb Mue Nahng 111	3	4	3
IR11288-B-B-144-1	Leb Mue Nahng 111	3	4	3
IR18152-4-1-2	Khao Dawk Mali 105	2	4	3
IR21015-137-3-2-2-1	Nam Sagui 19	3	4	2
IR21015-196-3-1-3-1	Nam Sagui 19	3	4	2
IR21178-21-3	Nam Sagui 19	3	3	2
IR21264-48-2	Nam Sagui 19	4	4	2
IR21313-28-1	Nam Sagui 19	3	4	3
IR21347-29-2	Nam Sagui 19	3	4	3
IR21347-50-3	Nam Sagui 19	3	4	3
IR21567-20-1	Klong Luang 6986	4	4	3
IR21587-44-1	Klong Luang 6986	3	4	3
IR21669-5-3	Nam Sagui 19	3	4	3
IR24760-24-2	Nam Sagui 19	2	3	1
IR24760-58-1	Nam Sagui 19	2	3	2
IR24761-35-3	Nam Sagui 19	3	3	2
IR24761-156-3	Nam Sagui 19	3	3	2
IR25929-13-3-1	Nam Sagui 19	3	4	2
IR25929-42-2-3	Nam Sagui 19	3	4	2
IR28252-102-1	Nam Sagui 19	3	4	3
Khao Dawk Mali 105		5	7	4
Nam Sagui 19		5	6	3
Salumpikit (tolerant check)		3	5	2
IR442-2-58 (susceptible check)		5	6	3
IRAT 9 (susceptible check)		6	8	8
IR20 (susceptible check)		7	8	5

[a]SES 1-9 scale, where: 1 = no to negligible effects of soil moisture stress and 9 = all plants apparently dead. [b]SES 1-9 scale, where: 1 = 90% or above of the plants fully recovered and 9 = no plants fully recovered. [c]SMT = soil moisture tension.

The semidwarf selections in Tables 6-8 should also be tested in deep water for yield and other characters. It is possible that the elongation ability of the deepwater parent and the high yield potential of the semidwarf parents are combined in some of these lines. These combinations should generate drought-tolerant, high yielding deepwater rices.

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DISCUSSION

DURVASULA: Nam Sagui 19 derivatives such as IR52, although showing consistent tolerance for drought in greenhouse tests at IRRI, were recorded as susceptible at some IRTP sites. What, in your view, are the reasons for such discrepancies?

DE DATTA: I hope very few have recorded such reactions. Possibly some soil problems could have modified the results.

PUCKRIDGE: Three important factors in drought tolerance are survival, recovery, and reproduction. In deepwater rice, elongation is affected by drought and flowering is delayed. Can you comment on the effect of drought on yield?

DE DATTA: Mass screening for drought tolerance cannot be used to determine yield potential of rices under drought conditions because many deepwater rices presently grown are photope-

riod sensitive as are most of the newly developed rices. To determine the effect of drought on yield, one can do it with a limited number of entries in the wet season.

DURVASULA: I would like to add that some of those screened were identified as tolerant of drought by Dr. De Datta and others. When some of the tolerant rices were entered in the IRTP trials where some drought was reported, some of them gave higher yields. So this may, somewhat indirectly, reflect on what is happening in the reproduction.

KANTER: Different dryland rice soils (including deepwater rice lands) may have different physical and chemical properties at different soil moisture tensions. These differing soil reactions may explain some variety and environment interactions observed among drought-tolerant material. Has any survey been made to determine the extent of soil problems, associated with dryland rice soils, that could mask drought resistance?

DE DATTA: Drought tolerance is often masked by susceptibility to soil problems. The extent of these soil problems is difficult to estimate. A rough estimate is 100 million ha. How much of these problem soil areas are grown to deepwater rice is not known. My suggestion is to screen rices for drought tolerance on good soils rather than to screen for multiple stresses — but it would be up to the national program to decide.

IDENTIFICATION OF DEEPWATER RICE FOR DROUGHT TOLERANCE IN BANGLADESH

A. R. Gomosta and D. G. Kanter

SUMMARY

Bangladesh farmers sow deepwater rice in March or April. Uncertain rainfall during the early growing period often leads to poor stand establishment or complete loss of the crop at the seedling stage.

Incorporation of drought tolerance at the seedling stage in a modern deepwater rice variety is an important requirement. Three hundred promising breeding lines were screened for drought tolerance at the seedling stage and 50 lines were selected.

Bangladesh farmers generally broadcast deepwater rice in dryland fields. Early vegetative growth and plant development depend on unpredictable rainfall. Studies have shown that seedlings must be at least 4-6 weeks old before they can elongate to withstand sudden submergence. Early seeding is, therefore, necessary.

Bangladesh farmers sow deepwater rice in March or April with the onset of premonsoon rains. Uncertain rainfall during the seedling stage often leads to poor stand establishment or complete loss of the crop. Presubmergence drought stress decreases the internode elongation ability of deepwater rice (Vergara and Mazaredo 1979).

The detrimental effects of drought on deepwater rice can be reduced by incorporation of drought tolerance in modern deepwater rice varieties.

Some rice varieties avoid or tolerate drought (O'Toole and Chang 1978). Of the several traits related to the avoidance mechanism, the root system has received maximum attention. In field tests the deep-rooted varieties were found drought tolerant (IRRI 1976a). Deep rooting ability, however, may not help to avoid drought stress in the deepwater rice areas of Bangladesh because the probability of drought is limited mainly to the early seedling stage during the preflood period. Two-week-old seedlings may even be subjected to drought stress. Our earlier research (unpublished) showed that deep rooting ability is not remarkably manifested before 1 month after seeding (unpublished data). Hence, drought tolerance at the early seedling stage and

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recovery ability following the stress period are more important than drought avoidance by the deep root system.

Several screening methods for drought tolerance have been developed (De Datta et al 1975). All of them, however, are not promising. The dry-season screening technique developed at IRRI (De Datta and Vicencio 1976) is not applicable in Bangladesh because low temperatures prevail in November and December. In the wet season, screening is not always successful because of the high probability of rainfall. Hence, screening in semicontrolled conditions is necessary.

Screening techniques in controlled environments to identify drought-tolerant deepwater rice varieties have been described by De Datta and O'Toole (1977). We describe the techniques for screening rices for drought tolerance in Bangladesh and identify breeding lines with drought tolerance and good elongation ability.

MATERIALS AND METHODS

Three hundred promising breeding lines were screened for drought tolerance. The seed was dry-seeded in wooden boxes (46 × 25 × 15 cm). The bottom of these boxes was galvanized wire netting. A layer of stones was placed in the net to facilitate uniform water drainage. The box was filled with granulated soil mixed with sand at a 50:50 ratio and fertililized with 5 g urea, 3 g triple superphosphate, and 2 g of muriate of potash.

OS4, a dryland variety from West Africa, was used as a biological check in the middle line and at the two ends as border. Sufficient water was applied by sprinkling for germination and growing seedlings for 1 week in normal air temperature. At 9 days after seeding (DS) the seedlings were thinned to 20 uniform seedlings in each line. At 10 DS the plants were placed in a glasshouse without added moisture and kept until the OS4 lines dried completely. The boxes were then taken outside and sprinkled with sufficient water. After 48 hours, all the nondried portions of leaves unrolled and the degree of drought tolerance was noted based on the percentage of leaf area damaged. Drought tolerance was scored on a scale of 1 to 9: 1 = 0-10% damaged leaf area, 3 = 20-30%, 5 = 40-50%, 7 = 60-70%, and 9 = 80-100%.

Within 10 days after reirrigation, many lines produced new leaves. The recovery ability was recorded visually based on the plant's vigor. Recovery ability was scored on a scale of 1 to 9: 1 = excellent, 3 = good, 5 = fair, 7 = poor, and 9 = very poor. IR20 and OS4 were used as moderately resistant.

Table 1. Selected breeding lines combined with both drought tolerance and recovery ability following drought. IRRI, 1981.

Designation[a]	Drought tolerance[b]	Recovery ability[c]	Stem elongation[d]
BR116-3B-28	3	3	6.7
BR222-B-263	2	1	6.7
BR222-B-358	3	1	7.0
BR222-B-191-1-2	3	1	4.0

Continued on opposite page

Table 1 continued

BR222-B-191-3-2	3	1	4.0
BR224-2B-2-5	3	1	3.5
BR232-2B-3-4	3	1	3.5
BR306-B-3-1	2	1	3.5
BR308-B-B-2-9A	2	1	3.5
BR311-B-5-4	2	1	3.5
BR314-B-4-6	2	1	3.5
BR516-11-2	4	1	4.0
BR516-333-1	2	1	4.0
BR522-3-1	3	3	4.0
BR522-31-3	4	1	4.0
BR523-3-1	3	3	4.0
BR523-11-3	3	1	4.0
BR523-11-4	3	1	4.0
BR523-31-1	2	1	4.0
BR523-46-2	3	1	4.0
BR523-93-4	3	1	4.0
BR523-97-2	4	1	4.0
BR523-93-4	3	1	4.0
BR523-97-2	4	1	4.0
BR523-168-2	3	1	4.0
BR523-168-3	3	1	4.0
BR524-56-1	1	3	4.0
BR524-291-1	1	3	4.0
DWC(T)-2B-6	3	1	4.0
DWC(T)-B-104	2	1	4.0
DWC(T)-B-283	2	1	4.0
DWCB-B-329-1-B	1	1	4.0
DWCB-B-109-2-B	1	1	4.0
T442-57-BR-2	3	1	6.0

[a]DWC = deepwater rice composite. [b]1 = 0-10% damaged leaf area, 3 = 20-30%, 5 = 40-50%, 7 = 60-70%, 9 = 80-100%. [c]1 = excellent, 3 = good, 5 = fair, 7 = poor, 9 = very poor. [d]Scored according to Standard Evaluation System for Rice (IRRI 1976b).

Table 2. Selected breeding lines with excellent or good drought recovery ability. BRRI, 1978.

Designation[a]	Drought tolerance[b]	Recovery ability[c]	Stem elongation[d]
IR424/Habiganj Aman II	6	3	4.0
CNL319	7	3	4.0
BR222-B-161-10-2-2	6	1	5.0
BR234-56-1-2	7	2	3.5
BR308-B-9-9	6	3	5.0
BR359-20	6	1	3.5
BR516-37-4	6	3	3.5

Continued on next page

Table 2 continued

BR516-48-3	6	3	3.5
BR516-72-1	6	3	3.5
BR523-88-3	6	3	3.5
BR523-193-1	7	1	3.5
BR523-193-3	7	1	3.5
BR523-3-1	6	1	3.5
DWC(T)-2B-169	6	3	3.5
DWC(T)-B-285	6	3	2.5
DWC(S)-B-199	6	3	3.5
DWCB-B-697	7	3	3.5
DWCB-B-3-1-B	7	3	3.5
DWCB-B-3-2-B	7	3	3.5
DWCB-B-3-3-B	7	3	3.5

[a]DWC = deepwater rice composite. [b]1 = 0-10% damaged leaf area, 3 = 20-30%, 5 = 40-50%, 7 = 60-70%, 9 = 80-100%. [c]1 = excellent, 3 = good, 5 = fair, 7 = poor, 9 = very poor. [d]Scored according to Standard Evaluation System for Rice (IRRI 1976b).

Table 3. Yields of selected breeding lines with drought tolerance and recovery ability following moisture stress. BRRI, 1981.

Designation	Drought tolerance[a]	Recovery ability[b]	Yield (t/ha) 75 cm depth	125 cm depth	280 cm depth	Mean
Ejuli Khama	5	1	3.2	2.7	3.2	3.0
Sadanpankaj	5	1	3.7	3.0	2.9	3.0
Kartiksail	8	3	2.6	3.2	2.7	2.8
BR224-2B-2-5	3	1	3.1	3.5	3.0	3.2
BR232-2B-3-4/A	5	1	3.1	3.7	3.0	3.3
BR311-B-5-4	2	1	2.3	4.0	2.7	3.0
BR314-B-4-6	2	1	2.3	3.4	2.9	2.9

[a]1 = 0-10% damaged leaf area, 3 = 20-30%, 5 = 40-50%, 7 = 60-70%, 9 = 80-100%. [b]1 = excellent, 3 = good, 5 = fair, 7 = poor, 9 = very poor.

RESULTS AND DISCUSSION

There was a wide variation in expression of drought tolerance as well as recovery ability among the test lines. Thirty-four entries were identified to have drought tolerance as well as excellent or good recovery ability (Table 1). Twenty lines had excellent or good recovery ability following the drought stress but did not exhibit good drought tolerance (Table 2). Most of these selected materials possess good elongation ability.

Both drought tolerance and adaptability to different water depths are equally important for better adaptation of a deepwater rice variety to Bangladesh conditions. Seven drought-tolerant entries were identified. They yielded about 3 t/ha in shallow, medium, and deep water tests (Table 3).

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DISCUSSION

KUPKANCHANAKUL: What is the relationship between your two systems of scoring for drought tolerance (tolerance vs recovery)?

GOMOSTA: By tolerance we mean the desiccation tolerance, which is measured by the percentage of leaf area damaged. By recovery we mean the ability to produce new leaves and tillers within 10 days after irrigation.

PETPISIT: One of the speakers this morning talked about screening techniques and the varieties that seem to be drought tolerant. Could you recommend to plant breeders the kind of morphology or agronomic trait that one can look for without actually screening for drought tolerance?

GOMOSTA: It depends on the specific requirement. We cannot recommend any.

DE DATTA: I don't think you need to do that. I think the GEU spirit is that you do the integration and other GEU scientists (the soil scientist, the agronomist, and the physiologist) can help you in screening. No trait is 100% fool proof. After you make the crosses give your

segregating material to the physiologist or agronomist, or whoever is helping you, and carry on that way. There is no need to look for a morphological trait.

McGEACHIE: You mentioned that these drought-tolerant materials had also been tested separately for elongation. Could you tell me if those plants that did show some drought stress were given an appreciable amount of water and perhaps had to elongate? Could they do that with just a small amount of water?

GOMOSTA: This was a separate experiment and we used a little water for recovery only. Under Bangladesh conditions we need recovery and we need all systems of elongation so we put water for recovery only.

SCREENING FOR SUBMERGENCE TOLERANCE AND ELONGATION CAPACITY

SCREENING METHODS FOR SUBMERGENCE TOLERANCE IN RICE IN BANGLADESH

A. R. Gomosta, M. M. Hossain, and M. Z. Haque

SUMMARY

Submergence tolerance in both floating and nonfloating rices is important in Bangladesh. Tolerance for prolonged flooding of the floating rice should be associated with rapid elongation ability. For nonfloating rice in areas with intermittent flooding rapid elongation is not desirable. Different screening techniques were used to identify submergence-tolerant materials among floating and nonfloating rices. Twenty-four varieties with more than 70% surviving basal tillers and 20 breeding lines with good recovery following submergence were identified.

Submergence tolerance is an important requirement for both deepwater and shallow-water wetland rices. Considering depth, duration, and rate of water rise, flooding in Bangladesh can be broadly classified as prolonged or intermittent. Prolonged flooding provides the true deepwater and floating rice environment where depths may rapidly reach 3 m or more and last for 5-6 months. In intermittent flooding the rice crop may be suddenly submerged in 50-100 cm water, which completely drains off the field within 1-2 weeks.

In prolonged flooding, basal tillers of floating rice with slow elongation ability may be partially or completely damaged because of sudden submergence. Thus, for prolonged flooding, submergence tolerance should be associated with rapid elongation. But rapid elongation is undesirable for areas of intermittent flooding because when the field drains the elongated plant lodges in the mud and the crop is damaged. This was confirmed by Maurya (1975).

The breeding program for development of varieties that tolerate flooding should consider specific situations. Screening techniques should also be different for different flooding regimes. We discuss screening techniques for floating and nonfloating rices.

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SCREENING FOR SUBMERGENCE TOLERANCE OF FLOATING RICE

Two hundred twenty-nine traditional floating rice varieties and 60 modern deepwater rice lines were screened for submergence tolerance. Two 25-day-old seedlings/hill were transplanted in a deepwater tank at a 50- × 15-cm spacing. The soil was fertilized with 60-60-40 kg NPK/ha.

The plants were allowed to produce basal tillers for 40 days and the water depth was increased 50 cm/day to a final depth of 150 cm. After 21 days at 150 cm the water depth was lowered to 70 cm. The initial and the surviving basal tillers were counted to calculate the percentage of basal tiller survival. Before flooding the tiller angles of different test lines were noted.

SCREENING FOR SUBMERGENCE TOLERANCE OF NONDEEPWATER RICE

For screening the submergence tolerance of nondeepwater rice, 250 breeding lines were used. One 35-day-old seedling/hill was transplanted in a concrete tank at 15- × 10-cm spacing. The soil was fertilized with 30-30-40 kg NPK/ha. FR13A and BR5 were used as tolerant and nontolerant checks and transplanted after every 20 test lines.

The plants were submerged in 70 cm of semiturbid water 5 days after transplanting. After 15 days the water was drained and submergence tolerance of the lines was noted immediately. Recovery ability as indicated by plant vigor and the number of tillers was recorded 15 days after the period of submergence.

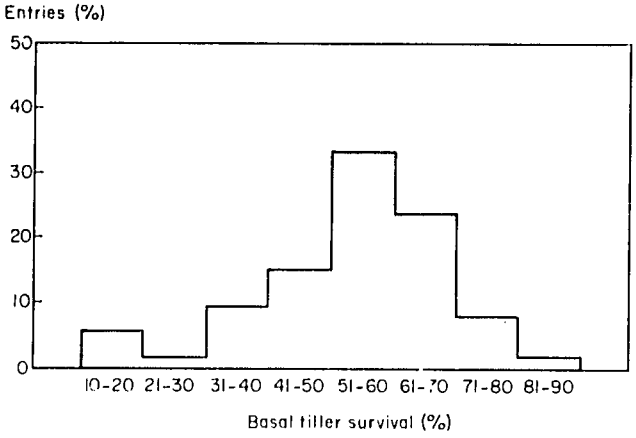
Generally, the percentage of the dead seedlings is considered an index for submergence tolerance, but this trial produced various symptoms. Some plants looked elongated but were apparently dead, others were elongated and green and vigorous. The following scoring system was used:

Score	*Plant characters*
1	erect, elongated, no or slight elongation
2	erect, green, elongated considerably
5	elongated and broken at the middle
7	elongated and lodged
9	elongated and apparently dead

SUBMERGENCE TOLERANCE OF FLOATING RICE

Floating rice varieties are reported to possess poor submergence tolerance at the seedling stage (Vergara et al 1975). Most of the screening for submergence tolerance in deepwater rice is with 10- to 12-day-old seedlings (Vergara et al 1975, Boonwite et al 1977). Application of these to tests in Bangladesh fields is, questionable, however, because floating rice varieties are generally not inundated until they are at least 50 days old.

Many floating rice varieties cannot keep pace with rapid increase in water depth and ultimately their basal tillers die. Our screening method considered the percentage of the surviving basal tillers as an index for submergence tolerance and eliminated a great number of test materials that did not have submergence tolerance associated with rapid elongation ability.



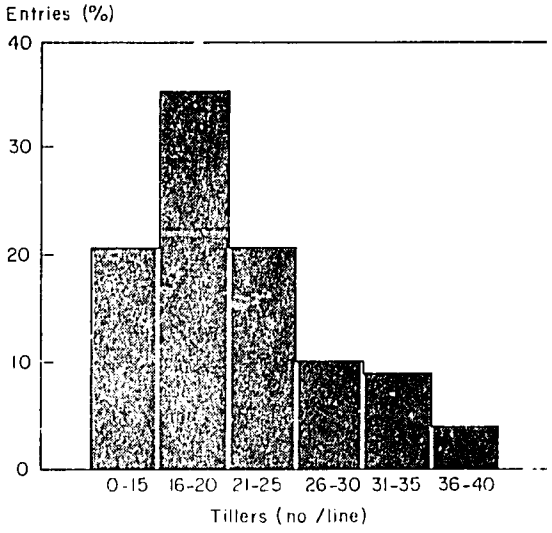
1. Frequency distribution of 229 traditional floating rice varieties according to the percentage of surviving basal tillers. BRRI, 1980.

The floating rice varieties we screened exhibited from near 0 to 90% survival of basal tillers. The largest percentage of the entries, however, had 51-60% basal tillers that survived (Fig. 1). Few entries, mostly in the Dhola aman and Kala aman groups (Table 1), which are suitable for growing in water about 3 m deep, had more than 70% surviving basal tillers. None of the modern lines survived the test because they had been selected in slowly rising floodwater.

Table 1. Floating rice varieties with more than 70% surviving basal tillers in screening of 229 traditional and 60 modern deepwater lines. BRRI, 1980.

Entry	Basal tillers (no./hill)	Openness of tillers[a]	Surviving basal tillers (%)
Khama 2	9	OP	77
Khama 49/2	15	OP	71
Dhola aman	9	SP	81
Dhola aman 664	10	SP	71
Dhola aman 719	11	OP	79
Dhola aman 973	13	OP	72
Dhola aman 981	9	SP	76
Dhola aman 746	10	SP	77
Dhola aman 504	12	SP	86
Dhola aman 662/2	11	OP	76
Kala aman 677	7	OP	82
Kala aman 243	9	OP	73
Kala aman 528	11	OP	83
Kala aman 737	9	OP	77
Kala aman 527	10	SP	84
Kala aman 1088	10	SP	70
Kala aman 735/1	13	SP	73
Kala aman 53/6	10	OP	73
Laki 25/3	13	OP	77
Gawai 279	7	OP	72
Gawai 39/3	6	OP	72
Gawai 131/35	6	OP	72
Moti aman 1075	9	SP	71
Moti aman 73/23	9	OP	79

[a]SP = spreading, OP = open.



2. Frequency distribution of 250 breeding lines according to tiller number after 15 days of submergence. BRRI, 1980.

Table 2. Twenty entries from nonfloating rice with good recovery ability after 15 days of submergence. BRRI, 1981.

Entries	Submergence tolerance	Vigor	Seedlings transplanted (no./line)	Tillers (no./line)
BR113-47-1-1-1-1-1-2	6	3	15	32
BR236-10-36-7-5-2	6	4	15	31
BR237-11-4-1-1-1	5	3	15	32
BR237-11-4-1-2-1-1	6	3	15	31
BR237-11-4-1-2-4-1	5	3	15	39
BR237-11-4-1-2-4-2	5	3	15	35
BR237-76-8-1-1-1	5	3	15	32
BR237-6-2-2-1 (tall)	5	3	15	43
BR239-6-2-2-1	5	5	15	34
BR304-21-2-6-1	5	5	15	34
BR304-43-3-3-1	6	6	15	33
BR593-1-1-1	7	5	15	34
BR593-46-1-1	8	6	15	32
BR593-46-4-3	7	5	15	34
BR593-647-9-1	6	5	15	34
BR593-647-10-1	6	6	15	36
BR593-647-16-1	6	5	15	38
BR593-647-25-1	7	5	15	34
BR593-647-25-3	6	5	15	41
BR593-693-1-1	7	5	15	36

[a]Score 1 = plant erect, green, no or slight elongation; 2 = erect, green, elongated considerably; 5 = elongated and broken at middle; 7 = elongated and lodged; and 9 = elongated and apparently dead.
[b]Score based on Standard Evaluation System for Rice (SES) 3 = plant vigorous; 7 = plant less vigorous than normal. [c]Counted 15 days after drainage.

SUBMERGENCE TOLERANCE OF NONFLOATING RICE

In intermittently flooded areas farmers usually transplant 30- to 60-day-old seedlings and the crop may be inundated any time within a month from transplanting. Earlier works showed excellent submergence tolerance of 30-day-old FR13A seedlings even when submerged on the date transplanted (Gomosta, BRRI, unpubl. data).

In our screening the test lines had various tolerance for submergence, with most scoring 5-7. Within 15 days after the period of submergence, many lines produced fresh leaves and tillers. The materials tested, however, exhibited degrees of vigor positively related with the degree of submergence tolerance ($r^2 = 0.25^{**}$). But submergence tolerance had no relationship with the tillering ability of a test line ($r^2 = 0.003$ ns).

Tillering ability among the test lines varied widely during recovery (Fig. 2). Some lines either did not produce tillers or could not recover, a few entries exhibited good recovery and produced at least one tiller/seedling. The 20 best lines, which showed good tillering ability, differed widely in terms of submergence tolerance and vigor (Table 2). At least one parent of these breeding lines is a traditional nonfloating wetland rice widely grown in intermittent flooded areas.

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DISCUSSION

HILLERISLAMBERS: In your test for intermittent flooding, did your floating rices reach the surface during the test?

GOMOSTA: During a week after submergence, none of the entries reached the water surface.

DURVASULA: In your submergence screening of floating rices, those found good may not be due to submergence tolerance per se but because of their rapid elongation ability. Please comment.

GOMOSTA: The floating rice varieties that did well definitely had good elongation ability. I believe they also had submergence tolerance because they were also under complete submergence for a week or more after sudden submergence in 150 cm water. We tested about 300 traditional floating rice varieties and a few had 70-80% survival tiller. In fact, floating rice in Bangladesh needs both submergence tolerance and elongation ability. I strongly feel that these

two important traits should not be tested separately — particularly when we are dealing with the floating-rice environment. I also advocated that we do not compare the submergence tolerance of floating rice, when tested in intermittent flooding, with that of FR13A, which has little elongation ability. In intermittent flooding, the floating rice usually scores poorly because of its high elongation ability, but high elongation ability is an important requirement for this group of rice. I suggest we use the method I described to screen for submergence tolerance and elongation ability at the same time.

HILLERISLAMBERS: We seem to be getting into terminology problems here. We usually restrict the term submergence tolerance to tolerance for complete submergence. The ability to emerge through the water is what we call rapid emergence. The two are fundamentally different. Tolerance for total submergence is finite whereas a plant, once surfaced, can survive.

GOMOSTA: I agree that submergence tolerance and elongation ability are fundamentally different. In our test, the plants remained completely submerged at least for a week or longer. There was a wide variation in basal tiller survival ability due to sudden submergence but all of them had good elongation ability. We selected only those with high basal tiller survival as well as good elongation ability. Entries with only 10% survival of tillers definitely had poor submergence tolerance but emergence of 10% of tillers through 150 cm water definitely proves good elongation capacity.

SUBMERGENCE TOLERANCE OF DEEPWATER RICE IN INDONESIA

S. Sulaiman and H. Anwarhan

SUMMARY

In Indonesia's swamp areas rice seedlings are normally killed by submergence. Submergence-tolerant rice varieties are needed for both tidal and nontidal swamplands. In direct tidal swamps, lodging resistance is also important because rice seedlings normally lodge because of tidal action. In the continuous swamps, especially where direct seeding is practiced, rapid elongation ability is needed in addition to submergence tolerance.

Trials in direct tidal and continuous swamps and in a laboratory water tank tested submergence tolerance. Several promising varieties and breeding lines were identified and should be further tested.

Indonesia has about 37 million ha of swampland, of which only a small portion is in agricultural production (Indonesia, Biro Pusat Statistik 1974). Deepwater rice areas are in tidal and nontidal swamplands of Sumatera and Kalimantan. During the rainy season the water level may range from 1 m to more than 2 m. Most of the area cannot be planted to rice because the water is too deep. Some rice cultivation is possible by transplanting at the beginning of dry season when the water has receded. However, heavy rains can still cause sudden flooding. A few farmers direct-seed at the start of the wet season, but that is risky because rapidly increasing water depth may damage the crop.

The same is true for tidal swamps. Therefore submergence-tolerant rices are needed for both tidal and nontidal swamps. In addition rapid elongation ability is necessary to cope with increasing water depths in the nontidal swamps.

TESTING FOR SUBMERGENCE TOLERANCE

Field experiments in tidal swamps

An experiment in a direct tidal swamp in Banjarmasin during the 1979-80 wet season tested 39 deepwater rice varieties or lines (4th IRDWON). Seeding was 27 March

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1980, transplanting 28 April 1980. Plant spacing was 25 cm × 25 cm in 1 m × 5 m plots. The traditional varieties Lemo and Bayar Malintang were used as checks.

During the early stage of growth rice plants were submerged daily by high tides for 4-5 hours. Data are presented in Table 1. Based on percentage of survival (95%) only 29 varieties or lines had high submergence tolerance. Varieties with the same degree of survival but higher number of productive tillers and better phenotypic acceptability were considered most promising. They were BR118-3B-17, FR13A, IR4570-83-3-3-2, CN539, and SPR7292-296-1-8-B.

Another test was made in the 1980-81 wet season in Banjarmasin (5th IRDWON). Of 60 varieties, 38 had 95% survival (Table 2). Twenty-three were discarded because of lodging. The lines considered best because of higher submergence tolerance, lodging resistance, and phenotypic acceptability were BKN6981-38-1, BKN6986-66-2, BKN7022-10-1-4, DWCT134-1-3-B, DWCT156-1-B-B, IET5656 (RP975-109-2), IR4570-83-3-3-2, IR7732-RGA-B-A96-1, and IR23430-R-R.

Field experiment in nontidal swamp

In the 1979-80 wet season in a nontidal swamp at Lianganggang (South Kalimantan) 12 lines were seeded 28 October 1979, at a 25 cm × 25 cm spacing in 2.5 m × 10 m plots. The water level was deepest (100 cm) in February.

Observations on plant height and seedling vigor were made before the flood covered the plants. At harvest, data for both plant height, number of tillers, and plant survival were taken.

B1050d-Kn-46-1-1-4-2-3 and B1050d-Kn-1-1-1-1-3 showed best seedling vigor (Table 3) but they were not submergence tolerant. B1050c-Mr-18-2 and BKN6986-

Table 1. Data of tidal swamp experiment (4th IRDWON), Banjarmasin Experimental Farm, BARIF, Indonesia, 1979-80.

Designation and cross	Plant height (cm)	Flowering date	Acceptability at maturity [a]	Survival (%)	Panicle number
BH2	175	4 Aug	3	95	12
BKN6986-108-3 IR262/Pin Gaew 56	125	14 Jul	5	95	13
BKN6986-147-2 IR262/Pin Gaew 56	152	4 Aug	3-5	95	15
BKN6986-173-5 IR262/Pin Gaew 56	172	12 Jul	3-5	95	13
BKN6986-66-2 IR262/Pin Gaew 56	113	26 Jul	5	95	10
BKN6990-63	161	10 Aug	3-5	95	24
BR118-3B-17 TKM6/Habiganj Aman VII	134	12 Jul	3-5	95	17
BR223-B-1 TKM6/Habiganj Aman II	134	2 Jul	5	80	23
B1050C-Mr-26-3 Pelita 1-2/T442-36	94	26 Jul	5-7	95	11

Continued on opposite page

Table 1 continued

B1050C-Mr-44-3 Pelita 1-2/T442-36	125	12 Jul	3-5	95	8
B1050C-Mr-7-3 Pelita 1-2/T442-36	122	12 Jul	3-5	95	15
CN539	140	12 Jul	5	95	27
CR1009 Pankaj/Jagannath	95	26 Jul	3	95	14
FR13A	105	22 Jul	5-7	95	32
IET3257 (CR149-3244-198) MNP/CR12/Pankaj	103	12 Jul	5	95	9
IET5656 (RP975-109-2) RPW6-13/Sona	97	27 Jul	5	95	12
IR3464-75-1-1 IR1628-68-3/IR841-1-1-1//IR2061-213	107	27 Jul	5	95	15
IR442-2-58 Peta 2/TN1/LMN	112	22 Jul	5-7	95	22
IR4570-83-3-3-2 IR1702-74-3-2/IR1721-11-6-8-3//IR2055-481-2	113 113	26 Jul 26 Jul	1 1	95 95	29 29
IR7732-B-A96-3 Tarao Bao/IR2061-213-2-16	111	4 Aug	5	95	17
IR9288-B-B-B252-1 Tarao Bao/IR2061-213-2 16/IR34	74	4 Aug	5	95	8
IR9288-B-B-B5-2 Tarao Bao/IR2061-213-2-16/IR34	72	26 Jul	5	90	13
RAU21-168-1-2	164	12 Jul	3	95	15
Sitpwa	207	20 Aug	7	95	28
SPR7292-296-1-8-B NKG/IR48	135	4 Aug	-	95	26
SPR7233-1-24-2-2-2-3	193	3 Jul	1	95	21
Baisbish	125	2 Jul	7	95	10
BR229-B-88 Habiganj Boro II/Habiganj Aman III	118	2 Jul	9	75	12
CNL 319	161	27 Jun	1	95	12
FRG 7	137	18 Jun	1	85	18
Chamara	133	2 Jul	3	60	9
Lemo	160	7 Jul	5	95	23
Bayar Malintang	175	12 Jul	5	95	20

[a]Phenotypic acceptability at maturity scored by SES (IRRI 1980): 1 = excellent; 9 = unacceptable.

Table 2. Data[a] of tidal swamp experiment (5th IRDWON), Banjarmasin Experimental Farm, BARIF, Indonesia, 1980.

Designation	Plant height (cm)	Flowering date	Tillers (no.)	Acceptability at maturity[b]	Maturity (days)	Lodging[c]	Survival (%)
BGD4-7-3PE-1-6	82	27 Aug	23	5	173	1	95
BH2	174	10 Aug	14	3	166	3	95
BKN9696-38-1	124	12 Aug	16	3	166	1	95
BKN6986-147-2	113	25 Aug	28	5	173	1	95
BKN6986-66-2	119	25 Aug	20	3	173	1	95
BKN6990-63	144	18 Aug	18	3	166	5	95
BKN7022-10-1-4	170	14 Aug	15	3	161	1	95
DWCT37-2-B-B	130	17 Aug	12	5	166	3	95
DWCT134-1-3-B	111	15 Aug	24	3	161	1	95
DWCT156-1-B-B	120	16 Aug	16	3	166	1	95
IET3257 (CR149-3244-198)	114	28 Jul	12	5	175	3	95
IET5656 (RP975-109-2)	122	17 Aug	15	3	166	1	95
IR3464-75-1-1	-	18 Aug	-	-	166	1	95
IR4570-83-3-3-2	106	19 Aug	30	3	166	1	95
IR5853-196-1-P1	94	15 Aug	28	7	163	1	50
IR5857-3-2E-1-2	-	12 Aug	-	7	161	1	95
IR5857-64-1E-1-6	105	14 Aug	26	7	163	1	95
IR7732-RGA-B-A96-1	126	27 Aug	20	3	173	1	95
FRG 10	145	25 Jul	15	7	144	3	95
FRRs43/3	166	-	16	9	-	-	25
GMS 12	179	-	32	9	-	-	10
GMS 13	189	-	17	9	-	-	-
Jalamagna	202	-	20	9	-	7	-
Janeria	145	25 Jul	22	5	144	3	95
Madhukar	118	27 Jul	14	7	144	1	95
NPS270	123	26 Jul	14	7	144	1	80
Thavalu (Acc 15325)	119	15 Aug	11	7	161	3	75
IR8234-OT-20	104	-	14	9	-	-	25
HTA7406-110-0-0	142	5 Aug	13	5	153	3	75
SPR7233-1-40-1-1-1-3	142	-	14	9	-	7	25
IR234-22-R-R	124	17 Aug	28	3	166	1	75
IR2347-R-R	132	18 Aug	30	3	166	1	75
IR3428-R-R	125	22 Aug	21	3	168	3	95
IR23429-R-R	148	7 Aug	17	3	154	5	95
IR23430-R-R	153	16 Aug	28	3	163	1	95
CN649-R-R	105	27 Aug	26	3	173	1	95

Continued on opposite page

Table 2 continued

Table 2 (cont'd).

Designation	Plant height (cm)	Flowering date	Tillers (no.)	Acceptability at maturity[b]	Maturity (days)	Lodging[c]	Survival (%)
IR7732-B-A96-3	124	15 Aug	25	3	163	3	95
IR9264-321-3	118	25 Aug	25	3	173	3	95
IR9288-B-B-B252-1	97	7 Aug	24	5	154	1	95
IR9288-B-B-B5-2	104	29 Jul	31	7	144	1	50
IR9764-45-2-2	113	23 Aug	32	7	173	3	75
IR13146-13-3-3	115	27 Aug	32	5	173	1	95
IR131-6-41-3	111	15 Aug	25	7	163	1	95
IR13149-71-3-2	-	27 Aug	-	3	166	-	-
IR13365-253-3-2	-	15 Aug	-	3	163	-	-
IR3426-9-2-1	103	15 Aug	21	7	-	5	50
RAU21-168-1-2	149	15 Aug	20	3	163	3	95
SPR7292-151-2-1-BB	155	12 Aug	19	5	161	3	95
SPR7292-296-1-3-B	156	13 Aug	16	7	163	3	95
Bajra	133	15 Aug	26	7	163	1	95
Baroger	151	15 Aug	19	7	163	-	-
BR223-B-38	-	15 Aug	-	7	163	-	-
Chamara	-	18 Aug	-	7	163	-	-
DW6167	-	18 Aug	-	7	163	-	-
FRG 2	125	10 Aug	22	7	154	3	90
CN650-R-R	157	17 Aug	19	3	163	3	95
CN651-R-R	123	16 Aug	24	7	163	1	95
CN671-R-R	161	12 Aug	16	3	161	5	95
BR1015-R-R	142	18 Aug	27	7	168	5	95
BR1162-R-R	203	27 Aug	20	5	173	3	95

[a]Dash indicates damaged by rats. [b]Phenotypic acceptability at maturity scored by SES (IRRI 1980): 1 = excellent; 9 = unacceptable. [c]Lodging scored by SES (IRRI 1980): 1 = no lodging 9 = all plants flat.

Table 3. Plant height, seedling vigor, phenotypic acceptability, tiller number, and survival percentage of 12 varieties or lines in a field experiment in a continuous swamp. Liang Anggang, BARIF, Indonesia (1979-80).

Designation	At 30 days after seeding		At harvest				
	Plant height (cm)	Vigor[a]	Phenotypic acceptability[b]	Plant height (cm)	Survival (%)	Tillers (no./hill)	Maturity (days)
B1050d-Kn-46-1-1-4-2-3	95	1	9	-	-	-	-
B1050c-Mr-18-2	63	5	3	176	95	16	175
BKN6986-108-2	72	5	3	179	95	16	178
B922c-Mr-69	79	4	7	166	50	5	166
IR42	59	4	5	155	80	16	155
IR4570-83-3-2 (GH 17)	78	4	7	167	10	13	167
B2487d-Pn-1-76-8 (GH 147)	75	4	7	176	25	10	176
B1043d-Sm-28-6-2-1	64	5	5	165	75	11	165
Siyam Halus	52	7	9	-	-	-	-
Lemo	63	5	9	-	-	-	-
Cisadane (B24846-Pn-28-3-Mr-1)	59	5	3	174	85	16	174
B1050d-Kn-1-1-1-3	90	3	9	-	-	-	-

[a]Vigor scored by SES (IRRI 1980): 1 = extra vigorous, 9 = plants very weak and small. [b]Phenotypic acceptability scored by SES (IRRI 1980): 1 = excellent, 9 = unacceptable. Seeding date 28 October 1979.

Table 4. Water depth (cm) at the experimental site Liang Anggang (South Kalimantan), BARIF, Indonesia, 1980-81.

Date	Dec	Jan	Feb	Mar	Apr[a]
1	-	80	77	69	47
2	-	85	74	67	50
3	-	90	73	71	54
4	-	96	71	70	70
5	-	99	75	71	81
6	-	99	79	69	87
7	1	101	85	64	90
8	4	101	85	60	90
9	5	100	95	57	92
10	10	100	100	59	92
11	15	100	100	60	94
12	20	99	100	61	95
13	25	99	90	59	100
14	30	95	98	59	100
15	32	93	97	58	98
16	33	90	95	55	100
17	34	85	94	53	95
18	35	92	93	50	55
19	40	80	92	49	92
20	40	75	90	45	90
21	41	74	85	45	90
22	43	73	83	41	92
23	45	72	80	38	94
24	50	70	78	35	82
25	55	71	75	35	80
26	55	73	70	35	75
27	57	75	70	33	75
28	62	80	69	35	71
29	62	80		37	70
30	64	81		35	75
31	75	84		40	

[a]Seeding 11 November, harvesting 10-23 April 1981. Dash indicates depth not recorded.

108-2 showed medium seedling vigor, but survived to harvest. Those varieties are considered promising and were tested at the same site in 1980-81.

Table 4 gives data on 1980-81 water depths at the experimental site. Plants were harvested in standing water (80-90 cm) in April. Table 5 gives data for 8 varieties. All survived to 30 DS, but only 5 survived until harvest, including B1050c-Mr-18-2 and BKN6986-108-2. IR4570-83-3-3-2, showed poor adaptability to nontidal swamps although it performed well in tidal swamps. That implies that high submergence tolerance in tidal swamps is not necessarily true for nontidal swamps.

Table 5. Seedling vigor, plant height, and tiller number of eight entries in a field experiment in continuous swamp. Liang Anggang, BARIF, Indonesia, 1980-81.

Designation	Vigor[a]	30 DAS		Flowering date[c]	At harvest[b]		
		Plant height (cm)	Tillers (no.)		Plant height (cm)	Tillers (no.)	Yield (t/ha)
B1050C-Mr-18-2	3-5	34	10	16 Feb 1981	152	5	1.0
Bkn6986-108-2	5	39	7	29 Feb 1981	173	6	1.6
IR42	5-7	28	9	-			
IR4750-83-3-3-2	3-5	37	9	-			
B1043d-Sm-28-6-2-1	3-5	37	9	25 Feb 1981	152	2	0.3
B24846-Pn-28-3-Mr-1 (Cisadane)	5-7	26	8	-			
PB Tinggi	3-5	34	9	29 Feb 1981	158	1	0.2
Amas Putih	3-5	36	9	20 Feb 1981	161	1	0.2

[a]Vigor scored by SES (IRRI 1980): 1 = extra vigorous, 9 = plants very weak and small.
[b]Seeded 11 Nov 1980. [c]Dash indicates no survival.

Table 6. Submergence tolerance of 22 rice varieties and their plant height after first (5 days), second (10 days), and third (15 days) submergence. Banjarmasin, BARIF, Indonesia, 1976-77.

Variety	Initial height (cm)	Submergence[a]								
		5 days			10 days			15 days		
		Height (cm)	Survival (%)		Height (cm)	Survival (%)		Height (cm)	Survival (%)	
Lemo	20	36	67	(7)	40	50	(7)	51	20	(9)
Raden Adil	20	32	60	(7)	42	43	(9)	57	27	(9)
Raden Rata	20	26	73	(7)	35	60	(7)	48	27	(9)
Raden Rata Kuning	18	28	80	(5)	34	67	(7)	44	20	(9)
Radan Jawa	20	33	90	(5)	40	67	(7)	51	53	(7)
Randah Padang	18	26	67	(7)	35	50	(7)	48	43	(9)
Ranuah Pilang	19	22	63	(7)	34	39	(9)	46	17	(9)
Siyam Krepek	17	28	50	(7)	32	40	(9)	44	30	(9)
Siyam Kuning	19	27	67	(7)	35	50	(7)	43	23	(9)
Siyam Panangah	17	28	87	(5)	34	63	(7)	46	23	(9)
Bayar Putih	16	29	67	(7)	37	50	(7)	50	43	(9)
Bayar Kuning	18	35	67	(7)	40	60	(7)	50	50	(7)
Bayar Malintang	18	34	67	(7)	40	63	(7)	51	53	(7)
Banih Runtai	19	34	83	(5)	45	67	(7)	61	50	(7)
Pandak	17	35	90	(5)	49	83	(7)	50	70	(7)
Datu	19	36	73	(7)	43	67	(7)	57	53	(7)
C4-63	15	27	67	(7)	29	50	(7)	32	33	(9)
IR5	16	29	67	(7)	34	60	(7)	44	50	(7)
IR20	14	24	73	(7)	26	50	(7)	29	27	(9)
IR26	15	27	93	(5)	28	67	(7)	29	43	(9)
IR28	15	30	83	(5)	34	67	(7)	48	50	(9)
IR30	18	25	93	(5)	27	67	(7)	38	43	(9)

[a]Figures in the parentheses indicate numerical value of survival.

Test in deepwater tank

In a 1976-77 experiment rice was grown in a tank 150 cm × 180 cm × 100 cm. The tank was filled with soil to 10-cm depth and pregerminated seeds of 16 tidal swamp and 6 improved high yielding rice varieties were direct-seeded in single rows at 7.5 cm × 7.5 cm spacing. Ten days after seeding plant height was measured and seedlings were submerged at 30-cm water depth for 5 days. On the sixth day the water tank was drained and survival and plant height were recorded. The next day, a second 10-day submergence was made at 40-cm water depth. A third (15-day) submergence took place in 55 cm of water.

During the first flooding 5 traditional varieties and 3 improved high yielding varieties were moderately tolerant with a score of 5 (Table 6). After the second flooding only Pandak showed moderate tolerance. After the third flooding none of the varieties scored better than 7. The nontolerance could have been due to low elongation rate.

Table 7. Submergence tolerance of 24 varieties or lines, Banjarmasin, BARIF, Indonesia, 1980-81.

Designation	Recovery from submergence[a]
Bayar Putih	1
Bayar Malingtang	3
Siyam Halus	1
Thavalua 15325	1
Lempinang Putih	3
Pudak Sirih	5
Raden Langsat	5
Pinangkara	5
T442-57	5
BKN6986-108	3
BKN6986-66-2	5
BKN6986-141	3
Pelita I/1	3
C4-63	5
IR5	3
BKN6986-117-1	5
Pin Gaew 56	3
Leuang Pratew 123	1
Khao Dawk Mali 105	5
FR13A	3
Angkara	5
Uluran	3
Mainai	3
Kaluà	7

[a]Seedlings 25 days of age were submerged for 2 weeks in 55-cm-deep water. After a week of recovery a score of 1 = less than 1% dead plants and a score of 9 = more than 50% dead plants.

The experiment was repeated during the 1979-80 wet season with 24 entries consisting of 11 traditional varieties from South Kalimantan and the rest from other countries.

Five grams of pregerminated seeds of each variety were seeded in single rows at 7.5 cm × 7.5 cm spacing. Submergence for 2 weeks at 55-cm water depth started 25 days after seeding. Scoring for submergence recovery according to the Standard Evaluation System for Rice (IRRI 1980) was done a week after the plots were drained.

Different varieties showed different reactions (Table 7). Bayar Putih, Siyam Halus (traditional varieties), Thavalu 15325, and Leuang Pratew 123 were rated highly tolerant (score 1). Compared to the previous experiments some varieties showed higher submergence tolerance. The age of seedlings at submergence appears important in determining their tolerance.

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IRRI (International Rice Research Institute). 1980. Standard evaluation system for rice, 2d ed. International Rice Testing Program, International Rice Research Institute, Los Banos, Philippines. 44 p.

DISCUSSION

HILLERISLAMBERS: Was the type of excess water that you screened with, slowly increasing or increasing in an intermittent way?

SULAIMAN: It was slowly increasing.

HILLERISLAMBERS: Was the area far from the river?

SULAIMAN: It was about 40 km from the big river.

ELONGATION OF RICE IN DEEP WATER

S. K. Datta

SUMMARY

Seventy-five breeding lines or varieties were broadcast-seeded in a deepwater field for study of elongation behavior at different periods of growth. Entries showed striking differences in the rate of culm elongation and formation of internodes. Stem elongation was, in general, due to increase in length of individual internodes. At 10 weeks after seeding, elongation occurred in all the entries. The entries tolerant of early submergence showed early stem elongation, which was absent in many varieties. High rate of culm elongation at various periods of growth seemed an important character for survival during sudden submergence with an abrupt rise in water. Data from the study suggest that elongation ability is influenced by various environmental, genetical, and physiological factors.

The most essential morphological character of a deepwater rice variety is its capacity to elongate when subjected to prolonged deep flooding. The elongation ability of varieties in deep water depends on several factors, including rate of culm elongation and number of internodes per plant at different periods of growth and development. To provide a convenient test for elongation ability in the field and allow selection of better varieties for deepwater areas, the relative performance of several varieties in areas of prolonged deep flooding was studied.

MATERIALS AND METHODS

The stem development of 6-, 10-, 14-, 18-, and 22-week-old plants of 74 varieties or lines from different countries, exposed to varying depths of prolonged flooding, was studied (Table 1). The trial was at the Rice Research Station at Chinsurah. The field was connected with the main drainage channel and varying water depths were maintained after two or three monsoon showers. Monthly variations in water level at different periods of growth in the deepwater plot are in Table 2.

Agronomist, Rice Research Station, Chinsurah, West Bengal, India.

Table 1. Varieties and lines used for the study of developmental morphology of stem, Chinsurah Rice Research Station, India, 1980.

Variety or line	Source	Remarks
NC 678, NC 1281, Kumargore, Patnai 23, SR 26B, Achra 108/1, Jaladhi 1, Jaladhi 2	West Bengal	Recommended type
CNL 31, CNL 108, CNL 214, CNL 231 B/B, CNL 270, Mutant $8R_1$	West Bengal	
Kajal Kalma, Layjal, Lawphala 1, Lawphala 2, Gazal, Bakuidahan	West Bengal	Promising local type
GS nos. (Genetic Stock) 5, 9, 211, 245, 268, 279, 319, 333, 335, 336, 337, 339, 342, 343, I-79, II/A-5, 116/B	West Bengal	Promising type of germplasm
MTC 3, MTC 5, MTC 6, MTC 8, MTC 17, MTC 42, MTC 68, 19 MTC 16, TC 6, TC 10, TC 11, TC 12, TC 17, TC 24, TC 30, TC 38, TC 46	West Bengal	Deepwater composite lines (crossed materials received from IRRI)
Jalamagna, Chakia 59, Madhukar	Uttar Pradesh	Recommended type
Jalaj, BR 14	Bihar	Recommended type
SML Temirin, Baisbis, Jabra, KLG 9686-105, KLG 6987-59, KLG 6987-216, Nam Sagui 19, Bajal, Pether, Cauvary, Bhutahati, Acc 230, Acc 15433, Acc 16862, Acc 26286		Entries received from IRRI

Table 2. Monthly water depths in deepwater trials at Chinsurah Rice Research Station. India, July-December 1980.

Month and period of rice growth[a]	Water depth (cm)
Jul, 2.5 WS	5-20
Aug, 6-9 WS	20-35
Sep, 10-13 WS	75-90
Oct, 14-17 WS	100-110
Nov, 18-21 WS	130-150
Dec, 21-25 WS	85-90

[a]WS = weeks after sowing.

Direct seeding was in wet soil in late June, harvest was from November to December in nonreplicated 15-m^2 plots. The soil was heavy clay with pH ranging from 6.8 to 7.5. Farmyard manure at 9 t/ha was applied basally to all plots. Seeds were sterilized by soaking in 0.2% formalin for 4 hours before sowing. Other recommended agronomic practices were followed.

Plant samples of all the varieties were collected at different periods of growth and development. Five plants of each variety selected randomly from the plots were uprooted. The longest culm was separated from the other tillers, total stem length was measured, and internodes were counted. Tables 3 and 4 show mean data on stem length and number of internodes at different periods of growth.

RESULTS AND DISCUSSION

A rice variety resists waterlogging primarily by stem elongation and to some extent by the number of internodes formed. In general, the elongation capacity of a variety increases as plants become older. However, once the plants flower they partially lose their elongation capacity. A typical photoperiod-sensitive rice variety usually flowers in October-November and is, therefore, not subjected to submergence as the monsoon almost ceases in early October.

Table 3. Effects of deep water on stem elongation of 75 rice entries 6, 10, 14, 18, and 22 weeks after sowing (WS). Rice Research Station, Chinsurah, West Bengal, India, 1980 wet season.

Variety or line	Stem length (cm)				
	6 WS	10 WS	14 WS	18 WS	22 WS
Madhukar	10	40	99	125	
Acc 16862		7	39	75	123
TC 17		6	121	131	
GS 5		32	76	129	134
TC 11	16	41	81	137	
GS 211		20	63	128	138
TC 10	2	29	75	117	140
KLG 6987-216		47	130	140	
SML Temirin		7	58	140	142
SR 26B		19	75	129	143
TC 24	14	39	74	140	144
NC1281		11	67	133	144
TC 12	6	34	79	129	145
Acc 15433		23	69	145	145
KLG 6987-59		42	62	142	147
GS 9		39	75	148	
CNL 231 B/B	10	14	55	141	148
MTC 17		32	68	128	148
Lawphala 1	7	9	74	145	148
GS 319		34	83	136	149
MTC 6		58	65	144	151
Pether		35	55	147	152
Nam Sagui 19	5	40	77	133	153

Continued on next page

Table 3 continued

MTC 8		68	71	153	
GS 333		39	67	125	155
TC 30	9	52	133	155	
BR 14		36	60	140	155
Kajal Kalma		13	79	148	155
TC 38		59	85	111	156
TC 6		32	81	146	158
Jalaj		43	64	140	158
GS 342		8	66	149	159
GS 337	21	63	8	156	159
Mutant BR_1		20	65	142	160
Kumargore		34	75	160	160
KLG 6986-105		32	65	152	160
GS 268	2	26	65	148	161
GS 279		72	86	160	163
GS 343		51	75	160	163
GS 336	4	50	67	147	164
GS 116/B		28	67	147	164
Chakia 59	8	9	56	161	165
Bajal		21	68	157	165
CNL 108	17	42	65	167	168
Cauvary		22	69	132	168
CNL 270		48	75	166	170
GS 339		25	77	145	170
Patnai 23		33	60	135	170
Acc 230		73	74	102	171
Bhutahuti		40	87	171	
CNL 214		53	101	169	171
Jabra		72	82	165	171
GS II/A-5		21	72	171	
Gasal		8	66	156	173
Jalamagna		14	63	143	174
MTC 3	4	67	78	148	174
GS 335		76	80	163	175
Baisbis	8	42	96	165	175
TC 46		31	85	162	175
MTC 5	11	75	91	172	175
Lawjal		22	67	133	176
Achra 108/1	8	71	86	169	177
Acc 26286	2	44	72	177	178
CNL 31	2	23	74	165	178
GS 245		35	74	172	180
NC 678		29	75	181	182
CNL 180	4	48	84	178	182
Bakuidhan	16	26	61	136	185
MTC 68		22	66	174	188
Jaladhi 2		31	74	170	199
GS I-79	12	72	80	164	196
19 MTC 16		34	71	161	200
Jaladhi 1	6	71	87	164	201
Lawphala 2		20	64	173	202
MTC 42	15	97	98	176	205

Table 4. Effects of deepwater condition on internode formation of 75 rice entries after 6, 10, 14, 18, and 22 weeks of sowing (WS). Rice Research Station, Chinsurah, West Bengal, India, 1980 wet season.

Variety or line	Internodes formed (no.)				
	6 WS	10 WS	14 WS	18 WS	22 WS
Madhukar	1	5	8	9	
Acc 16862		1	4	10	10
TC 17		1	10	10	
GS 5		4	6	10	10
TC 11	1	4	10	10	
GS 211		4	8	9	9
TC 10		5	8	10	11
KLG 6989-216		5	8	9	
SML Temirin		1	7	10	10
SR 26B		2	8	9	10
TC 24	3	6	10	13	13
NC 1281		2	10	10	12
TC 12	2	4	9	11	13
Acc 15433		4	7	10	11
KLG 6987-59		7	11	12	12
GS 9		5	8	10	
CNL 231 B/B	1	2	6	9	9
MTC 17		3	8	10	14
Lawphala 1	1	2	8	10	12
GS 319		3	8	11	12
MTC 6		6	8	12	13
Pether		5	6	9	10
Nam Sagui 19		4	8	11	13
MTC 8		7	10	14	
GS 333		4	8	11	13
TC 30	3	6	11	12	
BR 14		5	7	10	11
Kajal Kalma		2	8	11	11
TC 38		8	10	13	16
TC 6		4	10	12	13
Jalaj		5	8	9	10
GS 342		2	7	10	10
GS 337	2	7	10	11	12
Mutant SR_1		3	8	11	12
Kumargore		4	8	12	12
KLG 6986-105		4	9	12	12
GS 268		3	6	11	11
GS 279		7	6	11	12
GS 343		9	9	11	12
GS 336	1	6	7	10	11
GS 116/B		3	12	13	13
Chakia 59	1	1	7	10	10
Bajal		3	6	9	10
CNL 108	4	6	9	11	11
Cauvary		4	8	10	11
CNL 270		4	8	11	12
GS 339		2	7	10	10

Continued on next page

Table 4 continued

Patnai 23		5	6	10	10
Acc 230		7	13	17	18
Bhutahati		3	8	10	
CNL 214		4	10	12	12
Jabra		6	9	13	13
GS 11/A-5		2	8	9	
Gazal		2	8	11	12
Jalamagna		3	7	11	13
MTC 3		6	10	12	12
GS 335		7	7	11	11
Baisbis	1	5	10	12	13
TC 46		4	10	11	11
MTC 5	3	7	10	12	13
Lawjal		2	8	10	10
Achra 108/1	3	6	11	11	13
Acc 26286	1	6	8	11	12
CNL 31		3	9	10	11
GS 245		4	8	12	12
NC 678		3	8	13	13
CNL 180	1	5	9	13	13
Bakuidhan	2	4	8	13	13
MTC 68		3	8	13	13
Jaladhi 2		3	8	11	11
GS I-79	3	5	9	14	14
19 MTC 16		4	9	13	16
Jaladhi 1	2	8	11	13	14
Lawphala 2		3	8	11	11
MTC 42	2	7	13	13	15

The internodes that elongated were those recently formed and those developing during submergence. The mature internodes in general did not elongate rapidly. The data in Table 3 also suggest that early-maturing varieties or lines may have relatively vigorous elongation capacity in the early vegetative growth phases, before the water starts to rise to its maximum level. Examples are Madhukar, TC11, TC17, GS9, MTC8, TC30, Bhutahuti, GS11/A-5, and KLG6987-216.

Elongation vigor, in general, is maintained with rising water, partly because of the increased growth seen in most rice varieties shortly before flowering. In general most of the shallow-water, short- and medium-duration, transplanted, photoperiod-sensitive (*aman*) varieties start to elongate at panicle initiation. But the long-duration direct-seeded photoperiod-sensitive deepwater varieties start stem elongation during the early vegetative phases when growing in deep water (Sircar and Ghosh 1947, 1964; Sircar 1948; Sircar and Sen 1953; Sen and Roy 1964; Vergara et al 1965; Vergara and Chang 1976; Datta and Banerji 1977a; Datta et al 1978). In the deepwater varieties, stem elongation starts between 6 and 10 weeks after germination when grown in shallow water (Tables 2 and 3). The main cause of this growth habit is the activity of the apical as well as the intercalary meristem at the nodes. Other variability such as genetic tolerance for prolonged waterlogging, soil fertility, and various environmental factors may also play some important roles when present (Kaufman 1960, Prechachat and Jackson 1975, Maurya 1978, Datta and Banerji 1979, Datta 1979).

There are reports of varieties that elongated after submergence (Sen 1937; Ghosh 1959; Sen and Datta 1967; Datta and Banerji 1977a, 1980). In general, those varieties

may have produced extended internodes but may or may not have produced more internodes when grown in deep water. Once internodes form, they gain elongation capacity and the total number of internodes may vary from 9 to 18 (Table 4). As seen in Table 4 Acc 230 had the most internodes but MTC42 had the highest internode elongation, closely followed by Lawphala 2 and Jaladhi 1. Madhukar had one of the lowest stem elongation ability (Table 3). Therefore, the number of internodes formed does not indicate actual elongation capacity. Among the 75 entries tested, however, these two characters were not interrelated. This suggests that the number of internodes and length of culm elongating in deep water appear to be controlled by different genes (Morishima 1975, Maurya 1978).

No elongation occurred in the 2- and 4-week-old seedlings. At 10 weeks, internode elongation occurred in all the 75 entries used. But at 6 weeks of growth, stem elongation was observed only in 25 entries (Table 3) and most of those varieties were highly tolerant of early submergence (Datta and Banerji 1973, 1977b; Maurya 1978; Biswas et al 1978; Mukherji and Datta 1979; Datta et al 1978). Total length of the stem after submergence varied greatly for all entries studied. Total stem length of 6-week-old plants ranged from 1 to 21 cm and that of 10-week-old plants was between 6.0 and 97.3 cm (Table 3). The ability to elongate rapidly in all the 75 entries could be remarkably differentiated at 18 weeks of growth. But difference among the rice varieties in their capacity to elongate could be seen even in 10-week-old plants. Stem length increased in most of the varieties although an appreciable number of internodes formed in few varieties between 18- and 24-week-old plants. Stem length increased as a result of increased length of individual internodes and to some extent, its number (Table 4), and this was greater in floating rices such as MTC42, Jaladhi 1, GSI-79, Bakuidahan, 19 MTC16, Jaladhi 2, Lawjal, Jalamagna, and Acc 230, which had high increase in stem length, even in the 22-week-old plant. At the late phases of growth, stem length was considerably different for plants of both ages of most of the entries, i.e. total stem lengths of 18-week-old plants ranged from 102 to 181 cm and that of the 22-week-old plants ranged from 127 to 205 cm (Table 3).

In many deepwater areas, the early rise of water level damages the rice crop severely. The availability to elongate apparently increases with age. Early stem elongation of plants may effect better survival by providing better tolerance for submergence. The rice varieties studied differed in the age at which seedlings began to elongate and the extent of elongation (Table 3). This capacity for stem elongation at an early stage of growth, as in Madhukar, may be an important character for rices where submergence comes during the early stages of plant growth (Dikshit and Maurya 1971, Setabutara et al 1975, Vergara et al 1975, Mazaredo and Vergara 1979, Saran and Sahai 1979, Seshu and Vergara 1979, HilleRisLambers et al 1977).

Varietal differences in the ability to elongate early should be considered when selecting varieties for deepwater areas where seeding is in the early monsoon and seedlings are often subjected to submergence at the seedling stage. Submergence, in fact, is a common cause of damage to young seedlings in deepwater areas (Datta et al 1978).

This study also indicates variation in rate of elongation according to the type of varieties. The ability for rapid stem elongation as in some varieties — such as CNL180, CNL31, CNL231 B/B, Madhukar, Chakia 59, CNL214, Jalamagna,

Jaladhi 1, Achra 108/1, and CNL108 — may be useful in areas where the water level rises abruptly (Datta and Banerji 1973, 1977b; Maurya 1975 a, b; Biswas et al 1978; Mukherji and Datta 1979; Seshu and Dewan 1979).

After 10 weeks of growth the wetland varieties attain an appreciable stem length that can easily withstand 1 m of water, even if such a water level is reached abruptly (Table 3). The tall improved indica varieties, such as Patnai 23, NC1281, Kumargore, Achra 108/1, and NC678 would have to elongate to stay above water even if it was only 1.5 m deep. A plant type taller than those varieties would have an advantage in areas where water depth is more than 2 m. Generally the wetland varieties showed changes in the structure of elongated stems when grown in deep water (Datta and Banerji 1974, Datta and Som 1974). In addition, morphohistological data on structure and development of stems of rice varieties in relation to adaptation under shallow-water cultivation were also indicated in the works of Juliano and Aldama (1937), Majumdar and Saha (1956), Kaufman (1960), and Basu et al (1970). Moreover, the deepwater rice variety has the inherent culm property for elongation with the rise in water level.

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DEEPWATER RICE TRIALS IN FARMER FIELDS IN THE MEKONG DELTA IN VIETNAM

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SUMMARY

Deepwater rice in the Mekong Delta is grown mostly on acid sulfate soils. From experiments in 1979 and 1980 at water levels ranging from 80 to 220 cm, BKN6986-29, BKN6986-44, BKN6986-70, Cula, Chenab 64-117, and LMN 111 were the most promising entries. They were also superior to the local check Nang Tay Dum. In a fertilizer trial with RD19 in 120 cm water, urea in mudball and urea supergranule gave yields of 2.7 and 2.6 t/ha, as good as 50% prilled urea plus 50% sulfur-coated urea, which yielded 2.6 t/ha. Control plots yielded only 1.3 t/ha. Fertilizer use gave a higher number of panicles/m^2, a higher percentage of filled grains, and higher yields.

Annually about 1.31 million ha in the Mekong Delta are flooded 1-4 m deep from July to November. Of this, about 500,000 ha grow deepwater rice. Attempts to reclaim the remaining area have not been successful because of adverse soils.

Almost all of the seasonally deep-flooded areas in the Mekong Delta are acid sulfate soils. Aluminum and iron toxicities often kill young rice plants before flooding, especially during irregular rainfall. For the Mekong Delta, a good deepwater rice variety must have:

- resistance to drought,
- tolerance for aluminum, iron, and acid toxicities, and
- resistance to damage by the ufra nematode.

We have deepwater rice experiments in farmer fields. In those, we often encounter:

- uncontrollable field water,
- unpredictable weather, and
- frequent damage to rice by crabs, rodents, birds, and fish.

This paper reports continuation of our previous work (Xuan and Kanter 1975, Ohta et al 1976, Xuan and Hiep 1977).

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INTERNATIONAL RICE DEEPWATER OBSERVATIONAL NURSERIES

The 1979 International Rice Deep Water Observational nursery (IRDWON) received from the International Rice Research Institute (IRRI) was divided into two unequal portions:

- The largest was transplanted on an Ustifluvent (pH 5.2) at Binh Duc, Angiang province (10° 24 N, 105° 25 E), at a 25 × 25 cm spacing with 1 36-day-old seedling/hill. Each entry had three 5-m rows. After every five entries, a local check (Nang Tay Dum, Trung Hung, or Trang Tep) was planted alternately. Fertilizer (25-25-0) was applied 1 day before transplanting.
- The other portion of seed, together with seed of other deepwater rice varieties collected since 1975 (making a total of 130 entries), was planted at the Cantho University Experiment Station on a Sulfaquept (pH 4.8) irrigated with fresh river water. Each entry was transplanted in a 5-m row. Plant spacing, fertilizer rate, and inclusion of the check varieties were same as at Binh Duc.

Water depth at both sites was maintained at 20-40 cm.

The 1980 IRDWON was tested as in 1979, except that we used a farmer field with deeper flooding in Vinh Hanh, Angiang province (10° 30 N, 105° 15 E). The soil was a Sulfaquept (pH 4.7). River water had pH 5.6 at transplanting.

1979 IRDWON results

In 1979 the Mekong Delta flood was moderate, which provided excellent crop growth. At the experimental site water depth was 23 cm on 9 August, 55 cm on 12 September, and 81 cm (the maximum) on 10 October (65,100, and 125 days after transplanting, respectively). Rats and birds caused heavy losses at Binh Duc and ufra disease (*Ditylenchus angustus* Butler) Filipjev damaged more than half of the entries at Cantho.

The ufra infestation was accidental because we used the contaminated water from adjacent plots that tested rice varietal resistance to ufra. Table 1 shows ufra resistance rating of the 37 deepwater rice varieties tested. Of the three local checks, only Nang Tay Dum was moderately resistant. Several promising lines and varieties showed marked ufra resistance.

The varieties and lines differed greatly in their flowering dates. Most entries flowered in September, which is not desirable because mature plants could not elongate while water depth was still rising in October. We observed that varieties that flowered during November, when the flood normally starts receding, were more desirable in the Mekong Delta. Setabutara and Vergara (1979) suggested that a desirable deepwater plant type should flower 4-8 weeks after peak flood.

The 1979 IRDWON entries showed good kneeing ability (Table 2). Stem elongation was evaluated at Binh Duc site; part of the results is included in Table 2. Only 12% of the entries showed excellent stem elongation, 31% had elongation as good as the check varieties. When compared for other traits, however, especially flowering dates, only 12 entries were selected for further yield trials.

1980 IRDWON results

We received the 1980 IRDWON seed 1 month later than the normal seeding date.

Table 1. Reaction of some deepwater rices to *D. angustus* at Cantho, Cantho University, 1979 wet season.

Entry	Rating[a]	Entry	Rating[a]
BH2	3-5	CNL31	1-2
BKN6986-147-2	3-4	CNL53	1
BKN6986-167	4-5	CNL180	1-2
BKN6986-173-5	3-4	CNL231B/B	1-2
BKN6987-161-1-3	4-5	CNL319	1
BR188-3B-17	4-5	Cula	1-2
BR223-B-1	3-4	Chenab sel. 64-117	1
CN539	3-4	FRRS 43/3	1
CNL241	3-4	GEB 24	1-2
Sitpwa	2-3	LMN 111	1-2
Tadaungpo	3-4	Mura Bazal	1-2
BKN6986-11-3	1	Peta	1-2
BKN6986-29	2	PG56	1
BKN6986-44	1	Saran Kraham	2
BKN6986-70	1	Yodaya	1-3
BKN6986-81-5	1	Nang Tay Dum	1-2
BR223-B-3	1-2	Trung Hung (check)	3-4
BR223-B-38	1	Trang Tep (check)	5
BR229-B-88	1		

[a]1 = plants not affected, 5 = all plants dead.

Table 2. Some characteristics of 12 promising lines and varieties selected for further testing under deepwater condition in Binh Duc, An-giang province, Vietnam Mekong Delta, Cantho University, 1979 wet season.

Entry	Flowering date	Plant height (cm)	Lodging[a]	Elongation[b]	Kneeing[c]	Nematode[d]
BKN6986-11-3	5 Nov	168	2	3	1	1
BKN6986-29	10 Nov	178	3-4	3	1	2
BKN6986-44	10 Nov	172	5	3	3	1
BKN6986-70	11 Nov	176	4	4	3	1
BKN6986-81-5	10 Nov	181	5	3	5	1
Cula	10 Nov	191	5	4	1	1-3
Chenab Sel. 64-117	10 Nov	201	4	5	3	1
FRRS 43/3	10 Nov	196	5	4	3	1
GEB 24	10 Nov	170	4	4	1	1-2
LMN 111	15 Nov	197	4	5	1	1-2
Pin Gaew 56	25 Nov	207	4	5	3	1
Yodaya	13 Nov	171	2-3	3	5	1-3
Nang Tay Dum (check)	15 Nov	180	4	4	3	1-2

[a]1 = no lodging, 5 = all plants flat. [b]1 = no elongation, 5 = best elongation. [c]1 = tiller angle greater than 45° for 50% of the tillers, 9 = no kneeing. [d]1 = plants not affected by nematodes, 5 = all plants dead.

Acidic soil and water at transplanting time unfavorably affected crop stand establishment. Flooding was more rapid than normal, and its recession was delayed longer than normal. Transplanting was 10 July. Water depth was 35 cm at the experimental site on 13 August, 105 cm on 17 September, 160 cm on 10 October, 220 cm on 18 October, 101 cm on 14 November, 115 cm on 26 November, and 106 cm on 30 November.

Of 54 entries, only 14 flowered at end October or later and thus escaped fish damage. Several kinds of fish ate rice grains from panicles that had barely emerged from the water surface. Chamara, FRRS 43/3, GMS 13, and Khama were most promising and performed better than the local check Nang Tay Dum (Table 3).

When planted in 20-40 cm water at Cantho University Experiment Station several entries of the 1980 IRDWON performed well (Table 4). They were tall but sturdy with erect leaves. We selected them for further testing in low-lying, intermediate deep (40 cm) or medium-deep (about 80 cm) rainfed areas in the Mekong Delta.

1980 REPLICATED YIELD TRIAL

From selections made during 1979, we tested 20 lines and varieties of deepwater rice in a farmer field at Thanh-an, Haugiang province (10° 11 N, 105° 28 E). The soil is a poorly drained Sulfaquept that flash floods for 10-15 days following several heavy downpours. Thirty-day-old seedlings of each entry were transplanted at a 25 × 25 cm spacing (1 seedling/hill, 6.5-m rows) in a randomized complete block design with 3 replications. Fertilizer at 23-40-0 kg/ha was applied 1 day before transplanting.

Maximum water depth of 120 cm was on 10 October 1980. A flash flood killed 7 entries and FRRS 43/3, the first to flower, was eaten by ducks. RD19 did not perform as well as BKN6986-29, Cula, Chenab 64-117, and LMN 111 (Table 5). These promising varieties were superior to the local check Nang Tay Dum, which yielded

Table 3. Some characteristics of 10 promising deepwater rice varieties and lines selected from 1980 IRDWON grown at Vinh Hanh, An-giang, Vietnam, Cantho University, 1980 wet season.

Entry	Plant height (no.)	Phenotypic acceptability[a]	Elongation[b]	Survival (%)
SPR 7233-1-24-2-2-2-3	235	2	1	95
SPR 7292-151-2-B-B	240	4	5	95
Chamara	240	2	1	90
DW6167	235	4	1	80
FRRS 43/3	227	3	3	99
GMS 13	250	3	1	80
GMS 12	224	4	3	40
Jalamagna	245	4	1	50
Khama	242	3	3	70
Nang Tay Dum (check)	240	4	1	70

[a] 1 = most accepted, 9 = not accepted. [b] 1 = best elongation. 9 = no elongation.

Table 4. Selected entries from 1980 IRDWON most adapted to semideep and medium-deep water at Cantho, Cantho University, 1980 wet season.

Entry	Phenotypic acceptability[a]	Flowering date
BGD 4-7-3PE-1-5	1	12 Sep
BKN5986-38-1	3	12 Oct
BKN6986-147-2 (RD19)	3	15 Nov
BKN6986-60-2 (RD17)	3	15 Oct
BKN6990-63	3	11 Oct
BKN7022-10-1-4	3	15 Oct
DWCT37-2-B-B	3	30 Sep
DWCT134-1-3-B	3	28 Sep
DWCT156-1-B-B	2	12 Oct
IR4570-83-3-3-2 (IR48)	3	3 Oct
IR5853-196-1-P_1	2	10 Oct
IR5857-64-1E-1-5	3	30 Sep
IR7732-B-A96-3	3	15 Oct
IR9264-321-3	3	15 Oct
IR9764-45-2-2	3	15 Oct
IR13146-13-3-3	3	9 Oct
IR13146-41-3	3	7 Oct
IR13149-71-3-2	2	11 Oct
IR13358-73-1-1	3	17 Oct
IR13365-253-3-2	2	8 Oct
IR13426-9-2-1	2	9 Oct
RAU21-168-1-2	3	15 Oct

[a] 1 = most accepted, 9 = not accepted.

1.9 t/ha. Saran et al (1979) reported a highest yield of 2.3 t/ha with Chenab 64-117, the most promising deepwater rice in Bihar, India. Cula, the Vietnamese variety, performed best in this trial. LMN 111 has consistently shown its good adaptability in the Mekong Delta. Wider scale yield tests with these promising 1980 entries were made during 1981.

RD19 RESPONSE TO FERTILIZER

Due to the generally low available phosphorus in the soils of the Mekong Delta, deepwater rice has shown excellent response to phosphorus fertilizers even in deeply flooded fields. It has, however, shown little response to nitrogenous fertilizer. Kupkanchanakul et al (1979) suggested that improved photoperiod-sensitive deepwater rices would likely respond to fertilizer application better than traditional ones. The International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) recently introduced several fertilizer materials, especially the sulfur-coated urea and urea supergranules. We attempted to find how improved deepwater rices respond to such fertilizers.

RD19 was grown in a farmer field at Thanh-an, Haugiang province. Eight treat-

Table 5. Yields and yield components of 11 deepwater rice varieties and lines grown in farmer fields at Thanh-an, Hau-giang, Vietnam, 1980 wet season.

Entry	Flowering date	Panicles (no.)/ m^2	Filled grains (no.)/ panicle	Empty grains (%)	1,000 grain wt (g)	Grain yield (t/ha)
BKN6986-11-3	24 Nov	52	103	32	26	1.4
BKN6986-29	23 Nov	58	130	13	25	2.2
BKN6986-44	24 Nov	74	117	13	24	2.1
BKN6986-70	25 Nov	50	156	23	23	2.0
BKN6986-81-5	25 Nov	68	102	14	25	1.8
Cula	25 Nov	68	136	28	24	2.3
Chenab Sel. 64-117	20 Nov	61	157	17	26	2.2
LMN 111	30 Nov	46	171	18	33	2.2
Yodaya	24 Nov	44	144	11	30	1.6
RD19	30 Nov	71	78	30	32	1.8
Nang Tay Dum (check)	30 Nov	57	141	26	22	1.9

ments with three replications were arranged in a randomized complete block design:

- no nitrogen,
- all prilled urea (PU) as basal application,
- all sulfur-coated urea (SCU) as basal application,
- half each of PU and SCU as basal application,
- two-thirds of PU basal and one-third PU as foliar spray,
- two-thirds SCU basal and one-third PU as foliar spray,
- PU in mudball, and
- supergranule urea.

We transplanted 192 hills/treatment in a 3 × 4 m plot at a 25 × 25 cm spacing, with 2 30-day-old seedlings/hill. Fertilizer rates were 54 kg N/ha and a blanket application of 40 kg P_2O_5/ha in all plots. Urea mudballs or supergranules were placed at a 10-cm depth between every 4 hills of rice.

Table 6 presents the yields and yield components of RD19 as affected by various treatments. Fertilizer effect was highly significant. We observed that during early growth, prilled urea and, to a lesser extent, sulfur-coated urea, gave better crop response as exhibited by greener foliage. However, soon after the maximum tillering stage, the plots treated with PU and SCU started showing nitrogen deficiency symptoms, whereas those treated with urea mudballs and urea supergranules stayed green. Plots with one-half PU plus one-half SCU were slightly better than plots with all PU or all SCU, possibly because the one-half PU promoted early growth and one-half SCU extended the nitrogen supply to the rice plant at the later growth stages. The all-PU treatment suffered at the later growth stages mainly due to fertilizer loss in surface water. The all-SCU treatment produced slow crop growth during the vegetative stage. The urea mudball treatment was the most promising method of prilled urea application.

Table 6. Yields and yield components of RD19 as affected by different fertilizer application methods, under deepwater conditions at Thanh-an village, Hau-giang, Vietnam, Cantho University, 1980 wet season.

Treatment[a]	Panicles (no.)/ m^2	Filled grains (no.)/ panicle	Empty grains (%)	1,000 grain wt (g)	Grain yield (t/ha)[b]	Difference (%)
No nitrogen	85	60	30	32.6	1.1 c	0
All prilled urea	113	65	22	32.9	2.2 b	92
All SCU	112	69	24	33.2	2.3 b	98
1/2 PU + 1/2 SCU	119	70	24	34.0	2.6 a	133
2/3 PU + 1/3 PU (FS)	101	69	30	32.6	2.1 b	84
2/3 SCU + 1/3 PU (FS)	103	72	23	33.6	2.2 b	91
Mudball	123	71	28	34.3	2.7 a	136
Supergranule	120	71	21	35.9	2.6 a	127

[a]SCU = sulfur-coated urea, PU = prilled urea, FS = foliar spray.
[b]In a column, means followed by the same letter are not significantly different at the 5% level.

CONCLUSION

With the introduction of early-maturing high-yielding rices such as NN7A (IR9129-192-2-3-5) and NN6A (IR2307-247-2-2-3), farmers in Angiang and Dongthap provinces are replacing their long-duration traditional floating rices with two crops of NN7A — a crop before and another after flooding. Thus, they may turn more than 140,000 ha of 1-crop area into a 2-crop/year area and increase yields from 1.5 t/ha per year to 8-10 t/ha per year. However, the remaining deepwater areas still need more attention.

In deepwater rice studies, varietal adaptability should be combined with soil and water management techniques to get good early stand establishment. We found the first 30 days after seed germination most critical in acid sulfate soil because during that time soil water became most acidic and aluminum toxicity harmed the young seedlings.

Our tests so far have not approximated farmer practices because we transplant our rice trials. Future experiments will be direct-seeded as much as possible.

The lines and varieties selected from the 1979 and 1980 IRDWON are promising and we tested them for wider adaptability in 1981. Simultaneously, we are breeding new deepwater rices to incorporate genes tolerant of acid sulfate soils. The yield potential of RD19 should be exploited further with better fertilization methods.

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PLANT ELONGATION SCREENING IN CONTROLLED FLOODING OF DEEPWATER RICES IN BANGLADESH

M. A. Wahab, B. A. Dewan, M. Nasiruddin, and D. G. Kanter

SUMMARY

Screening for elongation ability started at BRRI in 1977. The planting methods, namely direct seeding, transplanting, and panicle placement are described. Standard procedures for subjecting test materials to rising water levels are outlined. A panicle placement method helped accommodate three times more materials than the other methods on the same amount of land and allowed handling of more genetic variations. It also was less expensive.

Plant elongation is essential for deepwater rices to fit flooding patterns where water depth may rise to 5 m. Most traditional rices grown in flood-prone areas have elongation ability.

A major objective of the breeding program for deepwater rice in Bangladesh is to obtain progenies from crosses between traditional deepwater rices and nonelongating modern rices with a capacity to elongate and survive flooding depth ranging from 1 to 3 m.

SCREENING FOR ELONGATION ABILITY

Various techniques to test deepwater rices for elongation ability have been tried in different countries. Before the construction of deepwater tanks at BRRI, the Deepwater Paddy Research Station at Habiganj did screening for elongation ability. The technique used was laborious and had limited use.

Construction of deepwater tanks at BRRI was completed in 1977. The facilities consist of six tanks and a large reservoir (Fig. 1).

Testing procedures

Before the monsoonal rains in March and April seedbeds about 130 cm wide and the length of the large tanks (Fig. 1) are prepared and dry seeding is done. In case of early

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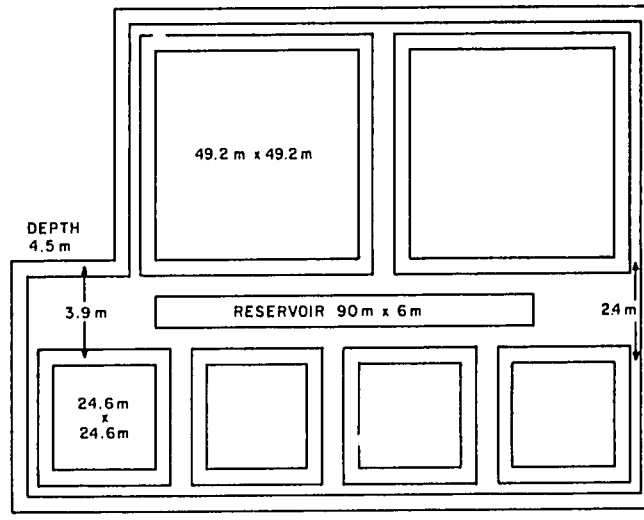

Diagram of tanks for testing deepwater rice plants

1. Diagram of deepwater tanks used for experiments at the Bangladesh Rice Research Institute. Elongation screening is done in two 49.2 × 49.2 m tanks (Zaman 1977).

excessive rain the land is puddled and raised seedbeds are prepared. Both techniques work but seedbeds with dry soil are prepared because movement is easier.

Furrows 125 cm long are made 25 cm apart on the seedbeds. Dry seeds (5 g) of each test line are sown in the rows and covered with soil (or lightly pressed into the puddled soil with wet bed). About 5 cm water is added to get uniform germination.

If a second test is done during the rainy season, test lines are transplanted. Frequent rains can cause erosion of the furrows and mixing of the seeds, or decrease germination due to excessive standing water.

We are primarily interested in those progenies with elongation ability as good as or better than T442-57, a semidwarf rice with moderate elongation ability. Habiganj Aman II, a traditional variety with good elongation, and T442-57 are alternately placed in every 20th row as check varieties.

A water depth 5-10 cm is maintained before the screening. When seedlings are 6 weeks old the water level is increased 10 cm every other day to a final depth of 150 cm which is maintained for about 2 weeks to allow the aquatic roots and tillers to grow. Scoring for stand, survival, and elongation is on a 1-9 SES scale (IRRI 1980) before harvesting the tillers.

After 2 weeks the water depth is reduced to about 75 cm and a maximum of 10 tillers each with 2 upper nodes are cut from each of the desirable surviving progeny.. The cuttings are transplanted in an ordinary transplanted wetland field where they develop into normal plants. Observations on disease and insect reactions and agronomic characteristics are recorded. Individual lines may be harvested in bulk or plant selections made at maturity.

From 1977 to 1980, we have screened 21,887 entries in the deepwater tanks (Table 1).

When advanced materials were screened for elongation few desirable segregants were obtained in 1977 and 1978 (Table 1). This may have been due to elimination of

Table 1. Progeny lines and varieties tested for elongation ability from 1977-80, and selections made from the test. BRRI, 1981.

Year	Entries	Lines tested (no.)	Elongating lines (no.)	Plant selections from elongating lines (no.)
1977	Germplasm,	436	224	1,071
	Thailand materials,	394	9	27
	advanced lines (F_7-F_n)	6,459	1,422	1,141
1978	F_3 and F_5 and DWC	5,220	1,956	708
	RGA	1,747	80	n.a.
1979	F_3-F_4	4,061	201	469
1980	F_3	3,570	495	1,450
1981	24,000	24,000	n.a.	n.a.
	Total	45,887	4,186	4,866

[a]DWC = deepwater composite, RGA = rapid generation advance. [b]n.a. = data not yet available. No plants selected from RGA 1978.

the elongating materials during the early generation selection in irrigated fields. Nasiruddin et al (1979) conducted an elongation and photoperiod sensitivity experiment with F_2 and F_3 generations and suggested the screening of materials in the early generations.

During 1981, a planting method to accommodate more materials per test was tried successfully. Instead of using a subsample of loose seeds to represent plant selections or other sources (bulked lines, varieties, etc.) panicles were placed directly on puddled soil. One or two mature panicles were selected from agronomically desirable plants of the F_2 populations. The panicles of each cross were stored as bundles. The procedure for planting on a well-puddled and leveled soil was similar to transplanted screening — a 30-cm spacing between panicles and a 50-cm spacing between rows are used. Each row of panicles was 10 m long, which reduced the area for footpaths. The F_3-generation panicles are placed singly on the puddled soil. It is desirable to press the panicles slightly into the mud to reduce drying and prevent the grains from being eaten by rodents. When all panicles of one cross are placed, a one-row gap is left and panicles of the next cross are laid down.

During germination a flush of water was given and then drained off as insurance for uniform germination. After 5-7 days, water depth was increased to 5 cm and maintained until the start of elongation screening. The water regime applied during the screening was similar to that in the former screening procedure.

A dry seeding method can be used if the soil is such that a seedbed of good tilth can be obtained. Using the same spacing and layout, individual panicles can be placed in short, shallow furrows and covered with soil. A flush of water can be added and subsequently drained to obtain uniform and rapid germination.

At selection, about 7 tillers (10 tillers were used in the former method) are taken from the panicle hills observed to have good elongation ability and phenotypic

appearance. These tiller cuttings are handled in a manner similar to that described previously. Record keeping is less in this case.

With this panicle planting procedure, we were able to screen about 12,000 progeny families/tank per planting, 3 times than in the prior procedure. Consequently it enlarged the range of genetic variation screened per fixed area, which increased the chance of selecting plants or progenies with other desirable agronomic characteristics. It also reduced labor and material requirements. Threshing and cleaning of seed samples were eliminated.

Some precautions should be exercised in adopting this technique. Soils should be thoroughly puddled or tilled, the seedbed should be level, and water control should be adequate to provide uniform germination for all the entries.

Plant selections made from the surviving progenies are promoted to the pedigree nursery the following year and evaluated in naturally flooded plots. In 1980 the flood depth in the pedigree nursery reached 280 cm. Survival of lines among different crosses was high. The percentage of phenotypically desirable progeny lines selected at harvest varied from 13 to 66 for different crosses.

Our feeling is that an elongation screening method should be modified according to the need of a program and the prevailing condition in the region. The panicle technique for planting in the seedbed seems to be promising, and is economical.

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DISCUSSION

HARAHAP: When did you start using the panicle row selection method and how many seedlings usually survive? We have used the method in Indonesia since 1976. It is practical and inexpensive.

WAHAB: We have used this method since 1980 in Bangladesh. Sometimes two or three, or sometimes many, plants may survive. But we select the best plant within the same panicle hill. It is really economical because we don't need threshing or cleaning of seed. Record keeping is also less.

STATUS OF SCREENING TESTS FOR DEEPWATER RICE SUBMERGENCE TOLERANCE IN THAILAND

C. Setabutara and S. Karin

SUMMARY

A technique used at Huntra Rice Experiment Station, Thailand, for screening deepwater rices for submergence tolerance is reliable, simple, and inexpensive. The technique uses 30-day-old seedlings and submerges them in water 1 m deep for 10 days. The variety FR13A has excellent submergence tolerance but has numerous undesirable characteristics such as red pericarp, short chalky grains, and long awns. The submergence tolerance of FR13A has been transferred into improved rices.

The development of a simple, rapid method for screening rice varieties and hybrid lines for submergence tolerance has been going on for several years. Repeatable results relevant to sudden flooding conditions affecting farmers are needed.

Early attempts to obtain consistent deepwater performance of breeding materials were not satisfactory. The first break in developing the technique used in Thailand, described by Supapoj et al (1979), was the discovery that a submergence depth of about 120 cm was necessary. The second break came from the outstanding performance of FR13A, which has now become a standard tolerant check in the screening tests.

SCREENING PROCEDURES USED IN SUBMERGENCE TESTS IN THAILAND

At the Huntra Rice Experiment Station, 60-m^2 ponds capable of water depths to 130 cm permit the screening of about 1,600 entries at a time. Raised seedbeds, 120-cm wide, are constructed at the bottom of the pond. Entries are direct-seeded on the bed in single rows (25 cm apart) of pregerminated seeds in the wet season and dry seeds in the dry season. FR13A, the tolerant check, and Khao Dawk Mali 105, the susceptible check, are seeded alternately in each 10th row. At 30 days seedling age, and just prior to submerging, height and estimated percent stand are recorded for each entry. The pond is then rapidly filled with water and a depth between 100 and 120 cm is

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maintained for 10 days. The pond is then drained and phenotypic appearance ratings for experimental lines and check varieties are immediately recorded. Ratings are repeated 10 days after water removal and the degree of recovery is recorded.

The procedures outlined have been developed from experience in testing over several years with varying conditions. A satisfactory and repeatable separation between tolerant and susceptible genotypes has been obtained. The most successful tests have involved a minimum water depth of 100 cm, 30-day-old seedlings, and continuous submergence for at least 10 days.

Earlier work revealed that BKN6986-108-2 exhibited better tolerance than the other entries but its performance was not consistent. In 1979 the Indian variety FR13A was included in the test and proved to be superior to any of the previously tested lines. FR13A became our standard resistant check. We also used varieties such as Thavalu and Kurkaruppan but found FR13A superior.

Khao Dawk Mali 105 was selected as the susceptible check because it is one of the most popular tall traditional varieties in northeast Thailand where sudden submergence is a problem.

Although our screening technique provides satisfactory and repeatable results, we need answers on:

- the effects of transplanting compared to those of direct seeding;
- the effects of fertilizer application before and after submergence;
- the effects of dry season vs wet season (cloudiness, temperature);
- the effects of plant age at the time of submergence,
- the correlation of performance in the deep pond with actual farmer conditions; and
- water turbidity.

We believe the procedure outlined here is reliable enough to effectively screen for submergence tolerance. In addition it is simple and inexpensive. Even though we have yet to verify results on farmer fields, we are confident that the use of FR13A as a tolerant check ensures meaningful results, based on the performance of this variety in India and its origin as a surviving plant after the floodwaters have receded. FR13A has

Table 1. The submergence tolerance and recovery rating of FR13A, KDML 105, and some promising lines.[a] Huntra Rice Experiment Station, Thailand, 1981.

Line or variety	Submergence tolerance	Recovery
FR13A (tolerant)	2-33	1-2
IR6402-0T-7-1	2-3	1-2
BKNFR76106-16-0-1	3	1-3
IR8234-0T-9-2	4-5	3
KDML 105 (susceptible)	8	7-9

[a]Rated on a scale of 1-9: 1 = very good, 5 = fair, 9 = very poor. Submergence tolerance rated 1 day after drainage, recovery 10 days after drainage.

numerous undesirable characteristics such as red pericarp, short grain, and low yield but we have transferred its submergence tolerance into improved lines. Table 1 gives the three promising lines in screening tests described here.

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DISCUSSION

DURVASULA: In your submergence screening, did you come across any entries that looked poor 1 day after draining but showed remarkable recovery after 10 days? The reason I ask this is that this would tell us the most appropriate time to do the rating. If there is some degree of recovery then maybe the entries can be rated a week or 10 days later, but if it's not going to make any difference, maybe a day after drainage will be all right. The reason is we should not be losing some of the genotypes, which are otherwise good, because their tolerance may not show up the day after drainage.

HILLERISLAMBERS: There is a difference between scoring immediately after drainage and after recovery. FR13A and its derivatives are usually still alive immediately after drainage, whereas other moderately tolerant entries look poor (but are still alive) immediately upon drainage, but recover with new leaves later.

SARKAR: Do you think the FR13A expresses its resistance to submergence equally at the seedling stage and after transplanting?

SETABUTARA: FR13A will show more resistance after transplanting than at the seedling stage. The plants show more resistance when aged.

MARTINEZ: In some of your slides I noticed a luxuriant growth of algae that covered almost all the surface of the water. Was that algal growth localized, or observed consistently in your tests? Do you think this algal growth has any effect on your screening tests?

SETABUTARA: Algal growth affects plant growth especially at the seedling stage and the growth is of high density. During submergence, the algae float over the plant and upon drainage they are deposited over the rice plant. This causes difficulty in plant recovery.

ANATOMICAL AND MORPHOLOGICAL STUDIES OF RICE VARIETIES TOLERANT OF AND SUSCEPTIBLE TO COMPLETE SUBMERGENCE AT SEEDLING STAGE

S. Parin, B. S. Vergara, and A. M. Mazaredo

SUMMARY

Anatomical and morphological comparison of rice varieties tolerant of or susceptible to submergence indicated that tolerant varieties studied had longer first and second leaf sheaths, and rounder culms. Selection of submergence-tolerant entries by measurement of the degree of overlapping of the leaf sheath and the roundness of the culm was found unattractive because of the relatively low percentage of tolerant entries obtained.

Varietal differences in submergence tolerance of rice at the seedling stage has been reported previously (Palada 1970, Vergara and Mazaredo 1975). We anatomically and morphologically compared tolerant and susceptible varieties.

Seedling height of 10-day-old seedlings measured before complete submergence did not show any significant correlation with submergence tolerance. However, the tolerant varieties were generally taller than the susceptible varieties both after complete submergence and after recovery.

LEAF BLADE LENGTH

The first and second leaf blades were generally longer in tolerant than in susceptible varieties. There was a significant correlation between length of the first leaf blade and percentage of survival ($r = 0.6715^*$). The longer leaf blades made it possible for some leaf tips to be above the water.

VASCULAR BUNDLE

The number of vascular bundles in the lamina of the first and second leaf blades in the varieties studied showed differences. However, there were no significant differences

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between the tolerant and susceptible varieties.

The leaf sheath is characterized by the presence of large air spaces, which alternate with the vascular bundles and are separated by narrow bands of parenchyma. There was no difference in number of vascular bundles in the first and second leaf sheaths of tolerant and susceptible varieties and no correlation to submergence tolerance.

ROLE OF AIR SPACE

The role of the lacunae, or air space, in submergence has not been fully studied. It is possible that the lacuna is important in submergence tolerance because it may serve as oxygen reservoir or, in case the leaf tips are above water, as a passageway for transport of oxygen from the leaf blade to the roots. On the other hand, the occurrence of large lacunae may result in spongy, weak leaf sheaths, which will make the plant prone to lodging when floodwater recedes. Chang (1964) reported that compact parenchyma cells and fewer or smaller lacunae resulted in higher lodging resistance.

The percent lacunae per unit area was negatively and significantly correlated to submergence tolerance ($r = -0.5997^{*}$). The lacunae on the first leaf sheath were already developed at submergence. In the second leaf sheaths, the susceptible varieties showed earlier development of lacunae. The susceptible varieties had a higher total number of lacunae in the second leaf sheath than the tolerant varieties at 10 days after seeding. The total number of lacunae in the first and second leaf sheaths was also negatively correlated to submergence tolerance ($r = -0.6657^{*}$).

SCLERENCHYMA TISSUE

The sclerenchyma are found on the abaxial side of the leaf sheath as 2-3 layers of cells. The layers were absent on the adaxial side, possibly because the seedlings were too young to develop the layers. The sclerenchyma tissue developed more rapidly on tolerant varieties. The sclerenchyma tissue was not developed in the leaf blade of 10-day-old seedlings.

The number of layers and thickness of the sclerenchyma layer of the first leaf sheath of the different rice seedlings tested did not correlate with submergence tolerance. However, the tolerant varieties FR13A and Nam Sagui 19 had one layer more than the other varieties. There were variations in sclerenchyma thickness in tolerant and susceptible varieties.

Anatomically, the main significant difference between tolerant and susceptible varieties was in the percent area occupied by air space and the number of air spaces. The more susceptible varieties had more air spaces.

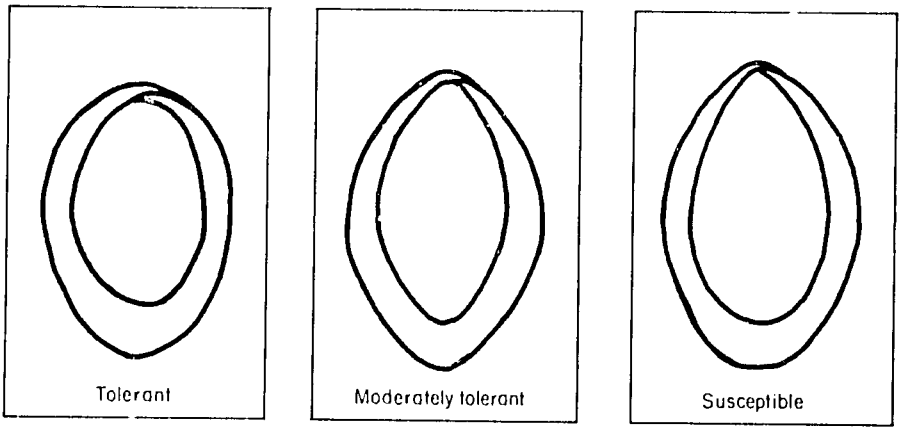
LEAF SHEATH AND CULM

The leaf sheath is characterized by the presence of large air spaces, which alternate with the vascular bundles and are separated by narrow bands of parenchyma. The number of vascular bundles in the first and second leaf sheaths did not show any difference between tolerant and susceptible varieties or any correlation to submergence tolerance.

Table 1. Overlapping of first leaf sheath and width-thickness ratio of culm at 3 cm above the seed of different rice varieties. IRRI, 1980.

Variety	Leaf sheath overlap (microns)	Culm width-thickness ratio
Tolerant		
FR13A	601	1.44
Kurkaruppan	639	1.40
Thavalu (15325)	608	1.46
Thavalu (15314)	505	1.45
Av	588	1.44
Moderately tolerant		
SML Temerin	594	1.44
Nam Sagui 19	460	1.50
Leb Mue Nahng 111	430	1.49
IR36	273	1.48
Av	439	1.48
Susceptible		
T442-57	410	1.55
IR8	364	1.54
RD7	289	1.52
IR42	204	1.51
Av	317	1.53

Measurement of the overlapping of the first leaf sheath shows that the tolerant varieties definitely had greater overlapping than the susceptible varieties (Table 1). Most likely the overlapping leaf sheaths (Fig. 1) provide a stiffer culm, which can prevent the breakage or collapse of the plant as the water recedes. There was a high correlation between overlapping of the first leaf sheath and percentage of survival



1. Culm shape (width-thickness) and overlapping of leaf sheaths in submergence-tolerant and susceptible rice varieties. IRRI, 1980.

($r = 0.7261$*). Studies of Chang (1964) showed that overlapping of the leaf sheath is an important factor in preventing lodging.

Factors affecting the stiffness of the culm such as overlapping leaf sheath, denser or less air spaces in the leaf sheath, and thicker sclerenchyma layer not only prevent lodging in normal conditions but also apparently help in preventing collapse of the plant, especially in varieties where elongation occurs.

The width-thickness ratio of the culm tends to be circular for tolerant varieties and slender or flat for the susceptible varieties (Table 1). The correlation between width-thickness ratio and percentage of survival is $r = -0.6450$*.

The shape of the culm is probably responsible also for the degree of overlapping on the leaf sheath or vice versa. Length of overlapping is negatively correlated with width-thickness ratio of the culm ($r = -0.7384$*). The round culms have more overlapping leaf sheaths than the flat culms.

FIELD SCREENING

There are many environmental as well as plant factors that determine the submergence tolerance of rice varieties. Two plant factors identified in this study that might contribute to submergence tolerance are overlapping of leaf sheath and roundness of culm. The possibility of using these plant characteristics to identify submergence tolerance in breeding lines was tested by screening 137 breeding lines for submergence tolerance and measuring their leaf sheath and culm diameter.

The data show that in the breeding lines tested, culm shape or roundness was the best criterion for selecting submergence tolerance (Table 2). The round-culm entries

Table 2. Submergence tolerance of 137 breeding lines classified according to roundness of culm and overlapping of leaf sheaths. IRRI, 1980.

Plant character	Entries (no.)	% submergence-tolerant entries[a]	% tolerant entries[b]
Overlapping leaf sheath	69	26	49
Non-overlapping leaf sheath	68	28	51
Round culm	64	33	57
Flat culm	73	22	43
Round culm + overlapping leaf sheath	39	33	35
Flat culm + overlapping leaf sheath	30	17	14
Round culm + non-overlapping leaf sheath	25	32	21
Flat culm + non-overlapping leaf sheath	43	26	30

[a] % submergence-tolerant entries = $\frac{\text{number of tolerant entries}}{\text{total number of entries}}$.

[b] % tolerant entries = $\frac{\text{number of tolerant entries}}{37}$.

had the highest percentage of entries with tolerance for submergence. However, there are many round-culm entries that are not tolerant and the low percentage (33%) of being able to select the tolerant varieties makes this selection procedure unattractive.

Selecting round culm and overlapping leaf sheaths did not improve selection criteria. Determining the percentage of survival of seedlings submerged in water for a period of time is still the most convenient method of determining submergence tolerance.

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DISCUSSION

OHTA: Could you explain in more detail how you measured the air space?

KARIN: We used a camera lucida under a microscope and measured the air space area with a leaf area meter.

SARKAR: Sometimes if we increase seedling age, even in case of susceptible varieties, the variety becomes somewhat tolerant. I think it is the physiological resistance of a plant. Do you think the genetically resistant plant and the physiologically resistant plant are the same?

KARIN: No, the submergence data presented by Jackson et al at this workshop show the effect of variety and plant age. The susceptible variety Khaw Dawk Mali 105, when submerged at 35 days of age, was more tolerant than the younger plant but still did not compare with FR13A, even young FR13A.

DE DATTA: You said that no matter how many anatomical or morphological experiments you have, you still have to go through the actual screening. If so, then these important findings are academic. If you are going to screen all the same, the reason why plants are resistant may not matter to the breeder.

DE DATTA: Have you found any advanced breeding line that has tolerance for submergence as good as FR13A and has agronomic acceptability?

KARIN: None.

DE DATTA: Then there are some interesting challenges left for the breeders.

CHAUDHURY: This is an interesting study and should be encouraged. More people should get involved in this sort of study. I agree with Dr. De Datta that actual screening is the most important way to reach the final decision on whether you select or reject a variety, but some of us don't have the screening facilities. If this anatomical study can give us some idea about selecting a variety then it will be helpful for many of us who do not have screening facilities.

HETTERSLEMBERS: I don't think facilities for screening for submergence tolerance are that difficult to get. Anyone who can put his hands on a couple of oil drums can make facilities for himself by just submerging flats of seedlings inside the drums and lifting them out after a couple of days. I think that is much better than finding anatomical traits just to replace completely the submergence tolerance screening.

YIELD COMPENSATING ABILITY BY AQUATIC TILLERS IN DEEPWATER RICE

A. R. Gomosta, M. H. Sarkar, and M. Z. Haque

SUMMARY

Both the Habiganj Aman I and Habiganj Aman VIII floating rice varieties increased their number of aquatic tillers when basal tiller number was reduced by artificial pruning or when no nitrogen was added to the soil. Panicles produced by aquatic tillers were, however, smaller than those produced by basal tillers. In both varieties yield compensation by aquatic tillers increased with increased basal tiller damage. The need for monitoring aquatic tillering ability in modern deepwater rice varieties is stressed to help improve their ability to compensate for damage — unpredictable adverse situations.

Floating rice in Bangladesh is usually broadcast. Plants normally grow for at least 2 months before the onset of flooding, and the basal tillers then produced primarily contribute to grain yield. When tiller numbers are drastically reduced by drought, flash floods, or insect attack, there is some compensation through formation of aquatic tillers following stabilization or reduction of the floodwater depth. Setabutara and Vergara (1979b) found varietal differences in aquatic tillering ability among deepwater rice varieties. The incorporation of aquatic tillering ability in deepwater rice was also emphasized by Mukherji (1975), Maurya (1975), Perez and Nasiruddin (1975), and Beachell (1975). Precise data relating aquatic tillering to basal tiller density have been lacking until now.

Panicle production from aquatic tillers requires a minimum of 1 month from aquatic tiller formation to panicle initiation. Fortunately, Bangladesh flood patterns usually allow such time and floating rice often includes mature panicles developed from aquatic tillers. However, their percentage contribution to grain yield has not been studied much. Our paper presents data and discusses the ability of aquatic tillers to produce grains.

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MATERIALS AND METHODS

Two experiments with the floating rice varieties Habiganj Aman I, a medium-deepwater (1-1.5 m) rice, and Habiganj Aman VIII, a deepwater (3 m) rice, studied the relationship between aquatic tillering ability and the number of basal tillers, and the contribution of aquatic tillers to grain yield.

Experiment 1

Variations in basal tillers were created by varying the application of urea fertilizer in earthen pots containing 20 kg soil. In the fertilized plots, 5 g each of urea, triple superphosphate, and muriate of potash were applied before seeding. An additional 5 g of urea was applied 25 days after seeding. In the control pots, only triple superphosphate and muriate of potash were applied before seeding.

Single plants per pot were grown for 50 days, and pots were then transferred to a water tank. Water depth was subsequently brought up to 150 cm in 50-cm daily increments and kept at 150 cm for 45 days. Basal tillers were counted before and after submergence and aquatic tillers/plant were counted after the submergence period.

Experiment 2

Variations in basal tillers were created by artificial pruning 1 day before submergence. Seedlings 25 days old were transplanted in a deepwater tank at 25 × 15 cm spacing. The soil was fertilized with 60-60-40 kg NPK/ha. Seedlings were allowed to grow for 45 days to produce sufficient basal tillers, and then basal stem density per unit area was reduced by 25, 50, and 75%. Water depth was increased 10 cm every other day to a maximum depth of 150 cm.

RESULTS AND DISCUSSION

Tillering ability

In experiment 1, basal tiller number of both Habiganj Aman I and Habiganj Aman VIII responded significantly to nitrogen (Table 1). Basal-tiller survival was higher in the fertilized pots than in the control.

Aquatic tiller formation was inversely related to the number of surviving basal tillers. This relationship was also found in experiment 2 for both Habiganj Aman I and Habiganj Aman VIII (Figs. 1 and 2). This confirms findings of Catling and Islam (1979) on the formation of compensating aquatic tillers in stem borer-damaged deepwater rice, and of Datta and Banerji (1979) who observed a higher number of aquatic tillers when basal tillers were reduced by submergence of Jaladhi I and Jaladhi II. Thus, aquatic tillering ability of deepwater rice is an adaptive and important trait that can be highly advantageous after droughts, insect attacks, or flash floods.

In our investigation, Habiganj Aman VIII showed a higher ability for aquatic tillering than Habiganj Aman I (Table 1). It also exhibited better aquatic tillering ability when basal tillers were damaged (Figs. 1 and 2).

Basal and aquatic tiller panicles

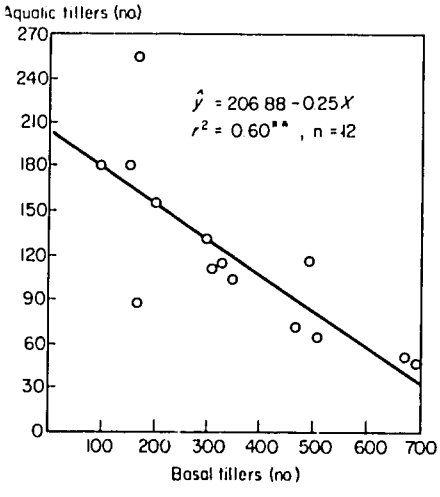
Basal and aquatic tillers both produced panicles in experiment 2. When basal vegeta-

Table 1. Tillering behavior of Habiganj Aman I and Habiganj Aman VIII as affected by application of urea (experiment 1). BRRI, 1980.

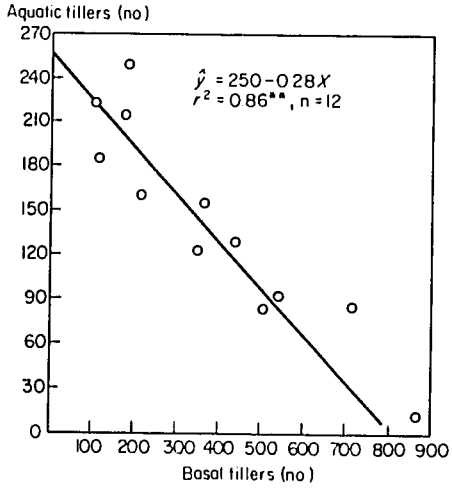
Treatment	Basal tillers/plant			Aquatic tillers per plant
	Before submergence	After submergence	Survival (%)	
		Habiganj Aman I		
Control	11.0 b	8.0 b	73	3.2
With urea	27.8 a	18.0 a	65	1.4
		Habiganj Aman VIII		
Control	10.4 b	8.8 b	5	6.4
With urea	35.4 a	21.8 a	62	2.8

tive tillers were reduced 50% or more, the percentage that produced panicles increased remarkably in both varieties (Table 2). Even so, the total number of panicles per unit area still decreased with the reduction of basal tillers.

In the 50% and 75% pruning treatment, the aquatic tiller panicles per unit area more than doubled compared to the control plot. In all treatments, the aquatic tiller panicles were smaller than those produced from basal tillers. This was also observed by Catling and Islam (1979) and Setabutara and Vergara (1979a). Aquatic tiller panicles were short and had fewer spikelets than corresponding basal tiller panicles. However, basal and aquatic tiller panicles produced a higher number of spikelets in most of the clipping treatments. Thus, in addition to compensation in the number of (aquatic) tillers, the floating rice in this experiment also compensated with a higher number of spikelets per panicle when the number of basal tillers was reduced.



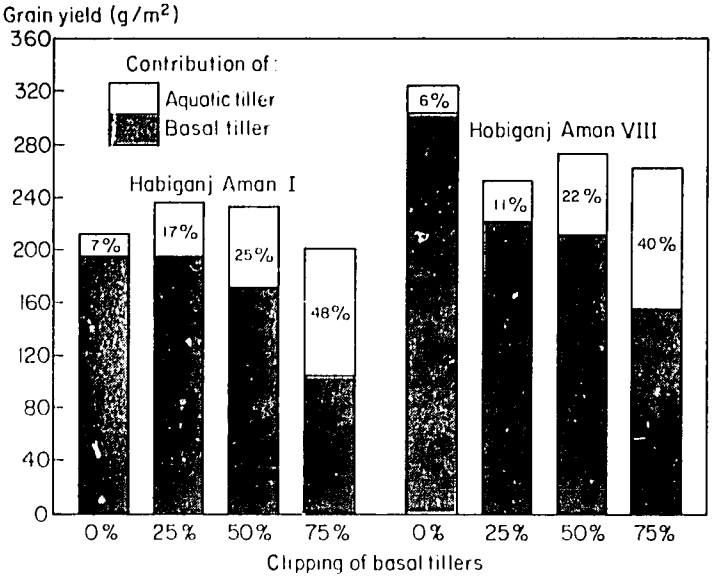
1. Aquatic tillering in relation to basal tiller per unit area in Habiganj Aman I. BRRI, 1980.



2. Aquatic tillering in relation to basal tiller per unit area in Habiganj Aman VIII. BRRI, 1980.

Table 2. Effect of basal-tiller clipping on panicle production of Habiganj Aman I and Habiganj Aman VIII (experiment 2). BRRI, 1980.

Basal-tiller pruning	Basal tiller(no.)/m^2	Basal tiller panicles (no./m^2)	Basal tiller panicles (%)	Aquatic tiller panicles/m^2	Total no.of panicles/m^2	Panicle length (cm)		Spikelets per panicle	
						Basal tiller	Aquatic tiller	Basal tiller	Aquatic tiller
				Habiganj Aman I					
Control	165	120	72	11	131	24	20	166	134
25%	122	85	70	21	106	23	21	177	145
50%	82	66	80	26	92	23	20	160	146
75%	41	34	83	45	79	24	22	180	165
				Habiganj Aman VIII					
Control	192	116	61	13	129	24	20	147	119
25%	148	93	63	19	111	24	21	164	110
50%	95	81	85	34	115	25	22	175	118
75%	47	40	85	52	92	24	22	160	112
LSD (5%)	-	12.9	-	11.6	15.8	1.6			
LSD (1%)	-	17.9	-	16.1	21.7	2.2			



3. Percentage of contribution of aquatic tillers to grain yields as affected by basal tiller clipping. BRRI, 1980.

These compensating processes in deepwater rice explain how grain yield can be similar at different stem densities.

Contribution of aquatic tillers to grain yield

In all the clipping treatments of experiment 2 basal tiller panicles were the main contributors to grain yield (Fig. 3). Aquatic tiller contribution varied with initial stem density. In Habiganj Aman I aquatic tiller panicles' contribution to yield rose from 7%, with basal tillers not damaged, to 48% when 75% of basal tillers were pruned. For Habiganj Aman VIII these proportions ranged from 6% at 0% pruning of basal tillers and 40% at 75% pruning.

These findings correspond with earlier findings of Setabutara and Vergara (1979a) who estimated the percentage of contribution of aquatic tillers to grain yields at 1% for Leb Mue Nahng and 7% for Kalarhasal at 85-cm water depth. They also agree with those of Datta and Banerji (1979) who found a 22-47% contribution of aquatic tillers to grain yield when flood levels changed from knee-deep to deep water.

Based on these facts we strongly emphasize the need to ensure incorporation of aquatic tillering ability in modern deepwater rice varieties for better adaptation in unpredictable adverse situations.

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DISCUSSION

DURVASULA: You indicated that the productivity of the aquatic tillers depends on the growing situation. Don't you think there are also varietal differences in the aquatic tiller potential and productivity?

GOMOSTA: Yes, there are, but the degree of expression of this character might be influenced by the growing situation.

NASIRUDDIN: Do you think your studies, which were controlled conditions, will also hold true in the farmer fields? You could make such studies by controlling plant density with different spacings or seeding rates instead of artificially cutting the basal and aquatic tillers.

GOMOSTA: I think the relationship we obtained between basal tiller formation and aquatic tiller formation will also hold true in farmer fields. However, we need to check this under different cultural practices, as you mentioned.

JACKSON: Your results strongly indicate that breeders should select for heavy main tillering ability because the main tillers contribute much more than aquatic tillers. Am I correct?

GOMOSTA: I think we should breed both for heavy main tillering ability and also for good aquatic tillering potential. In adverse situations, when basal tillers are heavily damaged, aquatic tillers make a significant contribution to grain yield. This was clearly exhibited when 75% of tillers were damaged.

YIELDS AND SOME QUANTITATIVE CHARACTERS OF DEEPWATER RICE IN BANGLADESH AS AFFECTED BY SEEDING METHODS AND FLOOD DEPTHS

M. Nasiruddin, A. Salam, A. Wahab, and A. Bakr

SUMMARY

Panicle density in deepwater rice, whether direct-seeded or transplanted, is a limiting factor to higher grain yield. Deeper water at the later growth stages of the rice plant tended to reduce yield and panicle weight and increase the grain-straw ratio. Aquatic panicles varied from 8 to 18%. Some basal tillers did not produce any panicles.

In South and Southeast Asia 15-20% of the rice growing land is subjected to floods ranging from 1 to 4 m depth. Rice in deepwater areas is dry-seeded. Drought stress commonly occurs during the preflood period. Yields are low — 1.2-1.8 t/ha in Bangladesh (Zaman 1978), 2.0-2.5 t/ha in India (Padmanaban 1974), 3.5-4.5 t/ha in Assam (India), Duara (1974), 1.3-2.1 t/ha in Thailand (Chai Prechachat and Jackson 1974), and 1-2 t/ha in Vietnam (Xuan and Kanter 1974).

Increasing water depths reduces the yield of deepwater rice (Kupkanchanakul et al 1977, Datta and Banerji 1979). Datta and Banerji (1978) also discuss yield components that affect yield potentials of deepwater rice. Our experiments investigated the effects of seeding methods and water depths on yield and related characters. We also sought to identify the limiting factor to higher yields and to establish optimum water depths for expression of the yield potential of deepwater rice.

MATERIALS AND METHODS

At BRRI, two yield trials — one direct-seeded in naturally flooded plots and another transplanted in plots with controlled flooding in a deepwater tank — were planted at Joydebpur. The direct-seeding rate was 12 g/row in an 8-row, 5-m plot with 3 replications. In the deepwater tank plots were 8 rows by 5 m with 3 replications. A 25 × 20 cm spacing was used at one 3-week-old seedling/hill. Each trial had three

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traditional and three breeding lines.

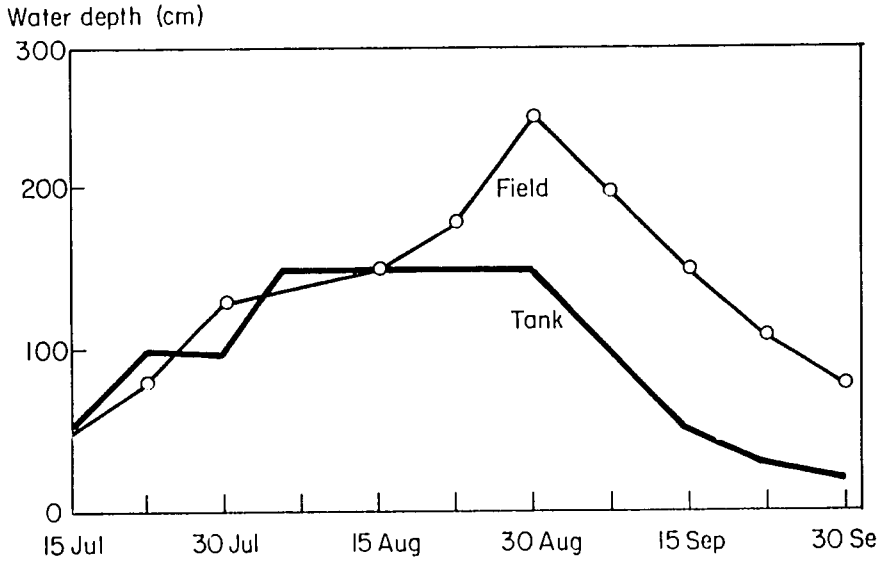
At 12 weeks, the water depth in the tank was increased 10 cm every other day to 50 cm. The water depth was then stabilized for 1 week, raised to 1-m depth at the same rate, and stabilized for another week. Final water depth in the deepwater tank was 160 cm. The final depth in the naturally flooded field was 250 cm. The time and the rate of water rise in the field and in the tank are shown in Figure 1.

At BRRI's Habiganj station in northeastern Bangladesh, a nonreplicated yield trial with 6 entries was direct-seeded in an 8-row, 5-m plot with rows 25 cm apart. Maximum water depths of 60, 125, and 200 cm were recorded at 3 sites. Data on characters related to yield were collected from one randomly selected row. The whole plot was used for collection of yield data.

RESULTS AND DISCUSSION

In the two BRRI trials, culm length was higher in the field than in the tank, even though the difference was not proportionate to water depths (Table 1, 2). The number of basal tillers and panicles/m^2 was higher in the fields but panicle weight and yield were higher in the deepwater tank.

Despite the controlled, favorable timing of water rise in the tank, production of basal tillers and panicles per unit was low, even though panicle weight and yield were



1. Flooding time, rate, and maximum depth of flooding for deepwater-rice trials in plots with controlled (tank) and natural (field) flooding. BRRI, 1980.

Table 1. Yield and some ancillary characters of 6 deepwater rice entries direct-seeded in a naturally flooded field (250-cm water depth; seeded 1 May) and grown in a tank with controlled flooding (160-cm water depth; transplanted 4 April). BRRI, 1980.

Entry	Culm length (cm)		Basal tillers (no./m^2)		Panicles (no./m^2)		Panicle weight (g)		Yield (t/ha)	
	Naturally flooded field	Deep-water tank	Naturally flooded field	Deep-water tank	Naturally flooded field	Deep-water tank	Naturally flooded field	Deep-water tank	Naturally flooded field	Deep-water tank
Habiganj Aman II	356	317	230	140	191	130	2.23	3.82	3.0	4.2
Kartiksail	319	324	172	123	140	108	2.60	3.62	-	3.7
Shada pankaish	361	338	116	120	-	100	3.41	-	3.9	3.9
BR308-B-2-9	302	305	140	109	121	100	2.78	3.25	2.2[a]	3.4
BR311-B-5-4	315	311	194	114	135	94	2.45	4.12	2.2[b]	3.5
BR314-B-4-6	308	301	147	103	121	87	2.36	2.88	2.2[b]	2.1[b]
Mean	326	316	166	118	141	103	2.63	3.53	2.7	3.4

[a]Affected by root knot nematode. [b]Damaged by rats.

Table 2. Yield and some quantitative characters of 6 deepwater rice varieties as affected by 3 water depths in nonreplicated yield trials (seeded 18 April) at Habiganj, BRRI, 1980.

Water depth (cm)	Culm length (cm)	Basal tillers (no./m^2)	Aquatic tiller panicles (%)	Panicles (no./m^2)	Panicle weight (g)	Yield (t/ha)	Grain-straw ratio
60	233	96	18	92	2.66	2.9	1:4.5
125	256	138	8	129	2.56	2.3	1:5.2
200	292	104	13	96	2.50	2.2	1:6.0
Mean		112	13	105		2.4	

higher. These two situations are incongruous. Datta and Banerji (1978) reported 4-6 basal tillers and 7-11 panicles/hill in a 25 × 40 cm spacing. Basal tiller production was low but aquatic tillers might have contributed to a higher number of panicles per hill.

In our study, the number of panicles per m^2 was always lower than that of basal tillers, indicating that many basal tillers failed to contribute to panicle production. In the naturally flooded field, plant-to-plant row spacing was not controlled, which might have allowed a higher production of basal tillers and, ultimately, panicles. But, the weight of such panicles was low which ultimately reflected in lower yield.

The higher panicle weight and yield from the controlled flooding trial might be explained by the age of the plant at the time of first flooding, the rate of water increase, maximum water depth, and the time of maximum water depth. The tank was flooded when plants were 12 weeks old; plant age in the naturally flooded field was 8 weeks at flooding. Water rise in the field was continuous from the first week of July and peaked (250 cm) on 30 August. Tank water was stabilized for 1 week at 50, 100, and 160 cm, and the maximum depth was reached in the first week of August (Fig. 1).

By early September many deepwater varieties reach the reproductive phase, during which any plant stress will reduce yield. In our trials the energy used for elongation at, or just before, the reproductive stage may have caused production of smaller panicles.

Yield trials at Habiganj

Table 2 shows yield and other related characters in the nonreplicated yield trial at Habiganj. The culm length, as expected, was proportionately higher as water depth increased. Gomosta et al (1982) reported that basal and aquatic tillers compensate each other. In our trials production of basal and aquatic tillers and their panicles was not consistent. At 125-cm water depth the number of basal tillers and that of panicles were highest even though this was not reflected in yield. Aquatic panicles were least at 125-cm water depth.

Panicle weight, yield, and grain-straw ratio were consistent with water depths. The higher the water depth, the lower the panicle weight and yield but the grain-straw ratio increased as water depth increased. The 60-cm depth gave a higher panicle weight and yield with a grain-straw ratio. Some aquatic tillers produced panicles but many basal tillers did not contribute to panicle production (Table 2).

CONCLUSION

Further studies on water depths, flood rates, and growth stages of the deepwater rice plant are needed for a better understanding of their relationship to yield and yield-related characters. Efforts should be made to develop cultural practices that will increase panicle density in deepwater rice.

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RICE WITH RATOONING ABILITY FOR DEEPWATER AREAS

S. K. Bardhan Roy, B. S. Vergara, and G. Patena

SUMMARY

In a single cross studied, long-duration plants showed good ratooning ability and a high concentration existed between the ratooning ability of F_2 and F_3 populations when grouped on the basis of growth duration. Elongation ability was higher in the ratoon than in the seedlings. The ratooning ability is recessive to nonratooning ability. Because of high correlation, plants with ratooning ability can be selected in early generations.

High yielding, photoperiod-sensitive rice varieties with good ratooning capability and a good degree of submergence tolerance or elongation capacity have potential as a dry season crop in areas such as the gangetic plains of West Bengal and Bihar, India, which are often completely submerged in the wet season. The rice production level of those areas is generally low. After the harvest of the wet season (aman) crop, farmers may grow a dry season (boro) rice crop (with residual water or irrigation), but low temperature in the early stage of the crop slows vegetative growth and subjects the crop to water stress at the booting stage. The delay in crop growth also cuts into needed time for land preparation for the following wet season crop.

An illustration on possible growing time with ratooning varieties is shown in Figure 1. The temperature and rainfall data recorded at the Rice Research Station, Chinsurah, India, show that after the harvest of first crop in April, the ratoon may be subjected to drought. The Southeast monsoon generally sets in by 10 June in this region. Traditionally, farmers of the low-lying areas broadcast seeds in April-May. In such cases, the ratoon should provide more tolerance for temporary drought than germinating seeds. With the onset of monsoon, the ratoon crop should grow vigorously and be able to tolerate varying degrees of submergence between July and September. However, in those areas with irrigation, the effect of drought would be marginal.

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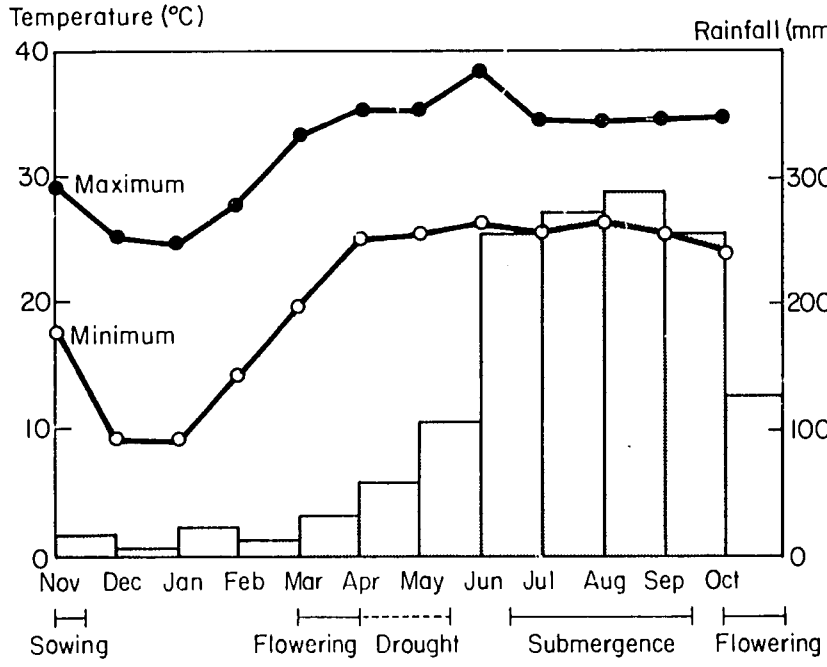

1. Prevailing mean temperature and rainfall in various months (Chinsurah Rice Research Station data, 1975).

Based on the existing problem, a variety suitable for the West Bengal and Bihar deepwater areas should have the following characteristics:

- photoperiod sensitivity;
- fertilizer responsiveness with yield around 4-5 t/ha;
- a ratoon that remains in the vegetative stage from April to August, i.e. photoperiod sensitivity of ratoon is needed;
- good ratooning ability and vigorous growth with first rain;
- some degree of drought and submergence tolerance or elongation ability for the ratoon; and
- ratoon resistance to virus diseases.

In our study a single cross was made between Kalar Harsall (a photoperiod-sensitive deepwater rice variety with elongation ability) and Mingolo (good-ratooning variety) to incorporate good ratooning ability with elongation ability. The F_1, F_2, and F_3 populations, with Kalar Harsall and Mingolo, were grown by rapid generation advance with the F_1, F_2, and F_3 ratooned. The flowering duration of the ratooned plants under 10 hours photoperiod was also taken into account — to remove those that flowered late.

To remove the elongation ability at the seedling stage and the ratoon tillers, the F_3 was subjected to complete submergence after 10 days of growth. In addition, plants that ratooned were submerged 20 days after harvest, as could occur in the field.

The mean flowering days of the main crop and ratoon crop of the three generations of the Kalar Harsall/Mingolo and their parents suggested that late-flowering ratoon plants could be obtained from the segregating generation (Table 1). The ratooning ability of F_2 and F_3 populations varied with growth duration. Late-maturing segregants had higher ratooning ability (Table 2) and a high correlation value

Table 1. Average flowering duration of Kalar Harsall/Mingolo cross in 10-hour day length. IRRI, 1980.

Crop	Av flowering duration (days)				
	Kalar Harsall	Min-golo	F_1	F_2	F_3
Main	68	110	69	89	81
Ratoon	25	49	n.a.	58	n.a.[a]

[a]Data not available.

Table 2. Relationship between ratooning ability and growth duration in the Kalar Harsall/Mingolo cross. IRRI, 1980.

Growth duration (days)	F_2 plants with ratoon (%)	F_3 plants with ratoon (%)
65-70	19	17
71-76	18	8
77-82	18	17
90-95	84	44

($r = 0.962^{**}$) was obtained between F_2 and F_3 ratooning ability classified according to growth duration. The same kind of result was also reported by Cuevas-Perez et al (1980), who attributed it to the shading effect of late segregants on early segregants in the field thus reducing their chances to ratoon.

In our study, however, each plant was grown in individual plastic pots, thus decreasing the chances of such shading effect. Even in such controlled condition, a late-maturing crop ratooned more. It may be assumed that there may be some kind of association between these two characters. This gives a promise for having plants with higher ratooning ability from late-duration or photoperiod-sensitive varieties. However, Sen and Banerjee (1960) observed higher occurrence of ratoon tillers in the early flowering F_2 segregants of day-neutral and short-day crosses. Garcia et al (1981) found that within a photoperiod-sensitive variety, the longer the growth duration, the less the ratooning ability. Ratooning ability was also correlated with the nitrogen content of the soil.

The elongation ability of Kalar Harsall, the F_3 bulk population, and its ratoons (Table 3) show that the F_3 had distinctly better elongating ability than Kalar Harsall both at the early seedling stage and as ratoon plants. However, the F_3 plants at the seedling stage elongated more than the ratoon under 35 cm of water because the initial height of the ratoon kept the leaves above the water surface and reduced the need for elongation. This is seen as an important advantage of early-ratooning wetland rice when initial water accumulation does not exceed 30-40 cm of water.

Our preliminary study seems to indicate that ratooning ability is recessive and its

Table 3. Average elongation ability (percentage of increase in plant height) of Kalar Harsall (elongation parent) and F_3 population of Kalar Harsall/Mingolo cross. IRRI, 1980.

	10-day-old seedlings	20-day-old ratoon
Kalar Harsall	11	31
F3 population of Kalar Harsall/Mingolo cross	50	46

distribution in the F_2 conforms with a one-gene hypothesis. The long-growth-duration lines in the F_2 generally had ratooning ability and the same lines also generally showed longer growth duration and ratooning ability in the F_3. This suggests the possibility of early selection of plants with ratooning ability.

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DISCUSSION

DURVASULA: In my view, planting a deepwater rice variety in the boro season and ratooning that for aman season crop may not be productive. The ratoon crop of a photoperiod-sensitive variety may not flower uniformly when attempted on a large scale by the farmers. Also disease and insect problems may be aggravated. Please comment.

HILLERISLAMBERS: The ideas on which this paper was based are being tested and these tests will supply an answer to your question. At any rate, a crop as proposed should be resistant to both wet season and dry season insects and diseases.

AHMAD: In Bangladesh we also tried ratooning of deepwater rice, but strong photoperiod-sensitive varieties do not flower uniformly, if at all, after the first crop. Also, many deepwater rices are susceptible to cold so when the ratoon crop finally starts tillering no flowering could be induced. Experience in Bangladesh with this idea was favorable.

TOURE: Apart from the increased incidence of insects and diseases connected with ratooning, I don't see the practical sense of ratooning where animal husbandry is important — for example in deepwater areas of West Africa.

HILLERISLAMBERS: I am not aware that animal husbandry is an important industry in West Africa, and therein may be the answer.

BREEDING OF PHOTOPERIOD-SENSITIVE WETLAND RICES BY MALE-STERILE-FACILITATED COMPOSITE UNDER RAPID GENERATION ADVANCE SYSTEM

R. C. Chaudhary, B. S. Vergara, and F. S. S. Lopez

SUMMARY

Progress in breeding photoperiod-sensitive rices for rainfed wetland areas has been slow because of the many additional characters needed for adaptation of those varieties to particular sites. Those characters cannot be easily combined by conventional crossing. A male-sterile-facilitated composite breeding scheme wherein a number of parents can be combined to develop a base population was devised. Selection can then isolate photoperiod-sensitive lines suitable for specific environments. It has been possible to synchronize the flowering and thereby enhance random mating by treating the segregating population to short days at 40 days after sowing. Two such male-sterile-facilitated composites, IR38497-CP101 and IR38498-CP102, were handled with the suggested procedures.

An ideal plant type of rainfed wetland rice is yet to be realized but the existing list of component characters is a long one: semidwarf to intermediate tall plant height, submergence tolerance, various types of flowering behavior including photoperiod sensitivity, acceptable grain quality, tolerance for adverse soils, resistance to insects and diseases, and high grain yields. To get all the components requires crossing a number of donors with the various characters. However, with the general crossing procedure, not more than four parents can be combined in one cross.

The availability of genetic male sterility in an indica rice, IR36(ms), makes it possible to use population breeding with male-sterile-facilitated rice composites and combine more than four parents to develop a population. In male-sterile-facilitated rice composites, as suggested by Ikehashi and Fujimaki (1980), there is the same free flow of gene or gene combinations as in cross-pollinated crops, which makes it possible to recover even the rarest combination of characters. A similar approach has been successfully used in barley, wheat, and soybean (Jain and Suneson 1966, Brim

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and Stuber 1973, Ramage 1977). It is possible to upgrade the characters to an exploitable level (Chaudhary et al 1981). In a population, characters that are governed by a number of components such as submergence tolerance, (Karin 1980; Mazaredo and Vergara, this vol.) can conceivably be upgraded to a much higher level by combining the best of all the donors. Moreover, such a population can serve as gene pool with a broad genetic base from which photoperiod-sensitive genotypes adapted to various agroclimates can be selected. The population would also fit into the scheme suggested by Ikehashi and HilleRisLambers (1979) for international collaborative research.

The requirement for photoperiod sensitivity, the availability of male-sterile lines, and the need for many plant characteristics governed by a number of components, plus the possibility of planting the lines close to each other, synchronous flowering, and the possibility of three generations per year through rapid generation advance (RGA), all fit fortuitously into the scheme we propose. The scheme should serve best in photoperiod-sensitive rices that require several different tolerances.

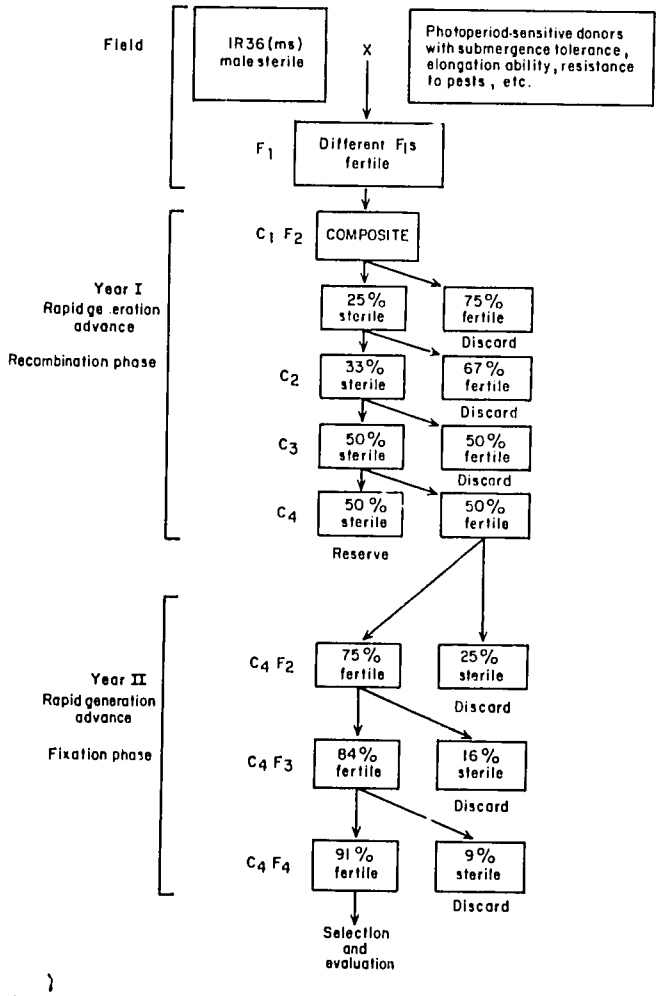
A SCHEME FOR HANDLING THE COMPOSITE

The general scheme to develop a male-sterile-facilitated composite and its further handling is illustrated in Figure 1. A number of photoperiod-sensitive donors are crossed with IR36(ms). The F_1 seeds are fertile and are grown in the field using a standard procedure. An equal quantity of seeds from each F_1 is bulked to produce the C_1 F_2 composite, which grows to give 25% male-sterile segregants. Seed set on male-sterile plants is then harvested and bulked to grow C_2 F_1. In the C_2 F_1 population, 33% of the plants are sterile and seed set on those is harvested to grow C_3 F_1 and C_4 F_1 populations. By the C_4 F_1 enough intermating has gone in to allow the selection of fertile plants to grow a C_4 F_2 population. By continued selection of fertile plants their frequency would be 91% by C_4 F_1. Selected fertile plants can then be grown in the field for further screening, evaluation, and selection. The sterile fraction of C_4 F_1 plants can be advanced further if more intermating is desired. C_2 F_1 - C_4 F_1 and C_1 F_2 - C_4 F_1 generations are handled by RGA to save time.

SYNCHRONIZATION OF FLOWERING AND MAXIMIZATION OF OUTCROSSING

The crucial point in handling the male-sterile-facilitated composite is synchronization of flowering of the population and close planting of plants to obtain maximum cross pollinations. If the C_4 F_2 to C_4 F_1 generations are in RGA, wherein plants are subjected first to long days in the early stage to prevent flowering and then to short days to induce flowering, it should be possible to make the flowering of the various segregants coincide.

An experiment with five F_2 populations and their composite, IR33497-CP101 (Table 1), examined the optimum plant age for start of the short-day RGA treatment. The population was divided into 2 groups — those grown for 20 days and those grown for 40 days in long day lengths before exposing them to short days to induce flowering. Flowering of the plants was counted daily. The plants grown first for 20 days in long day lengths had 75% or more of the plants flowering within a period of 13 to 21 days;



1. Scheme to develop and handle male-sterile-facilitated composite.

Table 1. The basic vegetative phase of the different crosses used including that of the composite IR38497-CP101.

Cross	Basic vegetative phase		
	Short-est	Long-est	Av
IR36(ms)/Jalaj	18	55	31
IR36(ms)/LMN 111	18	53	31
IR36(ms)//IR36(ms)/LMN 111	19	60	37
IR36(ms)/BKN6986-147-2	19	60	28
IR36(ms)/CN540	26	60	49
Composite (IR38497-CP101)	20	60	37

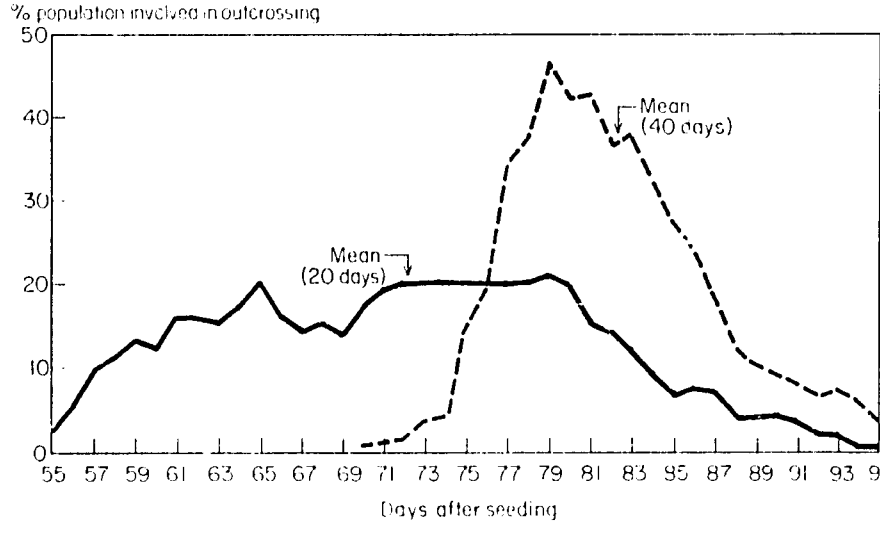
those grown for 40 days in long day lengths had 75% or more of the plants flowering within a period of 4 to 9 days. The shorter flowering range of the latter treatment ensured a better chance of random mating.

The advantage of a shorter flowering range is illustrated in Figure 2 wherein a plant flowering on a given day would most likely be pollinated by other plants heading 2 days before and 2 days after. Plants grown for 40 days before they are subjected to flower induction had a narrower flowering range causing a greater part of the population to be involved in outcrossing.

The need for 40 days growth before panicle initiation is the result of many lines having a basic vegetative phase of more than 20 days (Table 1). The basic vegetative phase of the experimental lines ranged from 18 to 60 days indicating that some plants can be induced to flower early whereas others need at least 60 days of growth before they can be induced. Preventing the plants from flowering until all have undergone the basic vegetative phase (about 60 days) will ensure 100% flowering within a week. However, this would mean growing them for an additional 20 days and would partially defeat the purpose of RGA. Handling the material from C_4 F_2 to C_4 F_4 through RGA reduces the time for fixing the fertile line.

MATERIALS AND HANDLING FOR A POPULATION

A program has been initiated at IRRI to generate male-sterile-facilitated composites of various lengths of photoperiod sensitivity and possibly combine the component characters necessary for rainfed wetland rice. A number of promising lines and varieties with various outstanding plant characters for elongating ability, submergence tolerance, aquatic tillering, aquatic rooting, resistance to bacterial blight, stem borer, problem soils, were crossed (Table 2) with IR36(ms). The F_1 was normally fertile and 30 g of seed produced on the F_1 were mixed to constitute C_1 F_2. An equal



2. Period of long-day treatment before floral inductive short-day treatment and percentage of composite population involved in outcrossing.

Table 2. List of crosses used in the composite IR38498-CP102.

IR no.	Parentage
IR27588	IR36(ms)BKN76059-16-2
IR27591	IR36(ms)/FRG 10
IR27606	IR36(ms)/Jaganath
IR27607	IR36(ms)/Jalaj
IR27611	IR36(ms)/Leb Mue Nahng 111
IR29878	IR36(ms)/Lambayque 1
IR29879	IR36(ms)/Padi Sasahal
IR29885	IR36(ms)/Beak Ganges
IR29886	IR36(ms)/FR13A
IR29887	IR36(ms)/FR43B
IR29900	IR36(ms/Sungail
IR29901	IR36(ms/Badhaia Chikon
IR29902	IR36(ms)/Bahagira
IR22903	IR36(ms)/Binni
IR29910	IR36(ms)/Bunajota
IR29911	IR36(ms)/Burabazal
IR29912	IR36(ms)/Digha
IR29917	IR36(ms)/Kalahaia
IR29918	IR36(ms)/Kalo Mota
IR29919	IR36(ms)/Pankiraj 1170
IR29920	IR36(ms)/Sulpan
IR31939	IR36(ms)//IR36(ms)//BKNFR76059-16-2
IR31940	IR36(ms)//IR36(ms)/FRG 10
IR31941	IR36(ms)//IR36(ms)/Goda Heenati
IR31954	IR36(ms)//IR36(ms)/Jaganath
IR31955	IR36(ms)//IR36(ms)/KLG6986-165-P
IR31956	IR36(ms)//IR36(ms)/Leb Mue Nahng 111
IR32119	IR36(ms)/BKN6986-147-2
IR32121	IR36(ms)/Dahanala
IR32160	IR36(ms)/Kalutalawee
IR32163	IR36(ms)/Ptb 21
IR32164	IR36(ms)/Thavalu
IR32167	IR36(ms)/CN540
IR32168	IR36(ms)/Cultivar 956
IR32169	IR36(ms)/Dudomona
IR32170	IR36(ms)/Goda Heenati
IR32177	IR36(ms)IR1060-90
IR32193	IR36(ms)/KLG6986-165-P
IR32194	IR36(ms)/Kurkaruppan

quantity of seed of bacterial blight-resistant IR1698-24-1 and stem borer-resistant IR1820-52-4-1 was also added. At flowering, sterile segregants were identified by their white, empty anthers, which contrasted with the yellow, plump anthers of the fertile plants. Poor panicle exsertion also marked male steriles. On nonwindy days, flowering panicles were shaken every 30 minutes with a stick to stir pollen and promote outcrossing. At maturity, seeds collected from sterile plants were bulked to

grow the C_2 F_1 population. Because RGA would be used to grow the material throughout, a high degree of outcrossing was expected. In RGA 1,500 plants were accommodated in 1.35 m^2 and cross-pollination of a male-sterile plant with as many fertile plants was expected. To accommodate 1,500 plants in the field, more than 60 times as much area would be needed and the probability of cross-pollination with as many plants would be much less.

The C_1 F_1 bulk will be grown in the field during 1982. Desirable fertile plants will be selected and handled through a normal pedigree system. Bulk seeds of C_1 F_4, or selected bulks from C_1 F_5, will be sent to national programs for further selection under actual situations. With the participation of interested breeders, we believe this method will greatly accelerate the development of photoperiod-sensitive varieties for rainfed wetland.

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VARIETAL DIFFERENCE IN NITROGEN UPTAKE AND UTILIZATION IN DEEPWATER RICE CULTIVARS

M. R. Khan and B. S. Vergara

SUMMARY

Distinct varietal differences were observed in deepwater rices' ability to absorb and use low and high levels of basal nitrogen in medium-deep and deepwater conditions. In terms of plant height, high nitrogen resulted in a Type A response characteristic of traditional deepwater rices where marked increase in plant height resulted in plant parts way above the water. A Type B response included the improved deepwater rices wherein plant parts above the water at flowering were optimum. Type C response, typified by the modern varieties with poor elongation ability, had plant parts below the surface of deep water.

Not all varieties have similar ability to absorb nitrogen in terms of production of basal and aquatic tillers, production of aquatic roots, and rapid elongation to cope with the rising water level.

Recent reports on some improved Thai deepwater rice lines (Kupkanchanakul 1979) and earlier reports in Nigeria (Waterworth 1967, Williams 1973) and Bangladesh (Roy 1975, Catling and Islam 1979) confirm the feasibility of fertilizer use for deepwater rice fields. According to Clay et al (1978) 19% of the deepwater rice farmers in Bangladesh apply nitrogen in their field. Jackson and Vergara (1979) questioned whether the new deepwater rice would respond to fertilizer better than the older varieties. Vergara and Dikshit (1981) gave a positive answer to that question but pointed out that the fundamental aspects of fertilizer response in terms of the physiomorphogenetic aspects are not known.

Ten varieties of diverse deepwater plant types (Table 1) were studied to elucidate the phenomenon of nitrogen uptake and use for growth and grain yield. Nitrogen levels were 2 and 6 g ammonium sulfate/pot containing 4 kg soil. The water depths were medium deep (30 cm) and deep (110 cm) with the deep level attained by gradually increasing the water level from an initial level of 30 cm.

Three types of response in terms of plant height were evident in the varieties tested (Fig. 1). Type A, which includes the traditional tall, floating rice varieties like Kalar

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Table 1. Production of aquatic tillers and roots of 9 entries under deep water (110 cm) at low (2 N) and high (6 N) levels[a] at flowering, IRRI 1979.

Entry	Aquatic tillers		Aquatic roots (no.)		Aquatic root weight (g)	
	2 N	6 N	2 N	6 N	2 N	6 N
Kalar Harsall	0	5	98	119	3.6	14.4
Habiganj I	1	1	68	68	5.6	5.7
Leb Mue Nahng 111	0	9	157	210	5.2	20.4
Chenab sel. 64-117	2	2	25	53	0.9	2.2
B1050-Mr-18-2	0	0	61	100	0.4	1.9
Br223-B-38	0	1	98	102	2.3	9.5
RD19	0	3	87	118	1.1	6.3
BKN6986-167	1	3	107	156	0.8	5.3
IR442-58	0	[illegible]	10	17	0.1	0.5
IR42[b]	-	-	-	-	-	-

[a]2 N = 2 g N/pot; 6 N = 6 g/pot. [b]IR42 died at 110-cm water depth.

Harsall, Leb Mue Nahng 111, and Chenab Sel. 64-117, showed a marked difference in plant height with higher nitrogen at both water depths. The plant parts above the water at flowering ranged from 120 to 130 cm in medium-deep water and 50 to 130 cm in deep water.

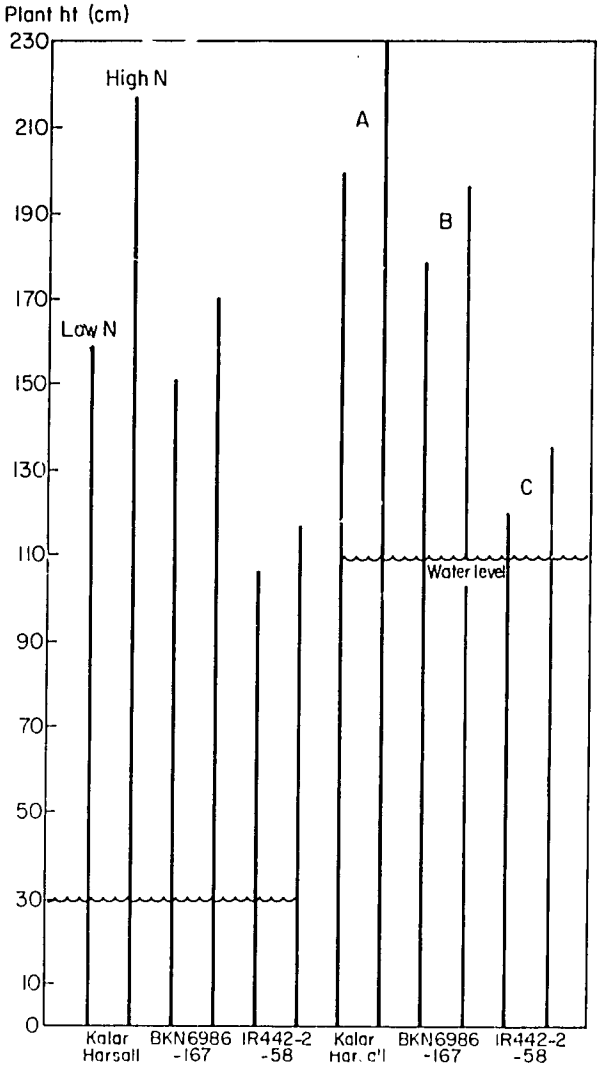
Type B response includes the improved deepwater rice lines like RD19, BKN6986-167, and BR223-B-38. These entries have intermediate height and limited elongation ability. Plant height increased with increase in nitrogen level but not as much as in Type A. The plant parts above water level at flowering was optimum — not too tall and not too prone to lodging.

Type C response is typified by IR442-2-58 and includes B1050-Mr-18-2 and IR42. These intermediate height varieties have poor elongation ability. Addition of nitrogen increased plant height only slightly. The plant parts above water in medium-deep water ranged from 70 to 110 cm, the optimum range under irrigation. However, in deep water, Type C (as in IR442-2-58) was barely above water (10 cm) and additional nitrogen did not increase plant height sufficiently.

Type A response is typical of traditional indica varieties in shallow water. If the water is not too deep and its rate of depth increase is not too rapid, additional nitrogen does not improve the plant's survival. Basal nitrogen may increase the basal tillers but not necessarily their survival. As in shallow water, application of basal nitrogen has a negative effect — the plants become too tall and are prone to lodge.

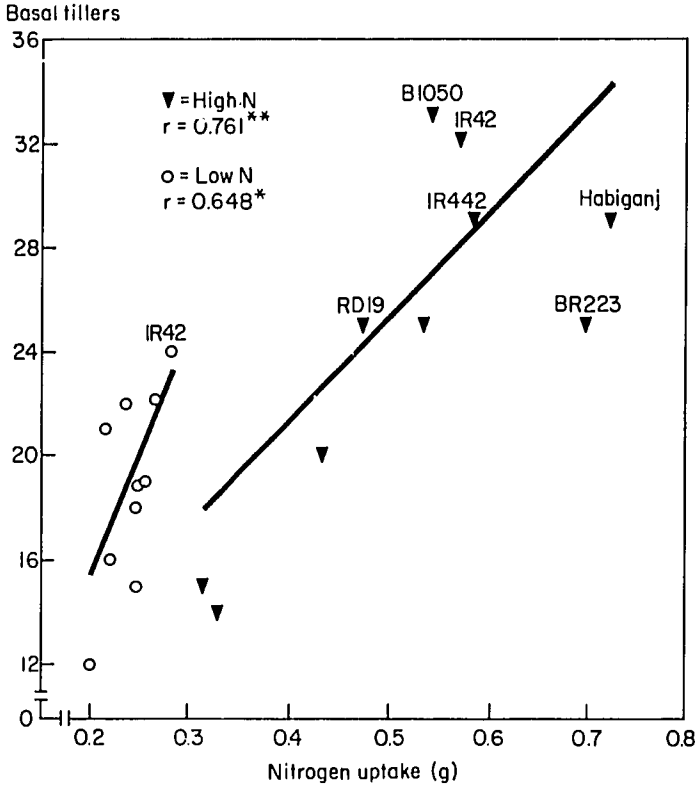
Type B is the response needed in deep water although the response at 150 cm has yet to be examined. Even in medium-deep water, Type B will be relatively shorter than Type A and should perform better.

Type C is ideal for medium-deep water but will be unable to give a reasonable yield in deepwater conditions, even with the addition of nitrogen.



1. Variation in plant height due to low and high N levels, at medium deep (30 cm) and deep (110 cm) water levels, of three plant types: A = traditional tall (Kalar Harsall), B = improved (BKN6986-167), and C = modern intermediate tall (IR442-2-58) at flowering stage.

Varietal difference in nitrogen uptake and production of basal tillers is best shown before water treatment (Fig. 2). Varieties with high nitrogen uptake had also a high number of basal tillers. Improved varieties such as IR42, IR442-2-58, B1050-Mr-18-2, BR223-B-38, and RD19 had high nitrogen uptake and high number of basal tillers at both nitrogen levels. The traditional varieties not only had poor ability to absorb nitrogen, they also had poor tillering ability. Habiganj Aman I showed a different and better response in terms of tiller production and nitrogen uptake than the other traditional varieties. The results showed that increasing the basal tiller number in deepwater rice culture may be possible by increasing basal nitrogen application and selecting varieties with both high tillering ability and ability to absorb nitrogen and use it effectively in further increasing the tiller number. Examples are B1050-Mr-18-2, IR42, RD19, BR223-B-38, and Habiganj Aman I. Their high tillering ability and



2. Relationship between nitrogen uptake and basal tillers per plant of 10 entries at low and high N levels before water treatment.

good nitrogen uptake was generally still apparent at flowering in medium-deep water. However, the relationship changed in deep water — Kalar Harsall and Habiganj Aman I, which have greater elongation ability, had the highest number of basal tillers. Although Leb Mue Nahng 111 had relatively good elongation ability, it had the poorest tillering ability.

In medium-deep water, varieties planted with low nitrogen level did not produce aquatic tillers. However, at high nitrogen some entries produced aquatic tillers. In deep-water, Kalar Harsall, Leb Mue Nahng 111, and IR442-2-58 had 5-9 tillers, especially at high nitrogen (Table 1). Some entries had few or failed to produce aquatic tillers even at high nitrogen but high nitrogen generally increased aquatic tillers.

Varietal difference in terms of aquatic rooting ability was marked in all types of entries tested. High nitrogen also induced increased aquatic rooting (Table 1). Apparently, the traditional types tend to produce more aquatic roots than the improved types. Among the improved types, BR223-B-38, RD19, and BKN6986-167 had good aquatic rooting ability in terms of aquatic root weight and number but this was not an appreciable number and weight of aquatic roots both in traditional (Habiganj Aman I), improved (B1050-Mr-2), and modern types (IR442-2-58), even at high nitrogen.

Table 2. Grain yield, panicle number, number of spikelets per paricle, and harvest index of some entries under 30- and 110-cm water at low and high N levels. IRRI, 1979.[a]

	Grain yield (g/plant)		Panicles (no./plant)		Spikelets (no./panicle)		Harvest index	
	2 N	6 N	2 N	6 N	2 N	6 N	2 N	6 N
Medium deep								
Kalar Harsall	9 d	24 a	8 cd	12 ab	57 f	95 cd	0.26	0.25
BR223-B-38	10 cd	20 b	9 c	13 ab	75 e	98 e	0.22	0.23
RD19	12 cd	26 a	7 cd	14 a	98 c	120 b	0.31	0.43
BKN6986-167	13 c	27 a	6	11 bc	90 d	130 a	0.35	0.26
Av	11.0	24.3	7.5	12.5	80.0	110.8	0.29	0.29
Deep								
Kalar Harsall	19 a	29 d	14 bcd	18 a	74 f	120 b	0.39	0.21
BR223-B-38	14 a	26 a	12 cd	17 ab	75 f	77 ef	0.29	0.21
RD19	18 d	32 a	7 f	16 abc	104 d	110 cd	0.38	0.37
BKN6986-167	18 a	31 d	10 ef	13 cde	116 bc	138 a	0.35	0.23
Av	17.3	29.5	10.8	16.0	92.3	111.3	0.35	0.26

[a]Means under 2 N and 6 N of a character, followed by a common letter, are not significantly different at the 1% level. CV (%) for grain weight, panicle number, and number of spikelets per panicle are 4, 12, and 4 in medium-deep water and 8, 15, and 4 for deep water.

Similarly varietal difference in aquatic tillering ability was distinct. Except for Kalar Harsall and Leb Mue Nahng 111, higher aquatic tillering did not necessarily lead to higher aquatic rooting. Some entries had poor aquatic tillering ability but high aquatic rooting ability or vice versa. Screening for these two attributes may lead to the selection of higher aquatic tillering and aquatic rooting ability, which may be recombined by breeding for wider adaptability in deepwater areas.

Higher nitrogen definitely increased grain yield in all entries due to increase in panicle number and spikelet number per panicle (Table 2). In medium-deep water Kalar Harsall, RD19, and BKN6986-167 had significantly higher grain yield than BR223-B-38 at high nitrogen and Kalar Harsall had the lowest yield at low nitrogen. Variety-nitrogen interactions were not, however, significantly different in deep water. The increased grain yield of RD19 and BKN6986-167 at both medium-deep and deep water at high nitrogen was influenced by increased panicle number and number of spikelets per panicle, which resulted in higher panicle weight, and consequently higher harvest index. In experimental conditions, higher harvest index may be used as a selection criterion for increased yield potential. The higher harvest index is related to the type B plant height response.

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UPTAKE THROUGH AQUATIC ROOTS AND DISTRIBUTION OF ^{15}N-TAGGED AMMONIUM IN DEEPWATER RICE

M. R. Khan, W. Ventura, and B. S. Vergara

SUMMARY

A technique of separating the activity of basal roots from that of the upper aquatic roots consisted of growing Kalar Harsall in pots and allowing the elongated plant to knee in a tray of 40 ppm ^{15}N solution, in such a way that the upper aquatic root region was fully submerged in the solution. The soil in the pot was kept flooded but completely separated from the ^{15}N solution in the tray.

Aquatic roots absorbed available nitrogen from the ^{15}N solution. The high activity of aquatic roots in the absorption of ^{15}N from the solution was indicated by their high proportion of ^{15}N to the total nitrogen uptake and by the considerable reduction in ^{15}N uptake when most of the aquatic roots were removed.

Nitrogen absorbed through the aquatic roots was distributed to the different parts of the rice plant. ^{15}N activity was initially higher at the aquatic roots, but new vegetative tillers became the predominant competitor for the partitioning of the nitrogen nutrient in the subsequent growth stages. ^{15}N became the major component of grain nitrogen when applied before flowering.

The submerged stems of deepwater rice plants produce clusters of aquatic roots that grow freely in the floodwater. It has always been assumed that aquatic roots play a role in the nutrition of the deepwater rice plant. Coffman et al (1979) stressed the need to incorporate aquatic rooting ability among a number of desirable traits in improved deepwater rices. The significance of aquatic roots in deepwater rice was earlier explained by Alim and Zaman (1958). Yamaguchi (1976) investigated the negative effects of removing adventitious roots on the growth and amounts of absorbed mineral nutrients.

There are various dissolved and suspended decaying materials in deep water that may provide sources of nutrients to rice plants. The large part of the plant under water also offers a substantial mass for colonization by aquatic microorganisms. Kulasooriya et al (1980) suggested that epiphytic algae on deepwater rice produce a substantial nitrogen input.

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Little is known about the mineral nutrition of deepwater rice. There is no direct evidence of absorption of nutrients, especially nitrogen, through aquatic roots in deepwater rice. Our study used ^{15}N to determine absorption of nitrogen via the aquatic roots and its distribution in deepwater rice.

MATERIALS AND METHODS

A technique was developed during the 1979 wet season and 1980 dry season to differentiate nitrogen taken up by deepwater rice through the aquatic roots from the available nitrogen absorbed from the soil.

Kalar Harsall, a deepwater rice variety, was used. Two 20-day-old seedlings were transplanted in pots (0.02 m^2) containing 3 kg (dry basis) Maahas clay soil (0.15% N, pH 6.6). The soil was basally supplied with 2 g ammonium sulfate (21% N), 1 g single superphosphate (18% P_2O_5), and 1 g muriate of potash (60% K_2O). The plants were subjected to an increasing water depth for 6-7 weeks for elongation and aquatic root development.

The rice plants were allowed to knee in a tray containing 100 liters of water as illustrated in Figure 1.

In the first set, 19.04 g of ^{15}N-tagged ammonium sulfate (21% N, 11.24 atom % excess to provide 40 ppm N solution) was added to a tray containing the aquatic roots of 8 plants. The pH of the water was maintained at 5 to 5.5. Water lost through evapotranspiration was replaced with deionized water every other day. Two control plants were treated in a similar manner but without fertilizer nitrogen in the tray. Two rice plants were harvested 3, 5, 10, and 96 (flowering) days after ^{15}N treatment. The control plants were harvested at flowering.

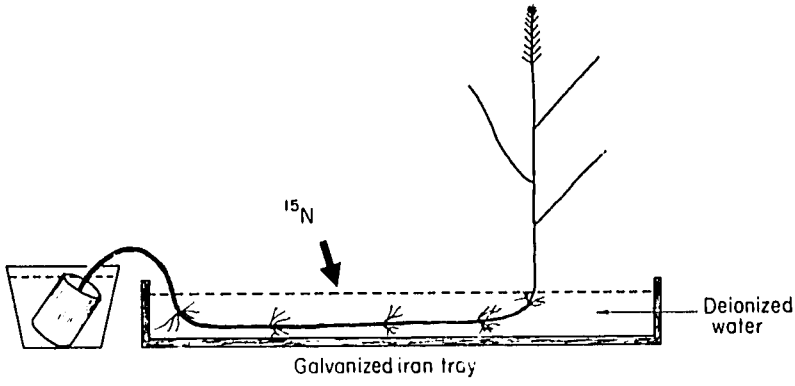
The second set had the aquatic roots of 4 plants in the tray with the same amount of ^{15}N-tagged ammonium sulfate (21% N, but with 40.54 atom % excess). The aquatic roots of two plants were excised as soon as they appeared and the aquatic roots of the two others were left intact and undisturbed. All the plants were harvested at flowering.

For both sets, harvested plants were separated into different parts and the dried ground samples were analyzed for total nitrogen by micro-Kjeldahl with automatic colorimetric ammonium estimation. ^{15}N samples were prepared by the Dumas method and analyzed by emission spectrometry (with NIA JASCO ^{15}N analyzer).

RESULTS AND DISCUSSION

Table 1 presents the amount of tagged N in different plant parts 3, 5, and 10 days after fertilizer application in the aquatic root region of Kalar Harsall. Three days after ^{15}N application, the amount of tagged N was 21% of the total absorbed by the rice plant. The percentage of ^{15}N uptake was considerably greater in the aquatic roots than in the other plant parts, suggesting aquatic roots as the active sites of nitrogen absorption from floodwater. Even the basal roots in the soil had a certain amount of tagged N (Fig. 2).

Accumulation of ^{15}N progressively increased with the growth of the rice plant, and in the increasing absorption of total nitrogen. The ^{15}N contributed 29 and 43% of the



1. Diagram of the setup of the ^{15}N treatment using Kalar Harsall that has elongated and has been induced to knee. IRRI, 1979-80.

total nitrogen absorbed 5 and 10 days after ^{15}N addition (Table 1). At flowering, the amount of ^{15}N in total nitrogen uptake increased further to 53% (Table 2). Most of the ^{15}N remained in the culms, which had the greater part of the dry matter weight.

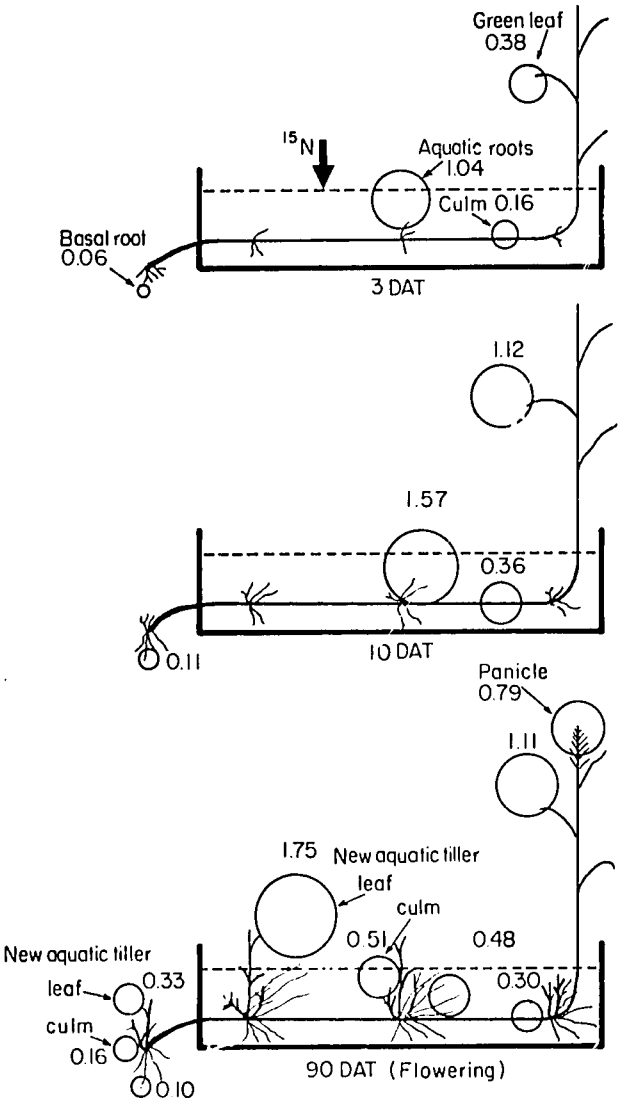
Among the plant parts, the aquatic roots exhibited the highest percentage of ^{15}N activity at the initial stages, but subsequently the new aquatic tillers, green leaves, and panicles became the primary sink of the ^{15}N activity at flowering.

The amount of ^{15}N absorbed from the aquatic root region was reflected in the dry matter weight of the rice plant. At flowering, the dry matter weight of the different plant parts and their total were remarkably higher in the ^{15}N plants than in the control plants (Table 2). The presence of a relatively greater amount of available nitrogen in the tray resulted in the greater number of late-developed aquatic and basal tillers. The diversion of the absorbed nutrient to the meristematic points of the new tillers may be detrimental to the grain yield.

The amount of ^{15}N absorbed by rice plants was checked with and without aquatic roots. It was not possible to totally eliminate the aquatic roots. However, the removal of most of the aquatic roots caused considerable decline in the absorption of ^{15}N, contributing only 33% of the total N uptake as against 60% with roots.

Table 1. Uptake of ^{15}N through aquatic roots and distribution to different plant parts 3, 5, and 10 days after ^{15}N-labeled fertilizer (40 ppm) was topdressed in the aquatic root regions of Kalar Harsall. IRRI, 1980 dry season.

Plant part	Days after ^{15}N treatment								
	3			5			10		
	Dry matter (mg)	^{15}N uptake (mg)	Percent of ^{15}N in total N uptake	Dry matter (g)	^{15}N uptake (mg)	Percent of ^{15}N in total N uptake	Dry matter (g)	^{15}N uptake (mg)	Percent of ^{15}N in total N uptake
Culms	24.7	39	25	25.4	53	33	25.8	93	49
Dead leaf sheaths	5.7	11	21	4.9	11	28	6.1	19	34
Green leaves	5.1	19	19	5.4	33	29	5.8	65	47
Dead leaves	5.1	4	11	3.9	4	17	3.9	8	28
Basal root	4.7	3	8	4.5	4	10	4.8	5	12
New aquatic root	-	-	-	0.2	3	60	0.4	6	75
Old aquatic root	-	-	-	0.4	5	62	0.6	9	75
Total aquatic root	0.4	4	66	0.6	8	61	1.0	15	75
Total or average	45.7	80	21	44.7	113	29	47.4	205	43



2. Diagram showing comparative ^{15}N activity (percent) in different plant parts 3, 10, and 96 days after ^{15}N fertilizer was topdressed in the aquatic root regions of Kalar Harsall. Numbers above the circle indicate percent tagged N. DAT days after treatment. IRRI, 1979-80.

As in the first experiment, the newly developed aquatic and basal tillers exhibited the highest ^{15}N activity both with and without aquatic roots at flowering (Table 3). With roots, ^{15}N contributed as much as 72% of the total nitrogen in the grains, but limited aquatic root activity reduced the amount of tagged N to 32%.

The removal of most of the aquatic roots reduced the total amount of ^{15}N absorption by 396 mg/plant and the total nitrogen uptake by 456 mg/plant, resulting in a 20 g/plant reduction in dry matter weight.

The distribution of ^{15}N among plant parts was similar in the 2 sets of pot experiments.

Table 2. Dry matter weight and nitrogen content (total and ^{15}N) in Kalar Harsall plant parts 96 days after ^{15}N fertilizer application. IRRI greenhouse, 1980 dry season.

Plant part	Days after N^{15} treatment				Control	
	96 (Flowering)				96 (Flowering)	
	Dry matter (mg)	Total N (mg)	^{15}N uptake (mg)	Percent of ^{15}N in total N uptake	Dry matter (g)	Total N (mg)
Culms	35.9	223	107	48	25.8	116
Dead leaf sheaths	11.1	56	29	52	4.8	24
Green leaves	10.6	200	118	59	5.6	71
Dead leaves	3.3	19	10	52	3.4	14
New aquatic tiller-culm	3.5	30	18	60	1.0	10
New aquatic tiller-leaf	2.3	63	40	64	0.6	8
New basal tiller-culm	1.4	11	2	18	-	-
New basal tiller-leaf	0.6	9	2	22	-	-
Basal root	5.8	38	6	16	5.3	36
New aquatic root	-	-	-	-	-	-
Old aquatic root	-	-	-	-	-	-
Total aquatic root	8.9	73	43	59	2.1	21
Panicle	6.4	82	50	61	4.1	10
Total or average	89.8	802	425	53	52.7	310

Table 3. Uptake and distribution of ^{15}N at maturity of Kalar Harsall when topdressed with ^{15}N-labeled fertilizer (40 ppm N) at the aquatic roots region before flowering, with and without aquatic roots. IRRI, 1980 dry season

Plant part	With aquatic roots				Aquatic roots removed			
	Dry matter (mg)	Total N (mg)	^{15}N (mg)	Percent of ^{15}N in total N uptake	Dry matter (mg)	Total N (mg)	^{15}N (mg)	Percent of ^{15}N in total N uptake
Culms	26.6	215	114	53	21.1	140	49	35
Dead leaf sheaths	4.1	31	15	58	4.3	35	17	48
Green leaves	7.1	127	47	37	2.5	32	6	19
Dead leaves	2.0	19	3	16	4.1	31	5	16
New aquatic tillers-culm	2.6	39	29	74	0.8	12	7	58
New aquatic tillers-leaves	1.8	62	51	82	0.4	13	8	61
New basal tillers-culm	2.2	17	10	59	1.1	10	4	40
New basal tillers-leaves	1.3	29	19	65	0.6	16	8	50
Basal roots	3.2	26	7	27	4.3	31	5	16
Aquatic roots	2.2	33	23	69	-	-	-	-
Rachis	1.2	15	7	46	0.7	8	2	25
Grains	14.0	306	220	72	8.4	119	38	32
Total or average	68.3	908	545	60	48.4	452	149	33

This study clearly demonstrated the importance of aquatic roots in the absorption of nutrients from the floodwater for deepwater rice. If these nutrients are available in the floodwater, they will contribute greatly to the growth of deepwater rice and in the grain yield. The importance of aquatic rooting ability and screening for such a plant trait is clearly indicated.

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DISCUSSION

JUGSUJINDA: I understand from the paper that basal and aquatic roots have equal abilities to absorb nutrient. Am I correct?

HILLERISLAMBERS: According to the results, the amount of ^{15}N in total nitrogen uptake was 53% at flowering.

WATANABE: This experiment was done by one of my research assistants. The reason we do not use this technique is that we don't know how much nitrogen content there is in actual field conditions. In addition to this experiment we also need to assess the actual role of the aquatic root in field conditions. That's why we developed another technique.

PHYSIOLOGICAL DIFFERENCES IN RICE VARIETIES TOLERANT OF AND SUSCEPTIBLE TO COMPLETE SUBMERGENCE

A. M. Mazaredo and B. S. Vergara

SUMMARY

In experiments on possible physiological difference. 12 varieties were used and classified as tolerant, moderately tolerant, and susceptible. Tolerant varieties maintained high photosynthesis and respiratory rates, high levels of carbohydrate and nitrogen, a high level of oxygen in the root environment, and stiffness and rigidity of the culm during submergence. Submergence tolerance and recovery rate were positively related to potassium and nitrate content of the culm before treatment. Submergence tolerance was negatively correlated, to the ratio of photosynthesis to respiratory rate, the decrease in oxygen release rate in 30 cm of water, nitrate reductase activity, and oxygen release rate in the roots of untreated plants at 16 days after seeding. Photosynthesis and respiratory rate, leaf area, plant height, and dry weight of 10-day-old seedlings before water treatment were not related to submergence tolerance.

During the monsoon season in Southeast Asia the rice crop is frequently inundated for a day or several weeks at varying stages of growth. Such inundation can destroy a rice crop.

Submergence tolerance — the ability of a rice plant to survive after complete submergence in water — is a genetic character. Several environmental factors affecting the tolerance of rice plants for submergence have been identified (Richharia and Parasuram 1963, Palada and Vergara 1972). Tolerance is related to duration of submergence, water temperature, water turbidity, light intensity, water depth, and nitrogen content of the soil. Plants are less tolerant of submergence at the early growth stages. Varietal differences in the degree of submergence tolerance have been noted (Palada 1970, Weerapat and Woraniman 1974, Supapoj et al 1979).

When a rice plant is submerged, its internal oxygen content decreases due to insufficient supply (Yamada 1959). Aerobic respiration is reduced, anaerobic respiration is promoted, and an increased consumption of respiratory substrate with

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decreased evolution of energy results. There is also a decrease in photosynthesis.

The nature of tolerance for flooding or anaerobiosis in higher plants has been the subject of many reports (Alberda 1953; Armstrong 1964, 1971; Healy and Armstrong 1972).

With the inclusion of submergence tolerance in the breeding program for deepwater rice at the International Rice Research Institute and in other cooperating countries, several methods of screening were used to evaluate possible parents as donors for submergence tolerance and to screen breeding lines (Vergara et al 1979). Most of the methods depended on the survival of the rice plants after submergence. We feel that a knowledge of some of the physiological characters of the rice plant associated with tolerance for complete submergence may be helpful in understanding submergence tolerance and in developing screening techniques.

DRY MATTER PRODUCTION OF SUBMERGENCE-TOLERANT AND SUSCEPTIBLE RICE SEEDLINGS

Twelve rice varieties with different degrees of submergence tolerance were studied at the seedling stage. Seedlings were grown by the method of Vergara and Mazaredo (1974). At 10 days after soaking the plants were submerged in water 30 cm deep for 6 days. After submergence, the plants were allowed to recover for 1 week.

Submergence tolerance

The survival of the varieties tested ranged from 26 to 84%. The tolerant varieties were Kurkaruppan, FR13A, Thavalu (15325), and Thavalu (15314). SML Temerin, Nam Sagui 19, Leb Mue Nahng 111, and IR36 were moderately tolerant. T442-57, IR8, RD7, and IR42 were susceptible (Table 1).

Leaf area and seedling height

Although leaf area tended to be greatest in the tolerant varieties, there was no correlation ($r = 0.1774$) between submergence tolerance and leaf area before treatment.

Seedling height before water treatment did not show any correlation with submergence tolerance (Table 1). Seedling height is not an index of the capacity to resist submergence (Ramiah 1953). Palada (1970) found a positive correlation between plant height after submergence and survival. Karin (1980) reported that susceptible varieties with taller plants after 6 days submergence had higher percentage of survival than the shorter varieties. A completely submerged rice plant increases plant height at all growth stages (Vergara et al 1974, Karin 1980).

The moderately tolerant varieties had higher percentage of increase than the tolerant varieties. There was a high correlation between tolerance and increase in plant height due to water treatment among the moderately tolerant varieties ($r = 0.8007^{**}$). The tolerant and susceptible varieties did not show significant correlation. The ability to tolerate submergence among moderately tolerant varieties like SML Temerin, Nam Sagui 19, Leb Mue Nahng 111, and IR36 was probably due to elongation and initial tall stature of the seedling.

Dry weight

The average total dry weight decreased due to submergence in water (Table 1). However, the tolerant varieties that rapidly recovered after submergence had a high percentage of increase in dry weight. The Thavalu varieties (15325 and 15314) had a slow rate of recovery from submergence. Both oxygen tension and aerobic respiration are reduced in submerged plants. Anaerobic respiration increases resulting in increased consumption of accumulated carbohydrates with decreased evolution of energy (Yamada et al 1955). This plus decrease in photosynthetic rate may explain the decrease in dry weight during submergence.

The change in dry weight due to submergence was not related to the resistance of rice seedlings to complete submergence, but to increase in plant height (r = 6838*). This indicated that factors other than accumulated carbohydrates, rate of photosynthesis, and respiration affect the decrease in plant weight. Seedlings that elongate during submergence and have leaves above or near the water surface may have better photosynthesis so that increase in dry weight is possible even during submergence, as in SML Temerin.

Changes in carbohydrate content

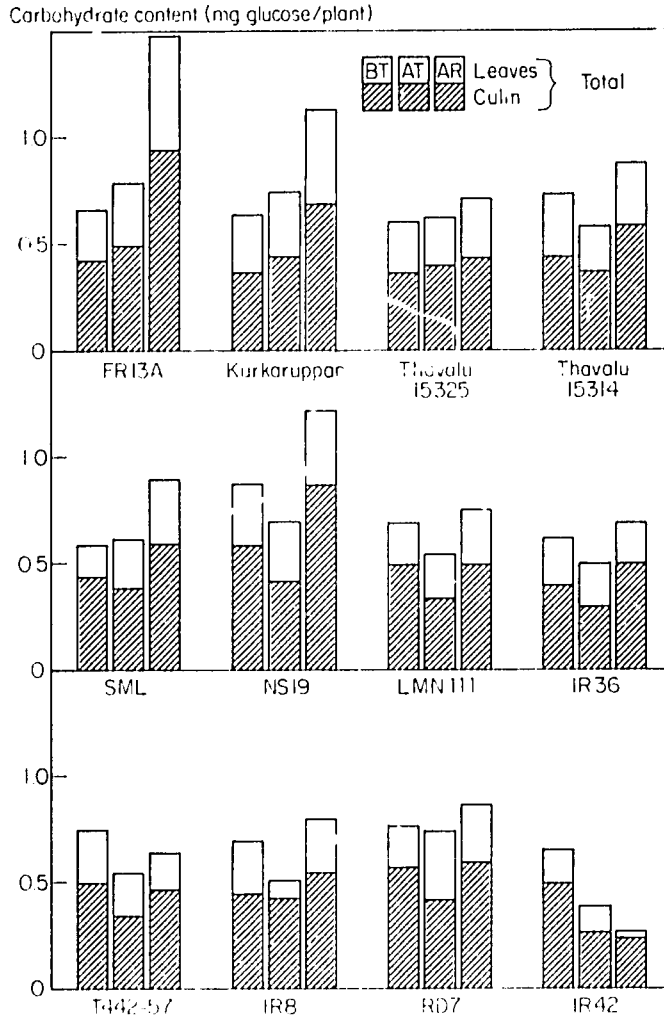
We used the anthrone method (Yoshida et al 1971) to analyze the amount of carbohydrate in the grains of the 12 varieties before the start of the experiments. The carbohydrate present in the seeds differed but did not show a relationship to submer-

Table 1. Survival, plant height, and total dry weight before treatment (BT); increase in plant height and total dry weight after 6 days of submergence (AT); and total dry weight 7 days after recovery (AR). IRRI, August 1980.

Variety	Survival (%)	Plant height (cm)	Increase in height (%)	Total dry weight (mg/plant)		
		BT	AT	BT	AT	AR
Tolerant varieties						
FR13A	84	19	17	16	16	26
Kurkaruppan	83	18	30	18	18	27
Thavalu (15325)	84	17	20	15	14	13
Thavalu (15314)	83	23	18	15	16	15
Av	83.5	19.3	21.3	16.0	16.0	20.3
Moderately tolerant varieties						
SML Temerin	76	17	80	12	14	13
Nam Sagui 19	64	23	23	19	19	20
Leb Mue Nahng 111	68	15	56	15	14	13
IR36	70	16	45	15	15	11
Av	70	17.8	51.0	15.3	15.5	14.3
Susceptible varieties						
T442-57	43	17	20	17	16	11
IR8	59	17	17	14	12	13
RD7	61	17	27	17	17	14
IR42	26	17	18	14	12	5
Av	47.3	17.0	20.5	15.5	14.3	10.8

gence tolerance. Thavalu (15325), a tolerant variety, had the lowest carbohydrate content in the seeds.

In 10-day-old seedlings, most of the carbohydrates are in the form of starch and found mostly in the culm (Fig. 1). Before submergence there were no apparent differences between the tolerant and susceptible varieties in terms of carbohydrate content. After 6 days of submergence, the susceptible varieties generally had a greater decrease in carbohydrate content than the tolerant varieties. The high average after-submergence carbohydrate content of the tolerant varieties indicates either respiration was relatively low or photosynthesis was relatively high during complete submergence, or both.



1. Carbohydrate content of 12 varieties with different degrees of submergence tolerance before water treatment (BT), after treatment (AT), and after 1 week recovery from submergence (AR).

After submergence, the tolerant varieties recovered faster than the susceptible varieties, hence the total plant height and the total carbohydrate content was higher than those of the susceptible varieties. FR13A and Kurkaruppan, the two most tolerant entries, had the highest carbohydrate content. IR42, the most susceptible, had the lowest carbohydrate content. However, the carbohydrate content alone did not explain the differences in tolerance for submergence. Thavalu (15325) and Thavalu (15314) were tolerant but had relatively low carbohydrate content after submergence and after recovery.

Yamada (1959) reported a high correlation between submergence tolerance and starch or total carbohydrate content before submergence but not with sugar or nitrogenous fraction content. In our experiment, there was correlation between submergence tolerance and the residual carbohydrate content after water treatment for 6 days ($r = 0.6841$) but not before treatment, which indicated that the survival and rapid recovery of the plants depended on the amount of carbohydrate available after submergence.

Nitrogen content

Most of the nitrogen in the seedlings was found in the leaves and there were no apparent significant differences between varieties in terms of nitrogen content and submergence tolerance (Fig. 2). After treatment most of the nitrogen in the leaves was lost, which indicated that some degradation of protein and chlorophyll occurred. Leaching out of nitrogen from the leaves was reported by Tanaka and Navasero (1964). During recovery for 7 days, nitrogen level increased among the tolerant varieties but decreased in the susceptible varieties. The results showed that the tolerant varieties, specifically FR13A and Kurkaruppan, took up nitrogen rapidly resulting in rapid recovery.

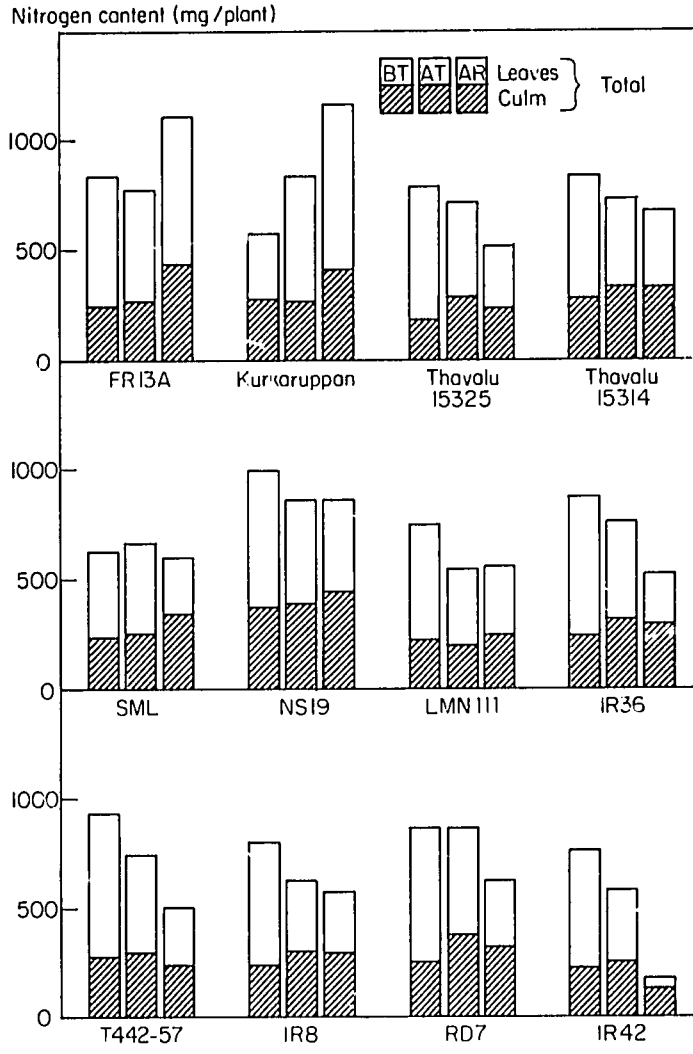
Silica content

High level of silica in plants is associated with stiffness of both stem and leaves (Tanaka and Park 1966). Stiffness of the culm prevents lodging of the seedlings or physical damage to the growing point. Erectness of the leaves lessens leaves sticking to the mud. Tolerant varieties were generally upright and rigid, especially in the culm section, even before submergence.

The silica level was generally higher in tolerant varieties than in susceptible varieties, especially in the culm (Fig. 3). The tolerant variety Kurkaruppan had the highest silica content.

PHOTOSYNTHESIS AND RESPIRATION OF TOLERANT AND SUSCEPTIBLE RICE VARIETIES

Photosynthesis and respiration are the two primary plant processes involved in the survival of rice seedlings after complete submergence. Changes in the two processes depend on the varieties used. The photosynthesis and respiration of the 12 varieties were determined both under submerged and nonsubmerged conditions. Soil culture was used for the nonsubmerged tests and culture solution (Yoshida et al 1971) was used for submerged tests to lessen contamination and damage to seedlings.

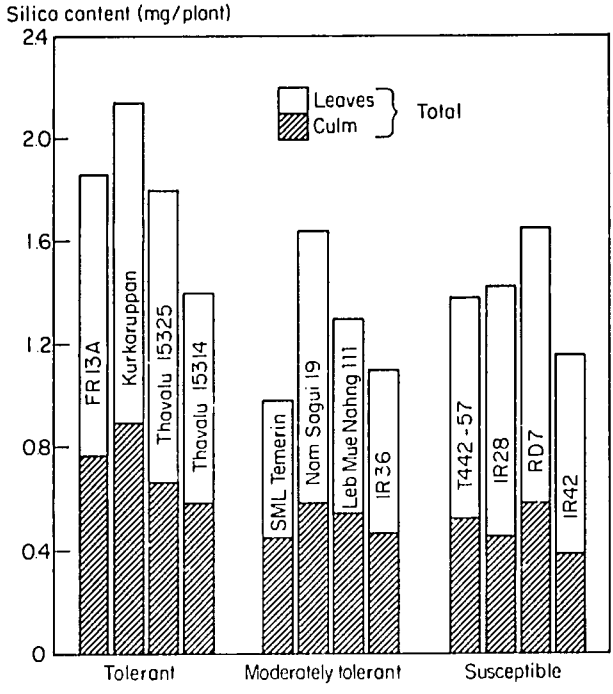


2. Nitrogen content of culm and leaves of 10-day-old seedlings before submergence (BT), after submergence (AT) for 6 days, and after recovery from submergence (AR).

Photosynthesis and respiration of nonsubmerged seedlings

Photosynthesis at 60 and 20 klux and respiration were measured on the second leaf blade of 10-day-old seedlings using an infrared gas analyzer. There were no significant varietal differences between photosynthetic rate both at 60 and 20 klux and percentage of survival of the varieties tested (Table 2). Photosynthesis at 60 klux was positively and highly correlated to specific leaf weight (r = 0.9611**). There was a significant decrease in photosynthesis due to decrease in light intensity ranging from 19% to 44%. The changes did not, however, show a relationship to submergence tolerance.

Tolerant varieties, except FR13A, had lower respiratory rates than susceptible varieties. Although there was significant varietal difference in respiratory rate and submergence tolerance, there was no significant correlation between respiratory rate



3. Silica content of 10-day-old rice seedlings of different varieties tested for submergence tolerance.

and submergence tolerance. Photosynthesis-respiration (P-R) ratio both at 60 and 20 klux also showed no significant correlation to submergence tolerance although tolerant varieties had higher average values at 60 klux than susceptible varieties. Photosynthetic activity at low light intensity or respiratory rate has no strong correlation with the ability of varieties to tolerate submergence.

Photosynthesis and respiration of submerged seedlings

The 10-day-old seedlings grown in culture solution were submerged in distilled water and incubated in the growth cabinet at 29° C. After 4 hours the amount of dissolved oxygen in water was measured immediately to determine the photosynthetic and respiratory rate (American Public Health Association 1976)

Varietal differences exist in rate of photosynthesis during 4 hours of complete submergence. However, there was no correlation between photosynthesis and submergence tolerance or percentage of survival of the variety (Table 3).

The tolerant varieties generally had higher respiration rate and there was a significant correlation between respiratory rate and submergence tolerance (r = 0.5787*). The significance of the generally higher respiratory rate was not clear. It probably indicated a reaction or response triggered by the submergence stress. This aspect needs further study.

The P-R ratio was generally lower in tolerant than in susceptible varieties. It was negatively correlated to submergence tolerance at high light intensity (r = −0.7572**)

Table 2. Photosynthesis and respiration of 10-day-old seedlings of varieties tolerant of and susceptible to complete submergence. IRRI, October 1980.[a]

Variety	Photosynthesis[b] 60 klux	Photosynthesis[b] 20 klux	Decrease (%)	Respiration[b]	Photosynthesis/respiration 60 klux	Photosynthesis/respiration 20 klux	Specific leaf weight (mg/cm^2)
Tolerant varieties							
FR13A	24.4	16.2	34	3.4 ab	7	5	1.96
Kurkaruppan	23.2	14.6	37	2.5 bc	9	6	2.03
Thavalu (15325)	26.3	18.8	28	2.1 c	12	9	2.05
Thavalu (15314)	21.6	15.4	29	2.6 bc	8	5	2.10
Av	23.88	16.25	32	2.65	9.0	6.5	2.04
Moderately tolerant varieties							
SML Temerin	25.9	14.6	44	4.8 a	5	3	2.07
Nam Sagui 19	18.6	14.3	23	4.0 a	5	4	2.01
Leb Mue Nahng 111	20.8	16.0	23	2.7 bc	8	6	2.00
IR36	26.5	19.8	26	3.7 a	7	5	2.05
Av	22.95	16.18	29	3.8	6.2	4.5	2.03
Susceptible varieties							
T442-57	25.8	20.8	19	2.9 bc	9	7	2.09
IR8	25.9	18.0	31	2.8 bc	9	7	2.17
RD7	27.1	20.8	23	3.1 b	9	7	2.17
IR42	24.0	16.3	32	3.2 ab	7	5	2.10
Av	15.7	18.98	26	3.0	8.5	6.5	2.13

[a]Means followed by the same letter are not significant at the 5% level. [b]mg CO_2/dm^2 per hour at 300 ppm CO_2.

Table 3. Photosynthesis and respiration of 10-day-old rice seedlings during submergence. IRRI, October 1980.

Variety	Gross photosynthesis (P) µg O_2/h per plant		Respiration (R) µg O_2/h per plant	Photosynthesis-respiration	
	30 klux	15 klux		30 klux	15 klux
Tolerant varieties					
FR13A	21	21	23	0.93	0.92
Kurkaruppan	18	17	19	0.97	0.92
Thavalu (15325)	23	23	26	0.88	0.87
Thavalu (15314)	22	21	22	1.00	0.96
Av	21.0	20.5	22.5	0.94	0.92
Moderately tolerant varieties					
SML Temerin	18	14	12	1.46	1.16
Nam Sagui 19	22	19	22	1.02	0.88
Leb Mue Nahng 111	20	19	18	1.12	1.09
IR36	16	15	16	1.00	0.96
Av	19.0	16.8	17.0	1.15	1.02
Susceptible varieties					
T442-57	21	19	17	1.24	1.13
IR8	25	25	22	1.14	1.13
RD7	17	17	16	1.05	1.03
IR42	13	9	11	1.17	0.79
Av	19.0	17.5	16.5	1.15	1.02

but not as low light intensity. At reduced light intensity, photosynthetic ability declines and respiration rate decreases (Tanaka et al 1966, Palada 1970). During submergence the rice seedlings with high photosynthetic rate (tolerant varieties) also had high respiratory rate so that the P-R ratio was relatively low. This indicated that photosynthetic products are used immediately for repair or growth of the plant.

OXYGEN TRANSPORT IN RICE SEEDLINGS SUBMERGED IN WATER

The varieties tested were grown in culture solution in the greenhouse and the capacity of each variety to transport oxygen from the shoots to the root system was determined on 10-day-old seedlings at different water levels after submergence for 6 days and after recovery for 5 days using YSI Model 53 Biological Oxygen Monitor (Ando and Yoshida 1980, Mazaredo 1981).

Oxygen release and uptake rate

Normal oxygen release rate (OR) of the roots of the 12 varieties ranged from 152 to 430 μml O_2/plant per minute (Table 4). SML Temerin, the moderately tolerant variety, had the lowest OR. Thavalu (15314), one of the tolerant varieties, had the highest.

Table 4. Oxygen release rate in the roots of a 10-day-old seedling submerged at different water depths[a].

Variety	O_2 release rate (μml O_2/plant per min)		
	0 cm	10 cm	30 cm
Tolerant varieties			
FR13A	296	94 bcd	11 bcd
Kurkaruppan	281	138 abcd	49 ab
Thavalu (15325)	293	132 abcd	26 abc
Thavalu (15314)	430	193 a	79 a
Av	325	139	41
Moderately tolerant varieties			
SML Temerin	152	64 d	- 10 bcd
Nam Sagui 19	287	93 bcd	- 48 de
Leb Mue Nahng 111	304	75 cd	-114 e
IR36	343	105 bcd	- 34 cde
Av	272	84	- 52
Susceptible varieties			
T442-57	318	154 ab	- 31 bcd
IR8	293	53 d	- 56 de
RD7	414	165 ab	- 52 de
IR42	251	71 cd	- 53 de
Av	319	11	- 48

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

There was no correlation between submergence tolerance and OR of 10-day-old rice seedlings.

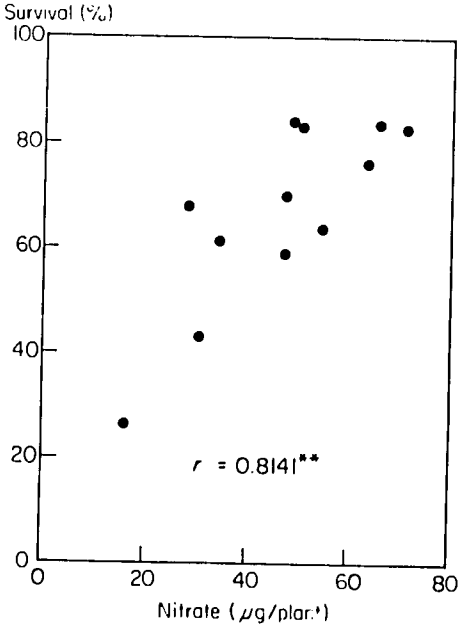
Oxygen transport from the shoots to the roots decreased with increasing water level or degree of submergence of the plant. When seedlings were completely submerged at 30-cm depth, the roots of susceptible varieties absorbed oxygen in water whereas the tolerant varieties continued to release oxygen at a low rate. The tolerant varieties apparently have a greater reserve of oxygen in the plant. It is possible that photosynthesis continues at a higher rate among the submerged tolerant varieties and the plants release oxygen as by-products through the roots.

The marked decrease in oxygen release from the roots with increasing degree of submergence shows the importance of the leaves and oxygen transport in maintaining aerobic respiration in the roots. The better maintenance of oxygen in the roots of tolerant varieties can be used to select tolerant varieties.

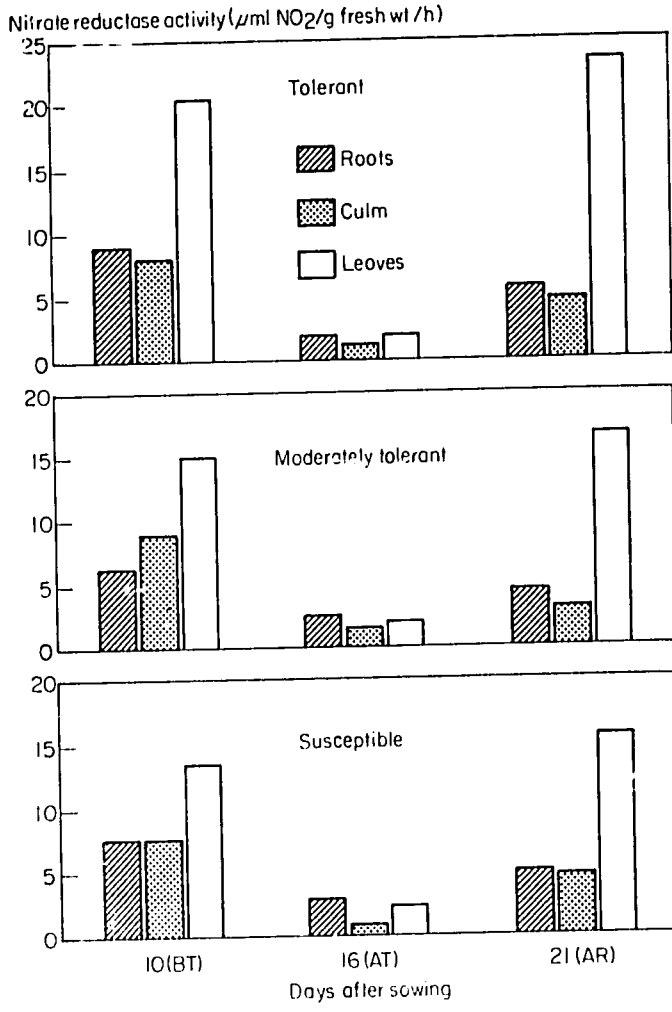
Nitrate and nitrate reductase activity

The nitrate content of 10-day-old seedlings of the 12 varieties was analyzed by the phenoldisulfonic acid method (Johnson and Ulrich 1950). Nitrate was found in all parts of the plants and the culm had higher average values in tolerant than in susceptible varieties. Based on dry weight, the tolerant varieties generally had more nitrate per plant than the susceptible varieties. Nam Sagui 19, SML Temerin, and FR13A had the highest values. Nitrate content in the culm before treatment was highly correlated (r = 0.8141**) to submergence tolerance (Fig. 4).

Nitrate reductase activity (NRA) of the rice seedlings was determined by Jaworski's method (1971). Before submergence the NRA of the plants was highest in the leaves and generally higher in the tolerant varieties in both roots and leaves than in the



4. Relationship of nitrate content of the culm before water treatment to submergence tolerance.



5. Nitrate reductase activity of roots, culm, and leaves of different varieties with varying degrees of submergence tolerance before water treatment (BT), after treatment (AT), and after 1 week recovery from submergence (AR).

susceptible varieties (Fig. 5). The NRA markedly decreased during submergence for 6 days and increased during the recovery period. The higher NRA and higher nitrate content in the culms of tolerant varieties may indicate a more rapid recovery from submergence but not necessarily a higher tolerance for submergence.

The marked reduction in NRA during submergence indicated a change in metabolic activity. Protein metabolism especially in the leaves was most affected. NRA in the roots of plants after submergence was negatively correlated to submergence tolerance ($r = -0.6917^{**}$). After submergence, plants with low root NRA reduced nitrate slowly and the immediate demand for carbohydrate in the roots decreased.

Analysis of the potassium content of the 12 varieties showed that the tolerant

Table 5. Physiological differences between rice varieties tolerant for and susceptible to complete submergence.

10-day-old seedlings of tolerant and susceptible varieties

↓

SUBMERGENCE
(6 days, 30-cm water depth)

Tolerant	Susceptible
•Plant height generally taller and in moderately tolerant varieties increased rapidly.	•Shorter plant height.
•Dry weight decreased and related to elongation.	•Dry weight decreased and related to elongation.
•Carbohydrate decreased at lower rate.	•Carbohydrate decreased at faster rate.
•Nitrogen was higher and decreased at lower rate.	•Nitrogen decreased at faster rate.
•High silica in culm, plant stiff protecting the growing point.	•Low silica, culm is soft causing physical damage to growing point.
•Longer roots, inhibited by submergence.	•Shorter roots, inhibited by submergence.
•Oxidizing power of roots did not change.	•Oxidizing power decreased.
•Photosynthesis decreased at lower rate.	•Photosynthesis decreased at higher rate.
•Higher respiratory rate.	•Lower respiratory rate.
•Higher oxygen release rate.	•Low oxygen release rate.
•Higher level of potassium, nitrate, and nitrate reductase activity.	•Lower potassium, nitrate, and nitrate reductase activity.

↓

SURVIVAL (Recovery)

High	Low
•Maintained high level of carbohydrate after treatment resulting in faster recovery.	•Low carbohydrate content.
•Fast recovery of lost nitrogen and new chlorophyll synthesized.	•Chlorophyll disintegrated.
•More stiff and rigid culm to protect growing point.	•Soft and collapsed culm causing physical damage to growing point.
•Maintained high photosynthesis and respiratory rate.	•Low photosynthesis and high respiratory rate.
•Higher nitrate reductase activity.	•Lower nitrate reductase activity indicating poor recovery.

varieties generally had higher potassium content than susceptible varieties. Potassium content was higher in the culm and leaves than in the roots. Potassium content in the culm was related to submergence tolerance ($r = 0.5767^*$). The presence of a higher level of potassium in tolerant varieties probably indicates that photosynthates are translocated rapidly and thus the energy released for oxidative phosphorylation is higher among tolerant varieties.

There is possibility of more active transport of photosynthate among the tolerant varieties especially in the culm. Reduction in photosynthesis was less in tolerant varieties than in susceptible varieties. Respiratory rate was higher among tolerant varieties and related to submergence tolerance.

CONCLUSION

Table 5 summarizes the physiological characteristics of 12 rice varieties differing in tolerance for complete submergence at the seedling stage. Tolerance for complete submergence in water at the seedling stage cannot be explained by a single physiological character. Some varieties survived due to elongation such that their leaves were above water. Others maintained a high level of carbohydrates during submergence; others had green and active leaves, stiff culm, and high nitrate reductase activity after submergence. Others maintained high photosynthesis and respiration during submergence.

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DISCUSSION

WATANABE: From the data any single root characteristic may not be enough to explain varietal differences in submergence tolerance but the nitrate and carbohydrate content may be factors affecting submergence tolerance a little bit. Do we know that when the seedling is dry-seeded, nitrate content and carbohydrate is generally high? As a soil microbiologist I suspect some material from the soil may affect the submergence tolerance and I raise the question of what technique to use to grow seedlings before a submergence tolerance test.

HILLERISLAMBERS: Several people have talked about submergence tests here. I think Mr. Setabutara has mentioned that wet-seeded rice on wet seedbed is usual in the wet season and dry-seeded rice on dry seedbeds is done in the dry season. But that is only one test that I am immediately aware of.

ESTIMATING ELONGATION EFFICIENCY IN DEEPWATER RICE

U. S. Singh

SUMMARY

Several mathematical equations were tested on data collected for total plant height. The best result evolved from the formula:

$$\text{Elongation efficiency index} = \frac{X_1(N-0) + X_3(N-2) + X_5(N-4) + X_7(N-6) + X_9(N-8)}{N\ (\text{maximum elongation observed})}$$

where X_1, X_3, X_5, X_7, X_9 stand for actual elongation in centimeters during the first, second, third, fourth, and fifth observations taken on alternate days, and N stands for the total span in days from submersion to the last observation. The formula provides a satisfactory index for assessment of comparative elongation efficiency of different varieties and may be used for a precise estimate of elongation efficiency.

Scoring of elongation ability of deepwater rices is based mostly on total plant or internodal elongation. This method of assessing the elongation ability provides a satisfactory estimate of increase in plant height but does not reflect the efficiency of elongation.

To evolve a method for precise estimation of elongation efficiency in deepwater rice, several mathematical equations were tested on actual data collected for total plant height in an experiment with 13 varieties. The model that gave the best results was selected, which provides a satisfactory index for comparison of elongation efficiency of different varieties.

THE BASIC HYPOTHESIS

Early start of elongation, rapid rate, and early attainment of maximum elongation to enable the plant to reach the water surface after submersion were taken as essential ingredients for elongation efficiency. The assumption was then made that in the event

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of 100% efficiency of elongation in any variety, all the plants' tillers would surface simultaneously on the earliest day, and elongation efficiency index shall be 1.0. In essence, the earlier the start of elongation, the faster the rate and the shorter the span of time, the closer to 1 the elongation efficiency index will be and vice versa.

THE FORMULA

A formula was derived from elongation measurements of 13 varieties. The height of submerged plants was recorded every 48 hours in rising water of 65-cm depth up to 10 days until all varieties that elongated emerged and began to grow normally. Varieties that did not elongate died. The elongation efficiency index is:

$$\text{Elongation efficiency index} = \frac{X_1(N-0) + X_2(N-2) + X_3(N-4) + X_4(N-6) + X_5(N-8)}{N\ (\text{maximum elongation observed})}$$

where X_1, X_2, X_3, X_4, and X_5 stand for actual elongation in centimeters during the first, second, third, fourth, and fifth observations and N is the total time in days from submersion to the last observation.

The validity of the formula was tested on the assumption that for 100% elongation efficiency, all the plants of a variety should attain maximum elongation by the first observation for an elongation efficiency index of 1.0. As seen in Table 1 entry 6 has a maximum elongation of 94 cm at the end of 10 days. Although maximum elongation of 94 cm is hypothetically recorded for the first, second, third, fourth, and fifth observations in Table 2, it is observed that elongation efficiency index, as calculated by the equation, comes to 1.0, 0.8, 0.6, 0.4, and 0.2 respectively, as follows:

$$\text{First observation} = \frac{94(10-0) + 0(10-2) + 0(10-4) + 0(10-6) + 0(10-8)}{10 \times 94} = 1.0$$

$$\text{Second observation} = \frac{0(10-0) + 94(10-2) + 0(10-4) + 0(10-6) + 0(10-8)}{10 \times 94} = 0.8$$

$$\text{Third observation} = \frac{0(10-0) + 0(10-2) + 94(10-4) + 0(10-6) + 0(10-8)}{10 \times 94} = 0.6$$

$$\text{Fourth observation} = \frac{0(10-0) + 0(10-2) + 0(10-4) + 94(10-6) + 0(10-8)}{10 \times 94} = 0.4$$

$$\text{Fifth observation} = \frac{0(10-0) + 0(10-2) + 0(10-4) + 0(10-6) + 94(10-8)}{10 \times 94} = 0.2$$

The results thus indicate that every 48 hours delay in attainment of the maximum required growth of 94 cm resulted in a simultaneous reduction of 0.2 in the elongation

Table 1. Actual elongation of 13 varieties after submersion for 10 days.

Entry no.	Actual elongation (cm/48 h) I	II	III	IV	V	Total (cm)	Elongation efficiency index
1	2	11	21	10	1	45	0.29
2	3	9	6	3	8	29	0.18
3	13	25	28	14	6	86	0.60
4	3	27	32	7	5	74	0.51
5	5	20	32	11	3	71	0.48
6	8	23	39	10	14	94	0.60
7	6	21	39	8	7	81	0.54
8	4	23	4[illegible]	6	6	82	0.55
9	3	4	17	1	1	26	0.18
10	6	15	52	6	3	82	0.56
11	4	0	15	4	3	26	0.16
12	3	2	18	4	2	29	0.19
13	2	0	3	1	2	8	0.05

Table 2. Hypothetic elongation of 10 varieties after submersion for 10 days.

Entry no.	Hypothetic elongation (cm/48 h) I	II	III	IV	V	Total (cm)	Elongation efficiency index
1	94	0	0			94	1.0
2	0	94	0	0	0	94	0.8
3	0	0	94	0	0	94	0.6
4	0	0	0	94	0	94	0.4
5	0	0	0	0	94	94	0.2
6	60	25	9	0	0	94	0.91
7	60	15	19	0	0	94	0.81
8	60	10	9	15	0	94	0,84
9	40	30	9	10	5	94	0.79
10	30	30	9	10	15	94	0.70

efficiency index. The equation, therefore, fully accounts for the early start and early attainment of maximum elongation. Likewise, speed of elongation is accounted for, as evident from the elongation efficiency index worked out for entries 6-10 in Table 2. Entries 6 and 7 attained maximum elongation on the same dates; entry 6, however, obtained a higher index (0.91) because it elongated faster. When the speed of elongation further decreased, as for entry 8, the index decreased to 0.84. That decrease in speed of elongation, which results in a decrease in elongation efficiency index, is further established from the results of entries 9 and 10.

The results thus show that early commencement and higher speed of elongation,

and early attainment of maximum elongation are well reflected in the elongation efficiency index.

RESULTS AND DISCUSSION

Table 1 presents the actual data obtained from an experiment with 13 varieties. The elongation efficiency indexes worked out with the formula provide evidence that there are wide differences among varieties in respect elongation efficiency. All varieties with an elongation efficiency index greater than 0.48 managed to reach the water surface. Varieties with index values between 0.05 to 0.29 remained submerged and died.

The formula thus provides a satisfactory index for assessment of elongation efficiency of different varieties and may be used for a precise estimate of elongation efficiency of any number of varieties grown in similar conditions. The formula's added advantage is that the data on plant height can be collected at shorter intervals and can be used to estimate the index value. It may also be used to assess the elongation efficiency of different varieties in normal deep water for any span of time desired. To do that, the formula may be expanded to the desired number of observations.

SUMMARY RESULTS OF AN INTERNATIONAL COLLABORATION ON SCREENING METHODS FOR FLOOD TOLERANCE

D. HilleRisLambers and B. S. Vergara

SUMMARY

Eighteen cooperators tested a uniform set of 12 rice varieties for submergence tolerance, using their own methods. Tests differed in the ability to distinguish clearly between tolerant and susceptible varieties. Results varied among tests but were consistent in identifying FR13A, Kurkaruppan, and two Thavalu entries as best performers, especially at seedling ages 21 days and more combined with water depths more than 80 cm (maximum depth tried was 155 cm). Water depth and turbidity of the water were clearly two of the most important factors that increased the severity of the tests and enhanced differences between tolerant and susceptible groups.

This report concludes the program proposed during the 1978 Deepwater Rice Workshop in Calcutta (Vergara et al 1979). The full background of the experiment can be found in this reference, but the following may sufficiently introduce the results.

At the time the program was proposed, various tests on submergence tolerance in rice had been reported. Unfortunately, those tests used different methods and test entries, so that comparison of results and methods was difficult.

The objectives of the collaborative effort reported here were 1) to lay a basis for comparison of testing methods, 2) to get information on the test entries, and 3) to provide interested researchers with a common set of reference varieties for research and breeding work.

MATERIALS AND METHODS

Experimental materials consisted of 12 rice varieties as listed in Table 1. The methods were left to the cooperators and are summarized in Table 2.

Plant breeder, Plant Breeding Department; and plant physiologist, Plant Physiology Department, IRRI, Los Banos, Laguna, Philippines.

Table 1. Percentage of submergence survival of 12 entries in 18 tests.

Variety	Submergence survival (%)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Highly tolerant																		
FR13A	80	50	54	100	120	98	30	55	93	60	100	80	30	100	25	100	100	65
Kurkaruppan	50	25	96	69	104	100	30	55	80	52	94	68	40	178	15	98	100	41
Thavalu 15314	20	20	86	87	70	71	15	20	71	32	99	75	0	100	10	99	100	61
Thavalu 15325	10	10	77	22	95	92	0	30	66	50	88	55	15	134	15	96	100	58
Av	40	26	79	70	98	90	19	40	78	48	95	70	21	128	16	98	100	56
Medium tolerant																		
BKN6987-161-3	0	40	23	12	30	30	15	55	60	30	82	55	35	122	15	98	100	68
BKN6986-108-3	40	0	32	26	22	50	5	15	46	30	82	40	0	100	10	93	98	55
IR33	0	0	8	14	52	26	0	0	44	29	81	60	0	100	0	100	100	59
Nam Sagui 19	0	0	16	14	47	16	5	5	64	38	56	50	40	78	45	76	90	46
Av	10	10	21	17	38	31	6	19	54	32	75	51	19	100	18	92	97	57
Low tolerant																		
BKN6986-66-2	20	0	11	23	24	40	5	15	41	30	68	46	35	78	15	97	98	45
SML Temerin	0	0	18	34	8	16	5	15	40	41	44	48	5	100	20	91	98	56
IR42	0	0	10	4	20	21	0	5	38	32	65	50	5	128	10	97	98	66
KDML 105	0	0	14	4	21	38	10	0	46	29	51	44	0	89	5	91	96	58
Av	5	0	13	16	18	29	8	15	41	33	57	47	11	99	12	94	98	56

Table 2. Characteristics of 18 tests used to test submergence tolerance of 12 rice varieties.

Characteristic	Test no.								
	1	2	3	4	5	6	7	8	9
Age at submergence[a]	12	13	44	21	25	39	10	10	21
Submergence duration	6	6	9	22	10	7	6	8	8
Water depth and quality[b]	40	35	155	80	115	115	30	35	32
Relative survival rate	53	5.2	4.6	4.2	3.5	3.0	2.7	2.4	1.6
F-value[c]		1.5	26.2**	51.5**		14.4**		2.5	2.1
	10	11	12	13	14	15	16	17	18
Age at submergence[a]	21	44	21	10	15	10	44	44	21
Submergence duration	12	9	10	6	7	6	9	9	6
Water depth and quality[b]	32	130	32	30	50	30	105	90	30
Relative survival rate	1.5	1.4	1.4	1.4	1.3	1.1	1.1	1.0	1.0
F-value[c]	3.1*	22.8**	5.5**				1.6	11.5**	

[a]Values underlined indicate that the tests were transplanted. Other tests were direct-seeded.
[b]Underlined values indicate turbid water [c]**Significant at the 5% level, * significant at the 1% level.

Results of the tests

Table 1 gives varietal survival percentage for all tests except for test 19 which had incomplete data.

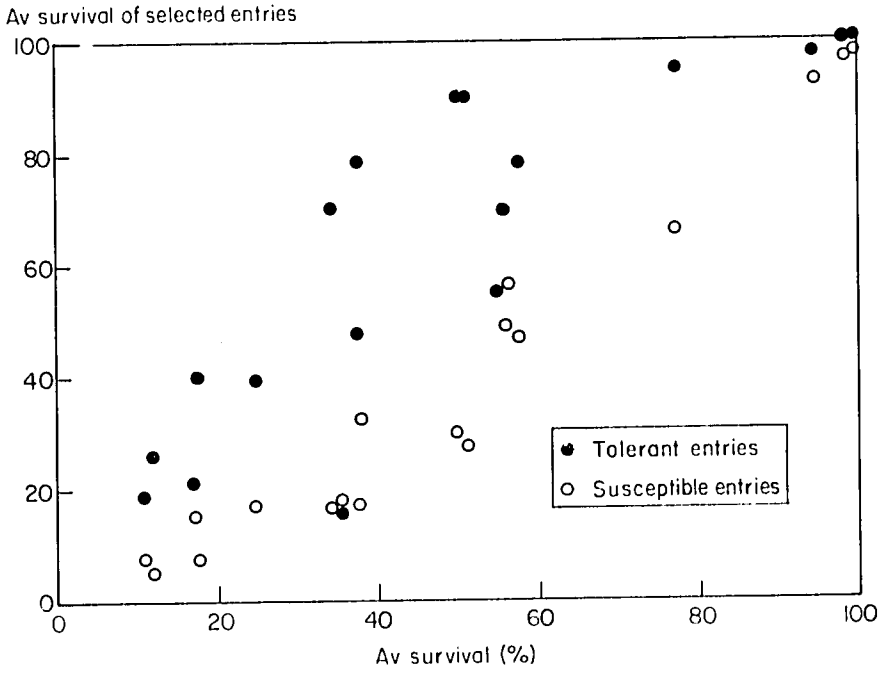
Results varied among tests but were fairly consistent in pointing out FR13A, Kurkaruppan, and the two Thavalu entries as the best performers. Varieties in the table have been grouped on the basis of their average performance.

Although survival percentages differed, some tests left appreciable numbers of plants of both highly tolerant and low tolerance entries alive, whereas other tests left only the few tolerant varieties with survivors. Figure 1 gives the average survival percentages for the 4 highly tolerant and 8 other varieties, plotted against average survival percentages of the test entries.

The difference in survival percentage between tolerant and susceptible varieties influences the efficiency of screening programs, especially bulk screening without replication of entries. In Table 2, the relative survival rate is the ratio between the average tolerant entry survival percentage and that of all other varieties.

Table 3 predicts, on the basis of the relative survival rate of tolerant entries, how many generations of bulk selection it would take to increase the proportion of highly tolerant plants in a heterogenous population from 50% to 60, 70, 80, and 90%. A relative survival rate of 3 is minimal for fast increase of the proportion of submergence tolerance when screening bulk hybrid populations.

For those tests with sufficient replication, F-test values are given. High F-



1. Average survival percentage of 4 submergence-tolerant entries (•) and 8 susceptible entries (o) in 18 tests, plotted against average survival percentage of all test entries.

Table 3. Number of generations of bulk selection at various relative survival rates to increase submergence-tolerant plants in a population from 50% to 60, 70, 80, and 90%.

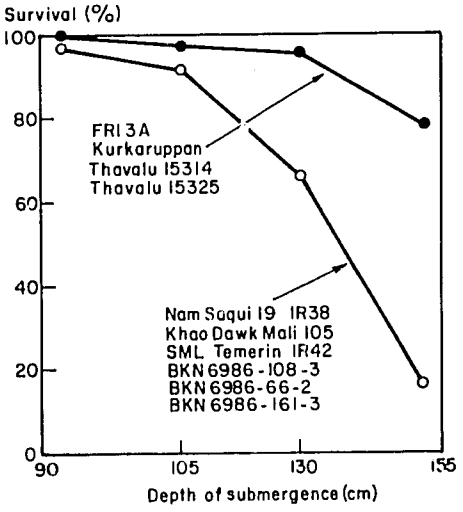
Relative survival rates	Generations (no.) of bulk selection			
	60%	70%	80%	90%
1.1	4	9	15	24
1.2	3	5	8	13
1.3	2	4	6	9
1.4	2	3	5	7
1.5	1	3	4	6
1.6	1	2	3	5
1.7	1	2	3	5
1.8	1	2	3	4
1.9	1	2	3	4
2.0	1	2	2	4
3.0	1	1	2	2

values were found in several tests (Table 2) using water depths of 80 cm or more. Test 16 combined a high F-value with relative survival rate of only 1.0, indicating that such effects as it (accurately) measured were not related to the submergence tolerance of most of the other tests.

Many tests also gave seedling height before and after submergence. A variety of opinion exists as to the relevance of the increase in seedling height during submergence, with some researchers indicating that submergence-tolerant varieties have a higher increase in seedling height than submergence-susceptible varieties, and others saying the opposite. Table 4 suggests that both opinions may be justified.

Table 4. Average percentage of seedling height increase during submergence in tolerant (R) and susceptible (S) varieties in turbid- and clear-water tests.

Water quality	Experiment no.	Av seedling height increase (%)	
		T varieties	S varieties
Turbid	3	12	-15
	5	-9	-31
	10	26	8
	16	32	21
	17	40	40
Av		20	5
Clear	1	18	41
	2	3	30
	4	46	79
	8	19	21
	14	94	140
Av		36	62



2. Survival after submergence of four submergence-tolerant varieties (top) and of a group of eight varieties without such distinction at four water depths. IRRI, 1980.

The average percentage of increase in seedling height during submergence was lowest for susceptible varieties in tests using turbid water, and highest in the same group in tests using clear water.

Figure 2 (from IRRI 1980) summarizes results from tests 3, 11, 16, and 17. Identical treatments were used except depth. The role of water depth in reducing survival of all entries but damaging the submergence-tolerant entries relatively less is clear. Relative survival rate and thus the relevance of the test increased as expressed in terms of FR13A, Kurkaruppan, and the Thavalu entries as the better survivors.

CONCLUSIONS

1. Most tests identified FR13A, Kurkaruppan, and the Thavalu accessions as the most tolerant varieties. Those tests that did not were the ones with low precision and/or low overall severity.
2. Tests combining high relative survival rate of the above varieties (relevance) with high F-values (precision) were done in water depths of at least 80 cm deep and seedling stage at least 21 days (direct seeding).
3. Water depth and turbidity were identified as important factors affecting behavior and survival of entries. For clear separation of susceptible and tolerant entries, a water depth of 1 m and seedling age of 3-4 weeks are recommended.
4. Submergence tolerance is of finite duration for both susceptible and tolerant varieties. The difference between the categories is that in tests of increasing severity (depth, duration, turbidity), the tolerant varieties get destroyed later and at a relatively slower rate than do the susceptible ones. The researcher will

have to adjust the severity depending on whether he wants to characterize varieties and stable lines for high, low, and intermediate tolerance (low-severity test indicated) or whether he wants to submerge an F_2 population and be left with the highest possible proportion of submergence-tolerant survivors and the lowest possible proportion of low-tolerance escapes (high-severity test indicated).

5. Several methods used by cooperators can effectively test submergence tolerance, with the severity of the test subject to manipulation by the researcher depending on degree of tolerance sought.

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DEEPWATER RICE IN INDIA: PROBLEMS AND PROSPECTS

U. S. Singh

SUMMARY

Crop failure, low production, and low soil fertility are recurrent in India's deep-flooded rice lands. Farmers' average yield is about 0.7 t/ha compared to 4-8 t/ha often obtained in experimental plots. Among the factors limiting yield, lack of suitable varieties and agronomic practices are important. The deepwater and floating rices commonly face prolonged submergence in water more than 6 m deep between June and December or 1-10 days of flash flood submergence 1-6 times during June-October. Research to develop varieties and technology suitable for deepwater and flood-prone water regimes is under way.

Rice crop failure or low production is a recurrent feature of India's flood-prone lands. The average yield of deepwater and flood-prone rice in India is about 0.7 t/ha, compared to 4.0 t/ha obtained in experimental plots of research stations. Even improved rices have failed to produce high yields.

Deepwater rice yields range from 0.4 to 0.5 t/ha in Uttar Pradesh, 0.5 to 1.0 t/ha in Bihar, 0.4 to 0.8 t/ha in Orissa, 1.0 to 1.2 t/ha in West Bengal, 0.8 to 1.0 t/ha in Assam and Andhra Pradesh, 1.0 to 1.5 t/ha in Tamil Nadu, and 1.2 to 1.5 t/ha in Kerala.

The great challenge in India is to increase these present yields sixfold to twelvefold. The low yields of today's deepwater rices in India are due to lack of suitable variety and improved cultural practices.

At a 1974 international seminar on deepwater rice in India, it was stressed that breeding work should be accelerated for deepwater rices and with greater emphasis on improved plant types tolerant of submergence and drought, resistant to insect pests and diseases, and more capable of producing roots and aquatic tillers. The seminar stressed that varieties with ideal plant type should be developed to combine the capacity of maximum number of panicles per plant, maximum fertile spikelets per panicle, and maximum weight of 1,000 grains.

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It is important to develop varieties and cultural practices for flooding, from slow and gradual rise of water (1-10 cm/day) to more than 6 m and for sudden flash flood of as much as 100-cm depth for varying durations.

PROBLEMS OF DEEPWATER RICES IN INDIA

Deepwater and floating rices in India are grown in areas flooded by rivers such as the Ghaghara, Ganges, Gandak, and Kosi in Uttar Pradesh, Bihar, and West Bengal; in the basins of the Baitarni, Brahmani, Mahanadi, and Rishikulya in Orissa; in the deep valleys of the Brahmaputra and Surma in Assam; in the catchments of the Krishna and Kavery in Andhra Pradesh and Tamil Nadu; and in the coastal and Kuttanad areas of Kerala and face both soil and climatic problems.

Edaphic problems

The pH of soils in Assam, West Bengal, and Orissa ranges from 4.5 to 7.5; that of soils in Uttar Pradesh and Bihar, from 7.0 to 8.5. The acidic soils of Assam have good nitrogen content, averaging 0.15%. The soils of West Bengal are poor in nitrogen, averaging 0.01%. Soils in other areas are intermediate in nitrogen content.

Phosphorus content is low (43 ppm P) in lateritic soils of West Bengal but high (86 ppm P) in the neutral Tarai soils of Uttar Pradesh. Likewise, potassium is lowest in lateritic soils of West Bengal and highest (0.5% K) in the alluvials of Orissa.

The submerged soils of the southern region of Andhra Pradesh, Tamil Nadu, and Kerala are alluvial and range from sandy loams to heavy clays and rich peats, from poor soils in Andhra Pradesh and Tamil Nadu to rich peat soils in Kerala. The pH ranges from 5.0 to 8.5, nitrogen from 0.04% to 0.40%, phosphorus from 43 to 36 ppm, and potassium 0.17% to 0.58%.

Climatic problems

Deepwater and floating rices are grown in India from 8°N to 30°N latitude. Average monthly temperatures are 15°C-35°C, day length is 11-13 hours with average sunshine of 4-10 hours, and rainfall is 100 cm-600 cm, during the crop life cycle. Rainfall, when erratic and unevenly distributed, causes the most difficult problem of crop submergence, which may be prolonged or as an intermittent flash flood. On the basis of water depth, deepwater areas were classified by Saran and Sahai (1979) as:

- deep (more than 100 cm depth),
- semideep (50-100 cm depth), and
- shallow (25-50 cm depth).

DEEPWATER RICE RESEARCH AND ITS ACHIEVEMENTS

According to Richharia and Govindaswami (1966) deepwater rice research in India has been conducted at Karimganj and Roha in Assam, Chinsurah in West Bengal, Cuttack in Orissa, Sabour in Bihar, Ghaghraghat in Uttar Pradesh, Pulla

and Marutera in Andhra Pradesh, Pattambi in Kerala, and Coimbatore and Adutrai in Tamil Nadu. In the recent past only experiment stations at Ghaghraghat, Pusa, and Chinsurah were involved in deepwater rice research (Saran and Sahai 1979). Research results can be summarized under crop improvement, crop production, and crop protection.

Crop improvement

Since the start of research to develop improved rice types for deepwater areas, about 50 deepwater and floating rices have been released for general cultivation in India (Table 1). All are tall types. The general features of the improved varieties with respect to plant type and yield potential follow.

Plant type. In breeding, greatest stress was put on the ability of plants to grow consistently with increase in water depth and tolerance for submergence. The deepwater areas required varieties with rapid elongation; those for flash flood areas needed submergence tolerance plus some elongating ability. Those characters were given considerable importance.

Elongating ability. Varieties that elongate up to 30 cm/day on initial submer-

Table 1. Improved deepwater and flood-resistant rices released in India.

State	Variety name		
	Deepwater (more than 1 m)	Semideep water (50 to 100 cm)	Flash flood (50 to 100 cm)
Uttar Pradesh	Jasuria Jalmagna Doodalachi	Chakia 59 Madhukar	Madhukar
Bihar	BR 14 BR 46	BR 7 BR 8	BR 13 BR 49
Orissa		Marsh 1 Marsh 2	FR 13 A FR 43 B
West Bengal	Jaladhi 1 Jaladhi 2 Dolaman Laki Badal	Chinsurah 21 Pankaj	FR 13 A FR 43 B
Assam	Habiganj 1 Habiganj 2	ARC 353-148 AR 614-258	T 2205 T 2208
Andhra Pradesh	AR 108/1 PLA 2	PLA 4	MTU 1
Tamil Nadu		CO 14 PTB 15 ADT 17	CO 17 PTB 7 ADT 12
Kerala	PTB 16	PTB 15	PTB 7

gence are now available. At the Agricultural Research Station, Ghaghraghat, it was observed that plants grown in pots that were completely submerged in rising water 65 cm deep at the age of 60 days elongated at the rate of 6.5, 12.5, 14.0, 7.0, 3.0, and 9.0 cm/day when the water rise was 3.6, 2.5, 12.0, 5.5, 2.0, and 9.0 cm/day in the 6 observations taken on alternate days. Within 12 days of submergence, the plants elongated to 104 cm, growing at almost the speed of water rise. The additional elongation during the next 17 days was 14.5 cm, in a water rise of 13.5 cm.

Correlation coefficients between water rise and elongation capacity during a 30-day submergence revealed a highly significant correlation between water rise and daily growth rate ($r = 0.70$). These results are similar to those of Datta and Banerji (1979).

In another experiment, Singh and Pandey (1981) observed that rice varieties such as Jalmagna, Nang Dumto, Boon Nahte, Saran Krahm, and several crosses in the F_6 generation had an elongation capacity of about 3.9 cm/day against the water rise of 3.7 cm/day and escaped submersion damage during 30 days. All other varieties with a slow rate of elongation (less than 3.9 cm/day) perished in water within 20 days. Varieties like Jalmagna and Nang Dumto, which elongated 5.9-6.1 cm/day during the first 10 days, elongated 2.5-3.5 cm/day during the next 10 days. Saran Krahm, Boon Nahte, and several F_6 generation crosses grew 2.1-4.1 cm/day during the first 10 days, and elongated 5.0-6.6 cm/day during the next 10-day period. During the third 10-day phase, all varieties elongated 0.9-2.3 cm/day. Thus, the elongation rate during the first 10 days was most important.

Tests with sudden recession of water level indicated that Jalmagna and Nang Dumto, which had a total height of 89 cm and 95 cm, respectively, floated on the water surface in 45 cm of water. Boon Nahte, Saran Krahm, and F_6 generation crosses, which had attained the height of 66, 69, and 44-62 cm, respectively, continued to grow erect. Within 2 days, however, Jalmagna and Nang Dumto showed signs of upward bending from the uppermost node and within a week their culms began to grow erect.

In screening 140 varieties in deep water only 24 varieties, which had an average growth of 5 cm/day or more during the 30-day period after start of flooding with 5.1 cm rise in water/day, escaped death due to submergence. All other varieties perished in water depths from 177 to 205 cm. Among the survivors, Jalmagna and 2 F_6 generation crosses exhibited the lowest elongation rate of 4.9 cm/day and 4.8 cm/day, compared to 5.1-6.6 cm/day exhibited by Nang Dumto, Boon Nahte, and other F_6 generation crosses. A highly significant positive correlation was observed between water depth and plant height ($r = 0.57^{**}$).

Varieties capable of growing in deep water made rapid growth after initial submergence, emerged from the water by 18-36 cm, and maintained equilibrium with water rise. At the end of a 1-month submergence test, the elongation rises were 31-49 cm above the water level.

Submergence tolerance. Investigations in Ghaghraghat have shown that submergence tolerance is not positively correlated with elongation ability. Rices with reduction in stem length and leaves often exhibit greater submergence tolerance than tall types. In a screening trial with 127 varieties that were submerged for a

week in 60 cm of water when seedlings were 36 days old, FR43B was most tolerant of submergence followed by a number of crosses of different generations.

Varieties that grew fast in water developed poor stems and at the end of submergence could not regain their vitality and normal growth. When the second submergence took place the varieties died. Only 80 varieties survived and had growth. They did not grow while submerged and their culms were strong.

At Ghaghraghat, under sudden submergence of about a meter, Jalmagna which elongated rapidly died earlier than Chakia 59 and Madhukar, which were unsuited for deepwater fields. Chakia 59, which has considerable submergence tolerance, survived when water rose from 80 cm to 124 cm after a heavy downpour and remained deeper than 100 cm for about 3 weeks. Chakia 59 yielded 1.4 t/ha compared to its yield of 4.2 t/ha in medium deepwater fields, in the same season.

Panda et al (1980) observed that yield declines consistently with increase in submergence from 25% to 75% of plant height. Therefore, submergence tolerance is an essential trait for success where flash floods occur.

Drought tolerance. In a pot culture experiment at Ghaghraghat, it was observed that varieties differed markedly in their drought tolerance. Jalmagna, which elongated rapidly in deep water, possessed the least drought tolerance, followed by Boon Nahte, Nang Dumto, and FR43B, which were moderately susceptible. Some F_6 generation crosses proved moderately tolerant, and IET5656, some crosses, Nam Sagui 19, Kottamalli, and Padi Ewang Jaggut were tolerant. Jalmagna plants appeared dead but recovered after application of water. The youngest leaf of all the culms dried, however, and resulted in a serious setback to the plants.

Plant character and yield potential. Varieties released for deepwater and flash-flood areas have 10-12% higher yield potential than local types but are still far behind the dwarf types in responsiveness to fertilizers. The tall, floating varieties exhibit a long lag phase between tillering and panicle initiation. During the lag, excessive leafy growth occurs and dies in water without benefiting the crop yield potential. Even semitall types such as Chakia 59 and Madhukar have relatively low yield potential due to low tillering.

Datta and Banerji (1979) observed that Jaladhi 1 and Jaladhi 2 produced aquatic tillers but those had lower grain yield than basal tillers. Similar observations have been made in the case of Jalmagna in Uttar Pradesh. Therefore, for high yield potential, the variety must have good basal tillering capacity. It is important to develop ideal plant types, which may have the essential characters for high yields under both prolonged and flash floodings (Table 2).

Crop production

When grown in various soils, climates, and conditions of submergence, a rice crop has certain essential requirements for obtaining maximum yield.

Optimum seed rate for sowing. The traditional tall deepwater varieties were grown at a 20 cm × 20 cm spacing and required 25 kg seed/ha. Today, with greater emphasis on closer spacing a higher seed rate is required. Subbiah et al (1977) determined that 44 to 60 kg/ha was the optimum seed rate for direct-sown wetland rice in Tamil Nadu. A seed rate up to 200 kg/ha, used by many farmers, may not be

Table 2. Essential genotypic characters for ideal plant types.

Nature of submergence	
Prolonged	Flash flood
Adequate drought tolerance at the seedling stage.	Adequate drought tolerance at the seedling and postflood stages.
Rapid elongating ability of stem, leaf sheath, and leaf blade.	Some elongating ability of stem, leaf sheath, and leaf blade.
Submergence tolerance for 10 to 15 days.	Adequate submergence tolerance for long periods from 10 to 20 days.
Aquatic tillering capacity to completely compensate for the loss in ground tillers.	Regeneration capacity to enable the plants damaged by floods to produce tillers.
Aquatic rooting to provide efficient absorbing system for nutrients from water.	Profuse and deep-root system for protection of plants from swift current and efficient absorbing system.
Kneeing ability to enable the plants to grow erect after recession of water level.	Erect habit to remain upright even after recession of flood.
Photosensitivity to enable the plants to flower after water begins to recede.	Photosensitivity to enable the plant to flower after the last flash of flood.
Large number of panicle productivity per unit area.	Larger number of panicle productivity per unit area.
Higher number of grains per panicle with least sterility.	Higher number of grains per panicle with least sterility.
Maximum weight of thousand grains.	Maximum weight of thousand grains.

essential for all situations.

In Uttar Pradesh, almost 50% more seed is used for broadcasting than for line sowing. Dixit et al (1979) observed that line sowing behind a plow resulted in significantly higher yield than broadcast seeding. Delayed sowing caused progressive decline in yield of deepwater rice.

Optimum spacing for transplanting. Transplanting results in better yields than line sowing. Murty and Murty (1981) observed that a 10 cm × 10 cm spacing gave maximum yield, which declined consistently with increase in spacing to 20 cm × 10 cm, 20 cm × 15 cm, 20 cm × 20 cm, respectively. This was due to decrease in productive tillers per unit area. The percentage of spikelets and weight of 1,000 grains were not influenced markedly by spacings.

Crop nutrition. Basak et al (1957) observed that compost and ammonium sulfate applied singly and in combination for an equal level of nitrogen gave a highly

significant (30%) increase in yield. Experiments have shown that in deficient soils, there is considerable benefit from phosphorus placement in the root zone of rice grown in deep water. In deepwater fields, phosphorus fertilizers should be applied at the rate of 17 kg P/ha, especially when nitrogen is applied at the optimal dose. Application of phosphorus alone may not improve yield.

Deepwater and flooded soils in India are generally rich in potassium and do not respond to its application. However, with high nitrogen and phosphorus applications about 33 kg K/ha should also be applied.

In waterlogged soils of Uttar Pradesh, nutritional problems like *Khaira* (zinc deficiency), *jhulsa* (iron deficiency), and chlorosis are common and zinc and iron sprays are generally needed. *Khaira* appears as a reddish brown pigmentation in the central portion of the leaf and later spreads on the entire lamina. The affected tissues turn papery and necrotic and the entire leaf soon collapses. Spraying the crop with 0.5% zinc sulfate helps the crop to recover.

Jhulsa was discovered for the first time in Ghaghraghat, Uttar Pradesh, in 1979. It caused seedling leaves to turn yellow and then white, and die. Application of 2% ferrous sulfate, at the rate of 1,000 liters/ha, 2-3 times depending on the intensity of chlorosis, caused complete cure of the disease and saved the seedlings from death.

Rice varieties showed considerable variation in tolerating iron deficiency and Madhukar, Chakia 59, CNL 231, IET5631, IET6208, IET6212, and IET6658 proved significantly superior to IET4087, IET4155, IET5852, IET5882, IET5889, IET5897, IET6207, IET6209, IET6271, IET5656, and Pankaj, which were most susceptible to chlorosis. Other varieties were between the two extremes.

Since 1979 iron deficiency has been observed every year and has been controlled by foliar applications of ferrous sulfate. Work on these deficiencies is in progress to determine precisely the soil factors responsible and the extent of damage caused at various intensities.

Crop protection

Deepwater and floating rices have generally shown less need for crop protection from insects and diseases than shallow-water, wetland rices. The difference is due to the peculiar conditions in which the crops grow. Stem borer, leaffolder, leafhoppers, ear-cutting caterpillars, and hispa are common insects of deepwater and floating rice.

Stem borer. This pest has caused 29% damage in West Bengal (Banerjee 1964) and 36% damage in Uttar Pradesh (Pandey et al 1981). Experiments at Ghaghraghat during 1979 and 1980 revealed that basal application of carbofuran 3 G at 1.5 kg a.i./ha at sowing followed 25 days later by 3 sprayings of 0.05% phosphamidon at 3-week intervals reduced stem borer incidence from 3.0% to 1.1% in 1979 and from 35.6% to 11.6% in 1980.

Of 37 indigenous deepwater varieties screened at Ghaghraghat 11 were resistant to stem borer (less than 1% incidence), 18 were moderately resistant (1-5% incidence), and the rest were susceptible (30-35% incidence). Of 61 floating rices, 23 were resistant, 17 moderately resistant, and the rest were susceptible (Chaudhary et al 1981).

Leaffolder. Leaffolder caused a 27% loss at Ghaghraghat. Basal application of phorate at 1 kg a.i./ha at sowing followed by sprayings of 0.03% phosphamidon 4, 7, and 10 weeks after sowing reduced the infestation from 13% to 7% (Upadhyaya, pers. comm.).

Leafhoppers. Leafhoppers are common in deepwater rice and can be controlled by the dusting of 25 kg BHC (5%)/ha (Srivastava and Saxena 1960).

Hispa. Banerjee (1964) observed that hispa is found in West Bengal, Orissa, Bihar, Andhra Pradesh, and Tamil Nadu but is of little importance in Uttar Pradesh. It can be controlled by 25 kg BHC (5%)/ha (Srivastava and Saxena 1960).

CONCLUSION

Farmers in India do not have improved technology for increasing deepwater rice yields. Research summarized here suggests that modest varietal improvement, primarily as selections from farmers' varieties, has been achieved. Research to hybridize rices to improve plant characters and yields for various flooding regimes is under way. Cultural practices are being evaluated and modified to suit a range of flooding regimes and growing conditions in deepwater and floating rice areas.

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PRODUCTION TECHNOLOGY

FERTILIZER MANAGEMENT FOR DEEPWATER RICE SOILS

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SUMMARY

Fertilizer management on a deepwater rice soil was studied at Prachinburi Deepwater Rice Experiment Station, Thailand. The station has a nitrogen- and phosphorus-deficient acid sulfate soil and floodwater rises to 120 cm in September. Rice responded well to phosphorus at a 16 kg P/ha rate.

The ability to elongate with rising floodwaters determined the success or failure of different genotypes, and elongation was affected by nutrient availability. For survival in deep water the promising lines required a higher fertilizer level than the traditional floating varieties and the latter performed better at a low fertility level. However, once the new rices, such as RD19, had sufficient fertilizer for survival they appeared able to respond to further increments of fertilizer better than the traditional varieties. RD19 yield increased up to the highest level of nitrogen used (75 kg N/ha), whereas optimum nitrogen level was lower for traditional varieties other than Nahng Kaew.

Deepwater rice soils are enriched by silt deposits carried by rivers (Hasanuzzaman 1974), but deepwater rice yields are relatively low because fertilizer management is not effective and traditional rices are not fertilizer responsive. Roy (1974) found that the response of deepwater rice to complete (NPK) fertilizer varied according to soil characteristics, and that some negative responses to fertilizer were due mainly to the high nutrient contents of the silt deposited by annual flooding. Sen (1974) reported that farmers do not usually apply any fertilizer because plant nutrients available in floodwater and deposited in the soil fulfill the needs of deepwater rice.

Jackson and Vergara (1979) posed the question "Do the new deepwater-tolerant types respond to fertilizer better than the older varieties?" Our objectives were to answer the question and to see if there is any suitable fertilizer management that can improve rice yield in the deepwater rice soils.

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MATERIALS AND METHODS

Our experiments were in a deepwater rice area at the Prachinburi Rice Experiment Station, about 135 km east of Bangkok. Water in the area accumulates rapidly to a depth of about 120 cm.

Soil at the experimental site

The soils belong to the Rangsit series. The soil texture is heavy clay. Soil chemical analyses, according to Srisen and Wisit (1980), were: pH (H_2O) 4.32, pH (KCl) 3.25, organic matter (%) 2.83, P (ppm P, total) 260, P (ppm P, Bray II) 3.1, hot concentrate $HClO_4$ extractable K (%) 0.81; extractable Fe (%) 2.03; extractable Mn (ppm) 114, total acidity (meq/100 g) 8.6, Al 1 NKCl (meq/100 g) 4.7, CEC (meq/100 g) 23.75, base saturation (%) 42.63, extractable cation (meq/100 g): K 0.55, Ca 4.25, Mg 3.57, Na 1.93.

Field tests of promising lines

A series of 3 experiments was conducted at Prachinburi in 1978, 1979, and 1980. The experiment was laid out in a split-plot design with four replications. Fertilizer rates (0-0-0, 0-16-0, 37-16-0, and 75-16-0 kg NPK/ha) were the main plots, varieties the subplots. Rice was broadcast-seeded at the time of basal fertilizer application.

Rock phosphate (8.4% available P_2O_5) was applied basally before the last land preparation. Nitrogen applications for the 1978 and 1979 cropping seasons were split, half at 30 days after seed germination and half when water in the field was 30 cm deep.

In the 1980 cropping season nitrogen applications were modified for both sources and timings. Nitrogen was split into 3 equal doses — at 30 days after seed germination, at 30-cm water depth, and at panicle initiation. Nitrogen sources were ammonium sulfate (20% N) for the first and second applications, and urea supergranules for the third application.

Different promising rice lines were used each year. In the 1978 experiment the rice lines and varieties were:

- RD17, cross IR262/PG56, 120 cm high, slight elongation ability, flowered in 120 days.
- BKN6986-81-5, cross IR262/PG56, 180 cm high, good elongation ability, flowered on 11 November.
- RD19, cross IR262/PG56, 145 cm high, medium elongation ability, flowered on 18 November.
- BKN6986-161-3, cross IR262/PG56, 120 cm high, medium elongation ability, flowered on 6 November.
- Tapao Gaew 161 (check variety), recommended native variety for deepwater areas, flowered on 9 November.
- Nahng Kaew (check variety), native variety grown in deepwater areas, flowered on 19 November.

For the 1979 experiment, promising rice lines and checks used were:

- SPR7233-44, cross LMN111/C4-63, 195 cm tall, good to medium elongation

ability, flowered on 28 November.
- SPR7292-8, cross NKG/IR648, 195 cm high, good to medium elongation ability, flowered on 18 November.
- RD19
- BKN6986-161-3
- Leb Mue Nahng 111 (check variety), recommended native variety for deepwater areas, 215 cm high, flowered on 16 November.
- Thevada, native variety grown in deepwater areas, 195 cm high, good elongation ability, flowered on 10 November.

In 1980 the following were used:
- SPR7233-44
- RD19
- Leb Mue Nahng
- HTA7205-11, cross RD1/wild rice, 210 cm high, elongation ability, flowered on 18 November.
- BKN6986-28-1, cross IR262/PG56, 160 cm high, medium elongation ability, flowered on 11 November.
- SPR7299-2

Effect of source and time of nitrogen fertilizer

Two separate experiments in 1980 were on an acid sulfate deepwater rice soil at Prachinburi. One used RD19 and the other used Leb Mue Nahng 111. The experiments were laid out in a randomized complete block design with three replications. Rice was broadcast-seeded on dry soil after the last land preparation. The 10 treatments in each experiment are shown in Table 1. Superphosphate (16 kg P/ha) and potassium chloride (31 kg K/ha) were applied basally and incorporated before the last land preparation in all treatments. Nitrogen treatments are detailed in Table 1.

RESULTS

Field tests of promising rice lines

1978 season. Grain yields for 1978 are shown in Figure 1. The results show that, in general, without fertilizer only RD19 and the two native varieties — Tapao Kaew 161 and Nahng Kaew — survived but they gave extremely low yields, which did not statistically differ from each other.

Phosphorus applied at 16 kg/ha increased grain yield of all rices significantly. BKN6986-81-5 and RD17 had significantly lower yields than the other rice lines and varieties.

Nitrogen added to phosphorus (37-16-0) increased grain yields of Nahng Kaew, RD19, and BKN6986-161-3 compared to the 0-16-0 rate. The grain yield of Nahng Kaew and RD19 again increased (it reached 2.3 and 2.1 t/ha) when another increment of nitrogen was added (75-16-0).

Two other lines showed some response to the increased nitrogen levels, but gave lower yields. On the other hand, Tapao Gaew 161 and RD17 responded only to phosphorus application at 0-16-0. RD17 had a much lower grain yield than Tapao

Table 1. Description of 10 treatments in the study of the effect of source and time of nitrogen fertilizer application on deepwater rice. Prachinburi Experiment Station, Thailand, 1980.

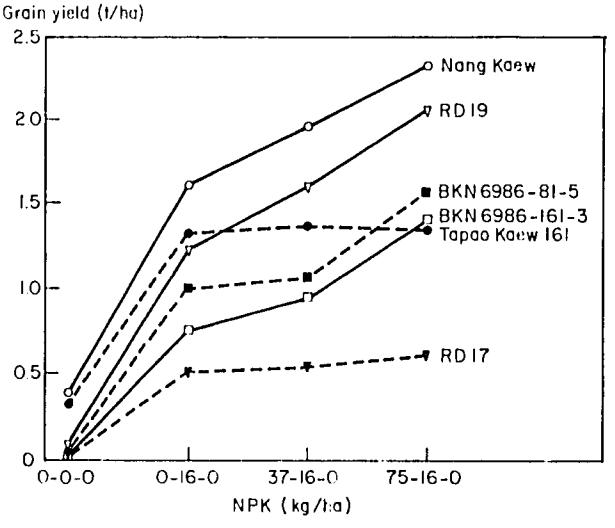
Treatment	Nitrogen (kg/ha)		Source and time of application[a]			
	RD19	LMN 11	BI	30 DE	30 CWD	PI
1	0	0				
2	75	50		(SGU)	(SGU)	
3	75	50		(SGU)	-	(SGU)
4	75	50		(SGU)	(SGU)	(SGU)
5	75	50		(U)	(U)	
6	75	50		(U)	(U)	(SGU)
7	75	50	(SGU)		(SGU)	(SGU)
8	75	50	(SGU)		(SGU)	
9	75	50	(SGU)			(SGU)
10	75	50	All (SGU) at BI			

[a]BI = basal and incorporated, DE = days after seedling emergence, CWD = cm of water depth, PI = panicle initiation, SGU = supergranule urea, U = ordinary urea (45% N). Within treatments applications were equally split.

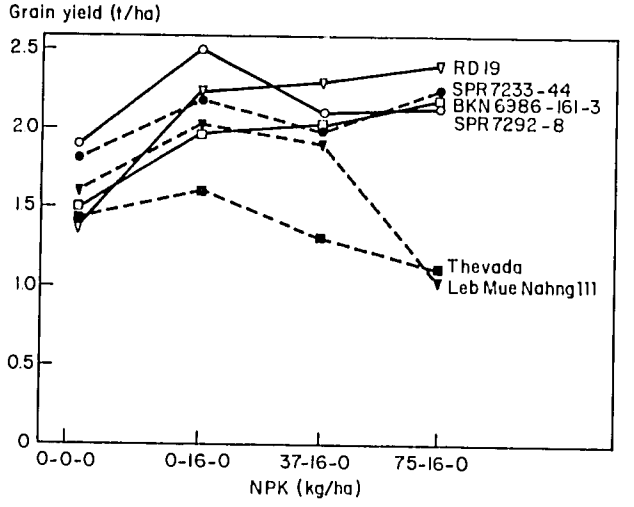
Gaew 161.

1979 season. Grain yields for 1979 are shown in Figure 2. Without fertilizer the semidwarf line RD19 and a native variety, Thevada, survived but at significantly lower grain yields than SPR7292-8. At the 0-16-0 treatment, all except Thevada gave significant yield increases due to phosphorus addition. SPR7292-8, SPR7233-44, and RD19 gave grain yields of 2.5, 2.2, and 2.2 t/ha.

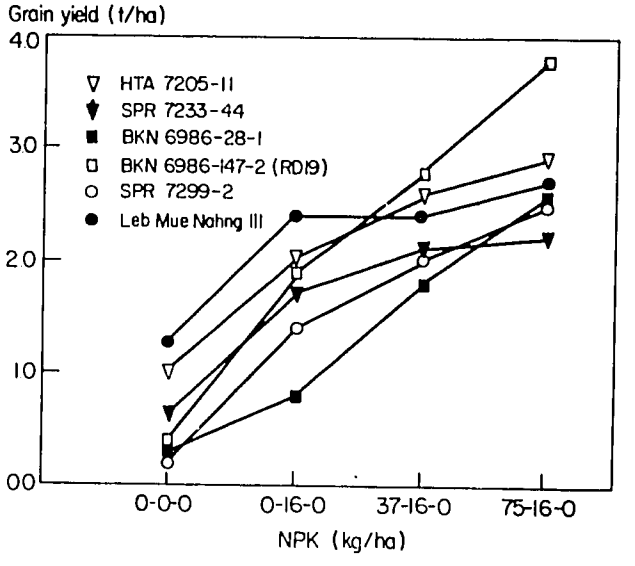
When nitrogen was added to phosphorus (37-37-0 and 75-16-0), only RD19 showed a slight nitrogen response. The rest showed no positive response, and the



1. Yield of promising rice lines and native varieties as affected by different fertilizer levels in acid sulfate deepwater soil, Prachinburi, Thailand, 1978.



2. Yield of promising rice lines and native varieties as affected by different fertilizer levels in acid sulfate deepwater soil, Prachinburi, Thailand, 1979.



3. Yield of promising rice lines and native varieties as affected by different fertilizer levels in acid sulfate deepwater soils, Prachinburi, Thailand, 1980.

two native varieties showed a negative nitrogen response.

1980 season. Grain yields for 1980 are shown in Figure 3. There was a rapid rise of floodwater to 120-cm depth 2 months after seeding. Without fertilizer only HTA7205-11 (semifloating plant type) and Leb Mue Nahng 111 (true floating type) survived and yielded 1.0 and 1.3 t/ha. All other entries elongated poorly and many rice plants were killed. Among the entries in the 0-16-0 treatment, HTA7205-11 and Leb Mue Nahng 111 outyielded all other entries at 2.1 and 2.4 t/ha. The yield of RD19 continued to increase with additional fertilizer and gave highest yields (2.8 and 3.8 t/ha) in the 37-37-0 and 75-37-0 treatments. RD19 was followed by HTA7205-11 and Leb Mue Nahng 111. All entries were highly

responsive to nitrogen and potassium. Both the negative varieties and the promising lines responded to the highest nitrogen level.

Effect of sources and time of nitrogen fertilizer applications

The results of the experiment on source and time of nitrogen application are shown in Table 2.

For RD19, the check yield was a low 0.9 t/ha. Supergranule urea applied all at basal and incorporated (treatment 10), and the split applications half basal and incorporated and half at 30-cm water depth (treatment 8), and half basal and incorporated and half at panicle initiation (treatment 9) gave highest yields.

For Leb Mue Nahng 111 split application of supergranule urea with half basal and incorporated and half at 30-cm water depth (treatment 8) significantly increased yield — 56.4% over that of the check, even though the check yield was already high (Table 2).

DISCUSSION

In the 1978 cropping season there was a rapid rise of floodwater to 120-cm depth 2 months after seeding. Because the acid sulfate soil is nitrogen- and phosphorus-deficient all entries were highly responsive to applied nitrogen and phosphorus, more so to phosphorus. Without fertilizer the growth of all rices was inhibited and only the true floating type survived.

Table 2. Effect of source and time of nitrogen fertilizer application on yield of deepwater rice in acid sulfate soil. Prachinburi, Thailand, 1980 wet season.

Treatment	Source and time of application[a]				Grain yield[b] (t/ha)	
	BI	30 DE	30 CWD	PI	RD19	LMN 111
1					0.9 d	2.3 c
2		(SGU)	(SGU)		1.9 bcd	3.0 b
3		(SGU)		(SGU)	2.4 abc	3.4 ab
4		(SGU)	(SGU)	(SGU)	2.4 abc	3.1 ab
5		(U)	(U)		2.7 abc	2.9 bc
6		(U)	(U)	(SGU)	1.8 cd	2.8 bc
7	(SGU)		(SGU)	(SGU)	2.8 abc	3.0 ab
8	(SGU)		(SGU)		3.0 a	3.7 a
9	(SGU)			(SGU)	3.0 a	3.1 ab
10	All (SGU) at BI				2.9 ab	2.8 bc
			Average		2.4	3.0
			CV(%)		23.6	12.3

[a]BI = basal and incorporated, DE = days after seedling emergence, CWD = cm of water depth, PI = panicle initiation, SGU = supergranule urea, U = urea ordinary (45% N). Within treatments applications were equally split. [b]Any two means followed by the same letter are not significantly different at the 5% level.

All the promising lines elongated poorly and many plants were killed. Although true floating varieties were less affected by deep water than hybrid rice lines, RD19 did not show a significantly lower yield than Nahng Kaew at high fertilizer rates. RD17, on the other hand, is a dwarf variety with slight elongation ability and did not show any response to nitrogen fertilizer application at the 120-cm water depth.

In the 1979 cropping season, some rice lines and varieties used in the 1978 experiment were replaced because they showed significantly lower yields than the older varieties. In 1979 all entries survived, even without fertilizer, in 120-cm water depth. This was due to the slow rise of floodwater after seeding, which allowed the plants to elongate. All entries except Thevada, the local semifloating variety, responded to phosphorus.

Although the acid sulfate soils contain little nitrogen, the low responses are puzzling. In the previous season, with similar water depth and fertilizer application, all entries except Tapao Kaew 161 responded to up to 75 kg N/ha. The second nitrogen fertilizer topdressing application 2 months after seed broadcasting at 30-cm water depth was probably too early and resulted in nitrogen starvation at later stages of plant growth. This appeared to be the only practical time of application, however, for a farming situation where the water level cannot be controlled. The fertilizer application was modified for both source and timing of fertilizer application in the 1980 experiment.

In 1980, urea supergranule fertilizer was used instead of ordinary urea. This provided the possibility of supplying nitrogen for deepwater rice at the panicle initiation stage. Again there was a rapid rise of floodwater. Water level measurements during the 1980 wet season at Prachinburi (Kupkanchanakul et al 1981) showed that the peak depth was 15 September with a maximum water depth of 110 cm and maximum 10-day increment of 43 cm. Many plants elongated poorly and were killed. However, all entries were highly responsive to phosphorus and to nitrogen (up to 75 kg N/ha) in contrast to the second season experiment, which showed a nitrogen response to up to 37 kg N/ha only. This may be partially explained by the beneficial effect of the urea supergranule treatment applied at the panicle initiation stage. Whether the yield increase is economically attractive will depend on the price of the urea, but the yield for each unit of nitrogen applied is high. With 75 kg N/ha, RD19 yielded 3.8 t/ha — 50 kg grain/kg N. It may be concluded that hybrid rice lines have a potentially greater response to fertilizer than the traditional varieties. However, to get more conclusive results, the experiment is continuing at the same site.

The experiment on source and time of nitrogen application indicated that some previous concepts of fertilizer supply to deepwater rice may need to be reconsidered. Nitrogen is commonly applied about 30 days after seedling emergence, but this experiment showed good response to incorporation of nitrogen at seeding time. Best yields for both RD19 and LMN111 were obtained with half the supergranule urea fertilizer incorporated at seeding and half applied at 30-cm water depth. This system of fertilization has potential advantages in ease of operation, such as plowing in seed and fertilizer together and making the second application before the water is too deep.

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DISCUSSION

FRANCIS: Are the original roots still functioning at the time the fertilizer is taken up at panicle initiation or, has the function of nitrogen absorption been taken over by aquatic roots?

JUGSUJINDA: Based on results by other workers at this workshop, both the aquatic roots and the original roots can absorb nitrogen equally. My field experiments do not show clear evidence.

SYARIFUDDIN: What characteristics or the part of the rice plant are affected by fertilizer application?

JUGSUJINDA: It depends on the time of fertilizer application and the stage of rice growth. From my observation, fertilizer application at sowing improved stand establishment; at 30 cm of water depth fertilizer improved elongation ability. The yield effect of fertilizer application at panicle initiation is not clear.

EFFECT OF AGRONOMIC PRACTICES ON TILLERING AND YIELD OF DEEPWATER RICE

T. Kupkanchanakul, B. S. Vergara,
and K. Kupkanchanakul

SUMMARY

Basal nitrogen application and attention to seed rate for high initial plant density, more vegetative tillers per unit area, and taller plants before the rise in water level led to more surviving tillers at maximum water level, greater leaf area index, and greater dry matter production, which resulted in more panicles per unit area and higher grain yield.

In deepwater rice-growing areas, the water level, including onset of increase, rate of increase, and maximum depth is the most important barrier that limits rice yield. Earlier studies indicated that deep water reduced tiller number by inhibiting tiller production and caused death of the young submerged tillers and ultimately resulted in low panicle number. Aside from the expensive step of improving drainage, which seems to be impossible in most deepwater rice-growing areas, varietal improvement and agronomic practices are the only means available to increase grain production from deepwater rice.

A series of experiments was conducted at IRRI and at the Huntra Rice Experiment Station, Thailand, to study varietal differences and the influence of cultural practices on tillering.

VARIETAL DIFFERENCES IN TILLERING ABILITY

In general, rice varieties differ greatly in their tillering ability. This ability is affected not only by the environment but also by plant type characteristics such as leaf arrangement, and leaf and tiller angle (Tsunoda 1959). Tillering ability is closely associated with plant nutrition (Tanaka and Garcia 1965, Yoshida and Hayakawa 1970). Theoretically, tiller production is closely correlated to rate of leaf development (Katayama 1931).

Four rice varieties of different plant types were compared: IR36 (semidwarf with short, erect leaves and upright tillers), RD19 (semidwarf with short and erect

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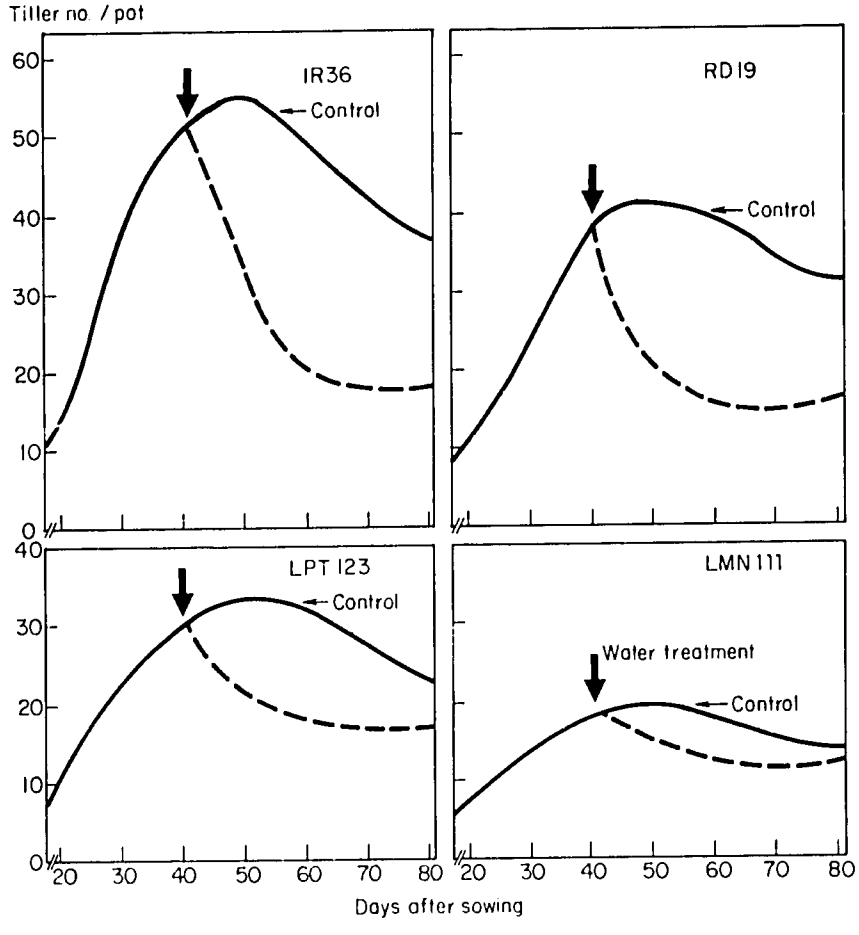
leaves, upright tillers, and fair internode elongation ability), LPT123 (tall stature, long and droopy leaves, open tillers, and limited elongation ability), and LMN111 (tall long droopy leaves, open tillers, and good elongation ability). These varietal characteristics are evident even at an early growth stage. LMN111, a traditional deepwater rice variety, tends to have low tiller numbers and IR36 has high tiller numbers.

The 4 varieties were planted in 4-liter plastic pots in an IRRI greenhouse. At the desired ages, the plants were placed on supports and subjected to deep-water treatment in drums. When the 4 varieties were subjected to 40 cm water at 40 days after sowing, there was marked reduction in tiller number in IR36 and RD19, which are high-tillering types, whereas LMN111, the low-tillering type, had little reduction in tillers and a high percentage of productive tillers (Fig. 1).



1. Diagram of tiller reduction of 4 rice varieties at 40-cm water depth 40 days after sowing compared to control. IRRI greenhouse, 1980.

In shallow water, high-tillering capacity is an advantage, but in other circumstances medium-tillering capacity may be desirable (Beachell and Jennings 1965). Because recently formed tillers die when the water level is increased, prolific early tillering may not be a desirable character for deepwater rice. Instead of being used in new tiller production, the photosynthate could be accumulated in the culm and used in internode elongation or further translocated to the panicle during grain filling.

EFFECT OF NITROGEN APPLICATION

The effect of nitrogen on tillering, plant height, elongation, and yield was examined.

Tillering

In general, nitrogen application increases tiller number (Tanaka et al 1964, Wilson 1965, IRRI 1968, Chandler 1969, Thenabadu 1972). In medium-deep water, basal nitrogen application significantly increased tiller number before the water depth was increased and those tillers were maintained in the successive growth stages during the wet season (Kupkanchanakul and Vergara 1980). Reduction in tiller number was more in plots with high level of nitrogen application than in plots without nitrogen or with a low level of nitrogen application (Fig. 2).

Similar results were obtained in other experiments, but tiller reduction was observed after a deep-water treatment.

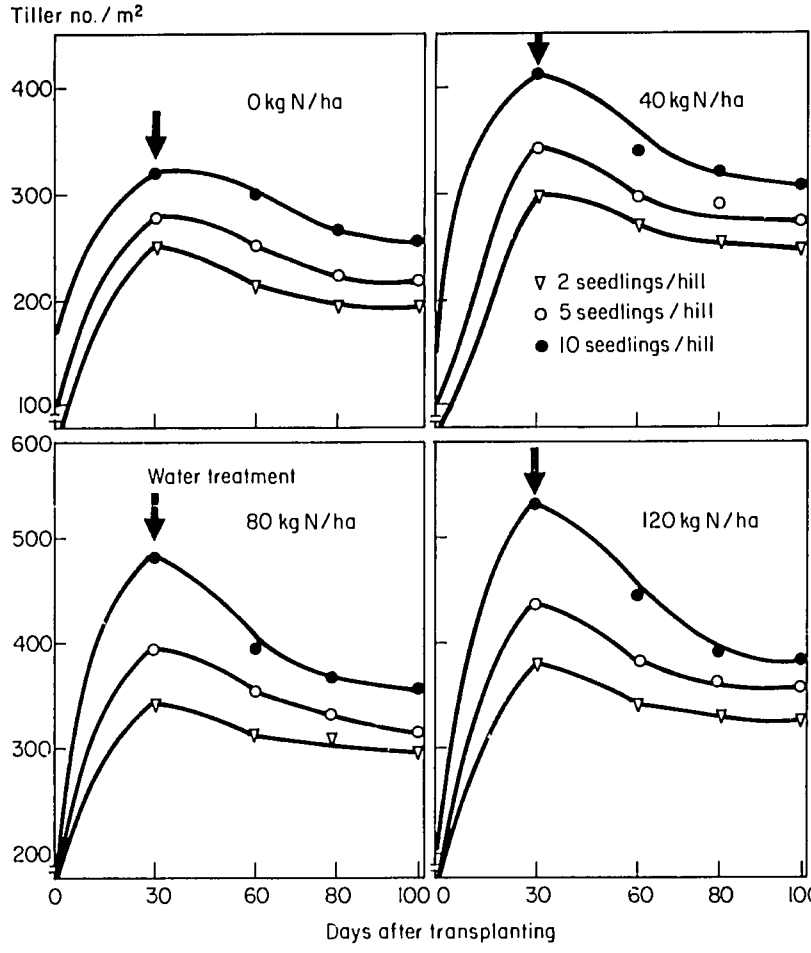
High nitrogen application resulted in continuous tiller production with non-uniform height and growth. Hence, the small, short, and weak tillers died when subjected to deep water. This suggests that photosynthate and nutrients used in the production of new tillers are wasted. This further points to the significance of low-tillering ability in deepwater areas where the photosynthate can be accumulated in the culm and used in internode elongation and grain filling instead of in tiller production. Khan (1980) found that nitrogen application appeared to promote aquatic tiller production.

Plant height and internode elongation

Basal nitrogen application significantly increased plant height at every growth stage (Fig. 3). This effect of nitrogen application on plant height — and internode elongation — was previously reported by Tanaka et al (1964) and Kupkanchanakul and Vergara (1980). The increased height of plants that received nitrogen was also responsible for greater tiller survival of the plants.

Grain yield and yield components

Basal nitrogen application significantly increased grain yield (Table 1). The main role of basal nitrogen application in increasing grain yield in deep water was associated with an increase in tiller number and plant height. These responses led to a larger crop canopy above the water and resulted in a higher percentage of surviving plants, which in turn produced more panicles per unit area and higher grain yields (Kupkanchanakul and Vergara 1980).



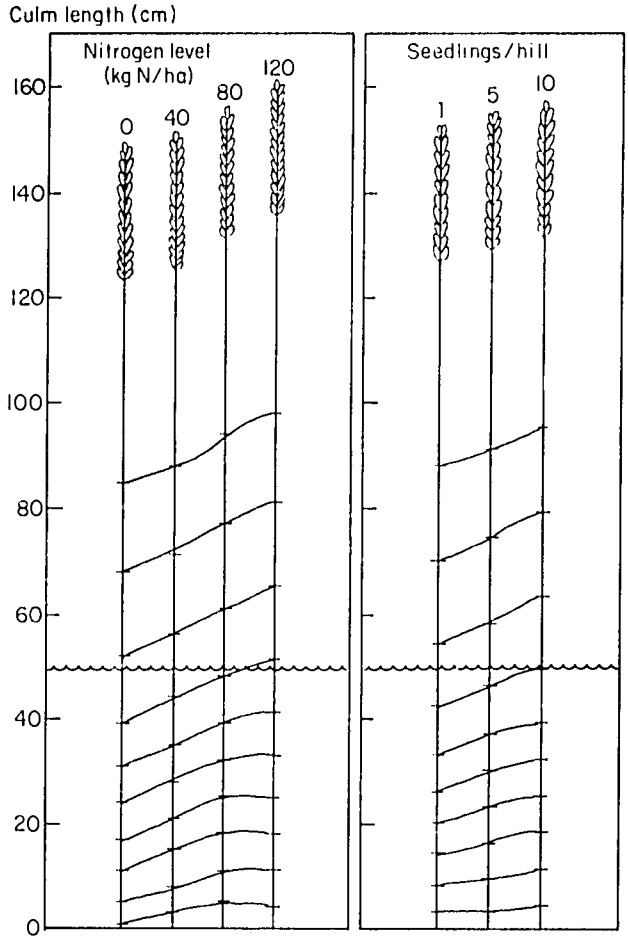
2. Effect of number of seedlings per hill at different levels of nitrogen fertilizer on tiller number of IR42 grown in medium-deep water. IRRI, 1980 wet season. Source: Kupkanchanakul and Vergara (1980).

EFFECT OF NUMBER OF SEEDLINGS PER HILL

Two wet season experiments at IRRI in 1980 studied the effect of number of seedlings per hill on tiller production and growth performance of rice. The treatments and varieties are the same as shown in Table 1.

Tiller production

Increase in plant population before the rice in water level can be achieved by increased plant density. In transplanted rice, more seedlings per hill can result in increased tiller number of the rice plant per unit area. However, increasing tiller number per unit area by increasing the number of seedlings per hill reduced tiller production per seedling, which was mainly because of intense plant competition in



3. Effect of nitrogen fertilizer and number of seedlings per hill on internode elongation of RD19 at flowering. IRRI, 1980 wet season.

the limited space of each hill. Seedlings in the center of each hill could not produce new tillers, and some tillers and seedlings may have died because of competition for nutrients and sunlight.

The relative increase in tiller number per unit area as induced by a high seedling number per hill was maintained better in the succeeding growth stages only in plots with low level of nitrogen application but tended to decrease greatly in the succeeding growth stages in plots with high levels of nitrogen application (Fig. 2). Generally, high number of seedlings per hill resulted in high panicle number.

Basal nitrogen application to increase tiller number and yield can, therefore, be replaced to some extent by increased number of seedlings per hill especially in deepwater areas where fertilizer application is usually not practiced (Kupkanchanakul 1981).

Table 1. Grain yield of IR42 and RD19 grown in medium-deep water, as affected by nitrogen fertilizer and number of seedlings per hill. IRRI, 1980 wet season.

Seedlings (no./hill)	Grain yield (t/ha) 0 kg N/ha	40 kg N/ha	80 kg N/ha	120 kg N/ha	Mean
			IR42[a]		
2	2.4	3.1	3.7	3.8	3.3 b
5	2.7	3.3	4.0	4.0	3.5 ab
10	3.1	3.6	3.9	3.9	3.7 a
Mean	2.8 b	3.4 ab	3.8 a	3.9 a	
			RD19[b]		
1	1.8	2.3	2.7	3.2	2.5
5	2.4	2.7	3.2	3.2	2.9
10	2.6	3.1	3.2	3.0	3.0
Mean	2.3	2.7	3.1	3.1	

[a]In a row or column, means followed by a common letter are not significantly different at the 1% level. [b]To compare the effect of nitrogen level at a certain number of seedlings per hill, LSD 0.01 = 0.64 t/ha. To compare the effect of seedlings per hill at a certain nitrogen level, LSD 0.01 = 0.60 t/ha.

Plant height and internode elongation

Increasing the number of seedlings per hill significantly increased plant height, mainly because of increase in internode elongation (Fig. 3).

Yield and yield components

A high number of seedlings per hill significantly increased rice yield, mainly due to increased panicle number per unit area. However, increase in yield resulting from the use of more seedlings per hill was more pronounced in plots without nitrogen or with low nitrogen application than in those with high nitrogen application. This reinforces the observation that increased grain yield is attained by planting more seedlings per hill in deepwater rice-growing areas where fertilizer application is normally not practiced. A high tiller number before the rise in water level ensures a high number of panicles per unit area at harvest. If floodwater contains high levels of plant nutrients, large panicles may develop and further increase grain yield.

EFFECT OF SPACING

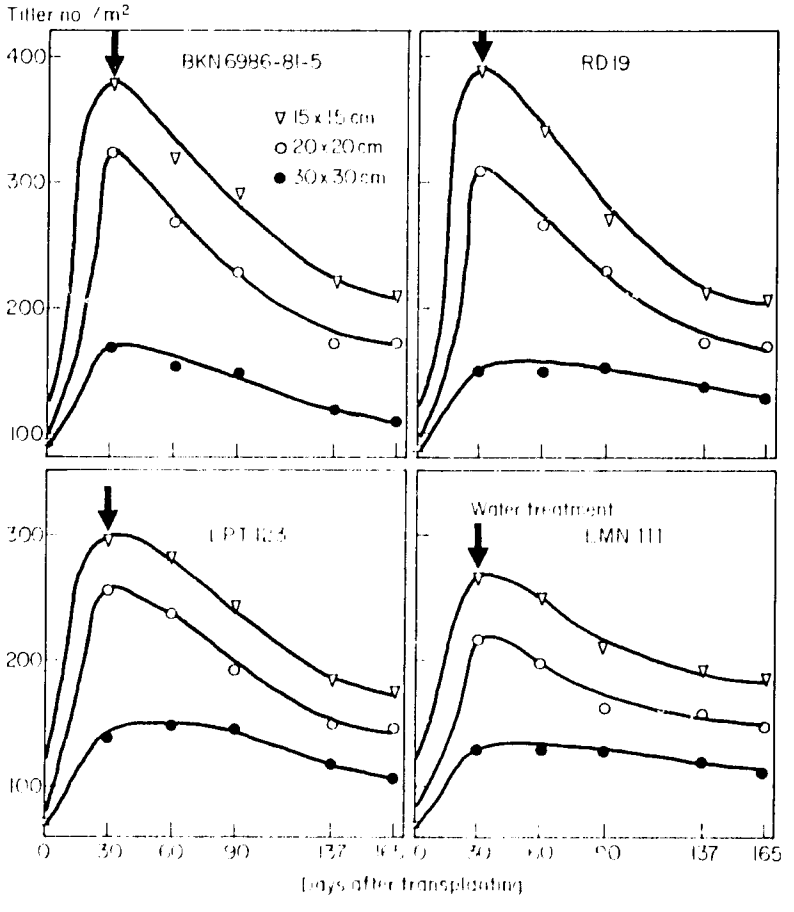
Three experiments at the Huntra Rice Experiment Station during the 1980 wet season included 4 rice varieties (BKN6986-81-5, LMN111, LPT123, and RD19) designated as main plots and 3 spacings (15 × 15, 20 × 20, and 20 × 30 cm at 3 seedlings/hill) as subplots. Responses of rice cultivars to spacings were evaluated at 30, 70, and 110 cm water depths.

Varietal response

Like nitrogen, spacing is an important factor in the yield production of various crops (Holliday 1960). Because tillering activity varies among varieties the relationship between spacing and variety is important. For shallow water, in general, closer spacing is more desirable for low-tillering than for high-tillering varieties, and for short-duration than for long-duration varieties (Ghose et al 1960). Nitrogen response is more pronounced at wide spacing than at close spacing and is more prominent in the dry season than in the rainy season (Tanaka et al 1964, Tanaka 1965). High-tillering varieties are well adapted to a wide range of spacing (Yoshida 1971). In deepwater tests in Thailand, close spacing was optimal and there was no varietal difference in the optimum spacing (Fig. 4).

Tillering

Close spacing significantly increased tiller number at every growth stage (Fig. 4). When deep-water treatment was introduced 30 days after transplanting, tiller



4. Effect of spacing on tiller number of three varieties grown at 70-cm water depth. Huntra Rice Experiment Station, Thailand, 1980 wet season

production ceased and tiller number per unit area was reduced as tillers died. The degree of tiller reduction was sharpest in plots transplanted at closer spacing. At harvest, tiller number per unit area was still higher in plots with closer spacing because more tillers were produced before water treatment was started. This points to the importance of early tiller production and crop establishment in deepwater rice-growing areas.

Grain yield

Increasing plant density can be an effective measure for increasing the number of panicles per unit area and subsequently grain yield (Tanaka et al 1966, Sakai et al 1977, Shieh 1979). Nguu and De Datta (1978) concluded that dense planting increased rice yields mainly by increasing the number of productive tillers, produced mostly during the first 30 days after transplanting. In deep water, wide spacing limits rice yield (IRRI 1980).

Close spacing significantly increased grain yield of rice varieties at 30, 70, and 110 cm water depth (Table 2). Increased grain yield as affected by close spacing was associated with an increase in panicle number per unit area.

Kupkanchanakul (1981) reports that in deep water close spacing did not show any effect on spikelet number per panicle, percent fertility, and 1,000-grain weight. This indicates that in deep water, differences in grain yield within a variety were entirely determined by panicle number per unit area, which in turn suggests that grain yield of rice in deep water can be increased by increasing panicle number.

EFFECT OF SEED RATE

A field experiment at the Huntra Rice Experiment Station during the 1980 wet season determined the effect of seeding rate on tillering and yield of rice in natural deepwater plots. Four rice varieties (the same as in the previous experiment) were used as main plots and 3 seed rates (200, 400, and 600 seeds/m^2) were designated as subplots. Maximum water depth (about 180 cm) was recorded just before flowering.

Tiller production

Broadcast seeding on dry soil is the common practice in deepwater rice growing areas. Tillering of deepwater rice at early stage is mainly determined by soil moisture content and weed competition (Hassanuzzaman et al 1975). The seeding rate should aim for the optimum initial plant population, which should ensure enough tillers after an increase in water depth. In general, the seed rate for growing deepwater rice is from 90 to 180 kg/ha. Farmers usually add extra seed in the deeper areas.

When rice was broadcast on a dry soil at a relatively high seed rate, the maximum tiller number was observed to be at about 10 to 30 days after seedling emergence (Fig. 5). Reduction in tiller number 30 days after seedling emergence may be due to the effect of drought stress and nutrient deficiency. The degree of tiller reduction differed among seed rate treatments. Plots with high seed rates

Table 2. Grain yield of 4 rice varieties grown under 3 water levels, as affected by spacing. Huntra Rice Experiment Station, Thailand, 1980 wet season.

Variety	Yield (t/ha)[a] at a spacing of 15 x 15 cm	20 x 20 cm	30 x 30 cm	Mean
	30-cm water depth			
BKN6986-81-5	2.9	2.85	1.81	2.51 b
LMN111	2.56	2.76	2.26	2.53 b
LPT123	3.08	3.07	2.35	2.83 b
RD19	3.67	3.56	3.23	3.49 a
Mean	3.05 a	3.06 a	2.41 b	
	20-cm water depth			
BKN6986-81-5	1.85	1.74	1.08	1.56 a
LMN111	1.70	1.79	1.48	1.66 a
LPT123	1.96	1.72	1.23	1.64 a
RD19	2.36	2.21	1.58	2.05 a
Mean	1.97 a	1.87 a	1.34 b	
	10-cm water depth			
BKN6986-81-5	1.50	1.13	0.79	1.14 a
LMN111	2.03	1.85	1.68	1.85 a
LPT123	1.70	1.52	0.78	1.33 a
RD19	1.96	1.85	1.21	1.67 a
Mean	1.80 a	1.59 a	1.12 b	

[a]At the same water depth, means of variety or spacing followed by a common letter are not significantly different at the 1% level.

experienced remarkably greater reduction than plots with low seed rate, regardless of variety. There was more competition for nutrient and moisture among seedlings in plots with high seed rate.

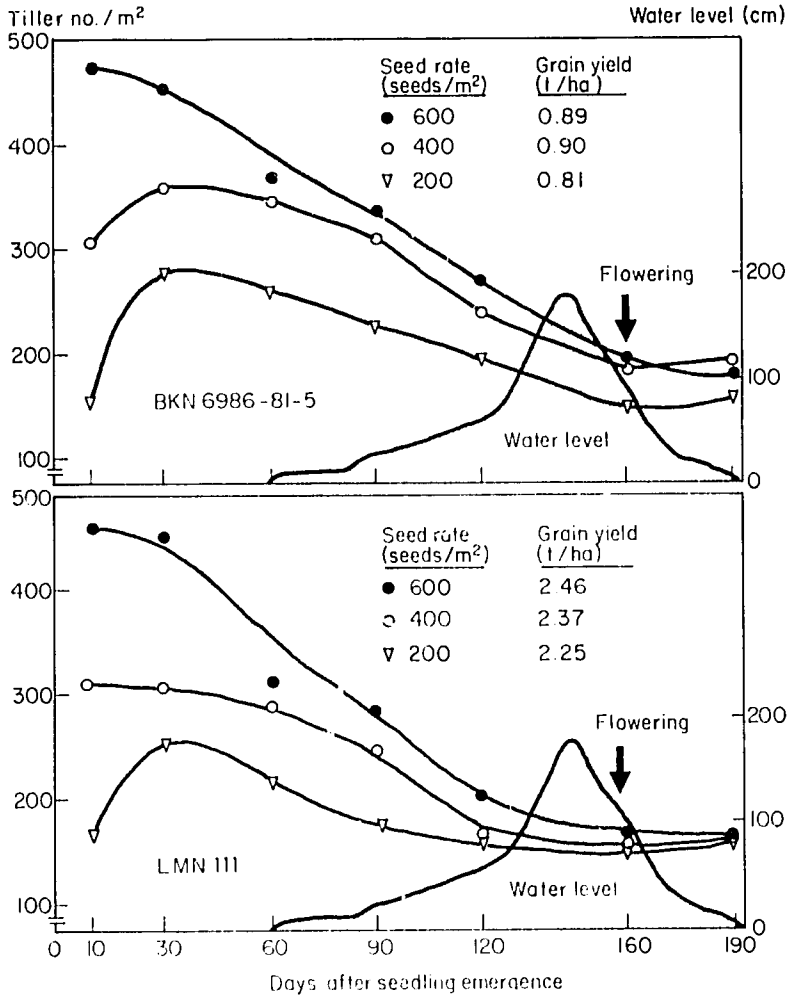
In deepwater rice growing areas, yellowing due to lack of nitrogen slowly disappears as the soil is submerged and floodwaters rise.

Grain yield and yield components

Seed rate did not show a significant effect on grain yield (Kupkanchanakul 1981). BKN6986-81-5 probably had low yield because of the effect of deepwater stress during panicle formation. LMN111 showed relatively good grain yield, indicating that varieties with tall stature and good elongation ability have better adaptability to deepwater stress.

The relatively high yield of LMN111 was associated with relatively higher panicle number per unit area and much higher spikelet number per panicle, as well as higher 1,000-grain weight compared to those of BKN6986-81-5. This shows the importance of sink size in deepwater rice and the general effect on panicle number.

Panicle number per unit area tended to increase with increase in seed rate in BKN6986-81-5, the improved plant type variety, but it tended to decrease in LMN111, the leafy and droopy type variety. However, the difference was not



5. Effect of seed rate on tiller number of BKN6986-81-5 and LMN 111 grown under natural deepwater condition. Huntra Rice Experiment Station, Thailand, 1980 wet season.

significant. This increase in panicle number with higher seed rate in plant types with erect tillers and erect leaves suggests that panicle number can be increased by improving the plant type.

EFFECT OF SEEDING METHOD

Seeding method not only affects crop stand but also determines the nature of subsequent cultural practices. Traditionally, broadcasting is the most common practice in growing deepwater rice. The rice and weeds germinate simultaneously as the soil absorbs moisture during the onset of the monsoon rains. Weed control and fertilizer application do not ensure profit and usually are not practiced.

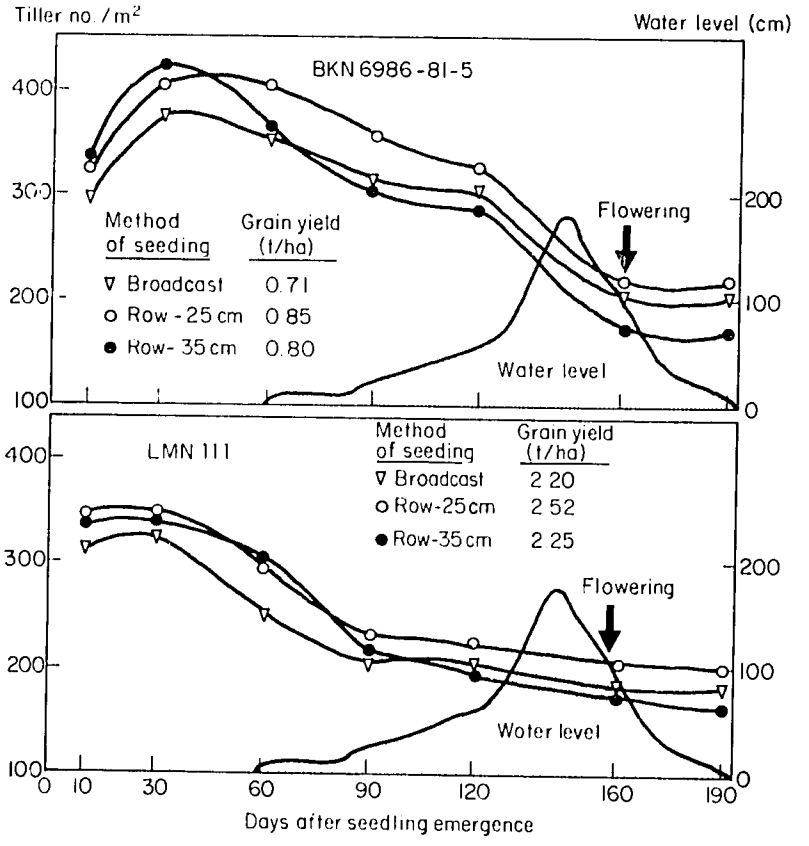
A field experiment in natural deepwater plots at the Huntra Rice Experiment

Station in the 1980 wet season evaluated the effect of seeding method on tiller production. Four rice varieties (the same as in the previous experiment) were designated as main plots and 3 seeding methods (broadcast, 25-cm row, and 35-cm row) as subplots. The treatments were repeated four times.

Tiller production

Row seeding resulted in the best crop stand at 10 days after seedling emergence (Fig. 6) but the difference was not significant. Seeding method did not show any significant effect on tiller number at the vegetative growth stage. However, greater differences were observed at the reproductive stage when tiller number in the 35-cm-row plot was low compared to the 25-cm-row and the broadcast plots. This suggests that 35-cm spacing between rows was too wide for the rate of 400 seeds/m^2.

Thirty days after emergence, tiller number began to decrease probably because of drought stress and insufficiency of available nutrients. Yellowing of leaves occurred earlier in LMN111 than in other varieties and was observed more in the 35-cm-row plots than in broadcast and 25-cm-row treatments.



6. Effect of seeding method on tiller number of BKN6986-81-5 and LMN 111 grown under natural deepwater condition. Huntra Rice Experiment Station, Thailand, 1980 wet season.

A marked reduction in tiller number in BKN6986-81-5 at maximum water depth indicates death of many tillers due to inability to cope with the sudden rise in water level. Regardless of variety, tiller reduction due to a sudden increase in water level was much more in 35-cm-row plots than in other treatments, resulting in low tiller number at flowering.

The greater tiller number reduction at wide spacing indicates that more seeds per row result in greater competition for nutrients, thus producing more weak and short tillers.

At higher seed rates, similar competition also occurs but this can probably be overcome by fertilizer application. Seeding methods did not show any significant effect on percentage of productive tiller.

Grain yield and yield components

LMN111 had much higher yield than BKN6986-81-5 in 180-cm water depth. The 25-cm-row plots tended to show better grain yield than broadcast and 35-cm-row plots. However, the differences were not statistically significant (Kupkanchanakul 1981). The better yield of LMN111 compared to that of BKN6986-81-5 was due mainly to higher spikelet number per unit area and significantly higher weight per grain. Differences in grain yield within variety were determined mainly by panicle number per unit area, which in turn suggests that grain yield of rice in deep water can be increased by increasing panicle number.

CONCLUSION

We have several conclusions based on the studies cited:

1. Deep water inhibits tiller production and a drastic increase in water depth reduces tiller number. The inhibitory effects of deep water on tiller production, however, can be overcome by increased initial plant population and sufficient fertilizer level at all growth stages. Moreover, tiller number in deepwater fields can be increased if plant type characteristics are improved.
2. Increased initial plant population significantly increased grain yield which was associated with an increase in panicle number per unit area. However, spikelet number per panicle, percent fertility, and 1,000-grain weight were not significantly affected.
3. The response to high initial plant population differed among rice varieties, water conditions, and soil fertility levels. Moreover, in deepwater rice-growing areas where fertilizer application is impractical, high initial plant population is considered advantageous.
4. The intermediate plant type with internode elongation ability appeared to perform better than the traditional tall in areas where water level does not exceed 1 m. However, in areas where water level is more than 1 m the tall plant type with good internode elongation ability is more desirable.
5. Aside from erect leaves and tillers, intermediate plant height, and good internode elongation ability, the importance of low tillering type and big sink size should be emphasized in breeding for improved grain yield of deepwater rice.

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DISCUSSION

VO-TONG XUAN: Can you comment on the effect on percentage of filled spikelets?

KUPKANCHANAKUL: There was no effect on the percentage of filled spikelets when water depth was the only variable.

GRIFFIN: What was the spacing in your seedlings/hill trial? Was the spacing constant?

KUPKANCHANAKUL: Spacing was constant at 25 × 25 cm.

FRANCIS: For dry soils where you cannot transplant would dibbling with hills at fairly close spacing and low number of seeds/hill be preferable to broadcasting at high seed rate?

KUPKANCHANAKUL: Dibbling may affect seedling emergence, which would result in a different stand establishment. We must risk heavy rain with standing water just after dibbling. Hill-sowing, if environmental conditions are good, would be preferable to broadcasting to conserve seed and obtain good stands. Experiments on this are needed.

STAND ESTABLISHMENT FOR DEEPWATER RICE IN THAILAND

P. Sittiyos, K. Kupkanchanakul, S. Phumiphol, and N. Supapoj

SUMMARY

Research on crop establishment of deepwater rice in Thailand during 1979-80 indicates that a 3-4 t/ha yield of deepwater rice should be possible if appropriate stand establishment methods are developed. Suitable seed rates should also be considered. This paper provides some ideas to improve stand establishment of deepwater rice.

Broadcast dry seeding is the Thai farmers' main method of deepwater-rice establishment. Recent experiments may provide possible means of improving deepwater-rice establishment in Thailand and elsewhere.

Prechachat and Jackson (1975) estimated that 0.8 million ha of rainfed wetland rice in Thailand are grown in deep water. Recently, it was reported that the area of deepwater rice in Thailand has decreased to 0.5 million ha (Somrith and Awakul 1979). The reduction was due to the construction of the Asian highway and irrigation dams. Most of the deepwater rice is grown on the Central Plain. The maximum water depth ranges from 60 to 400 cm, depending on the location and year.

Climate, varieties, and cultural conditions for deepwater rice in Thailand have already been described (Prechachat and Jackson 1975, Somrith and Awakul 1979). The average yield of deepwater rice is only 2 t/ha. Research on the cultural practices for deepwater rice is far behind that for modern high yielding varieties.

Time of planting seems to be unimportant if rice seed can be planted in advance of the onset of rains (De Datta et al 1979). For interrow planting, the competitive ability of rice varieties must be equivalent, otherwise the lower competitor will be eliminated as shown by Jennings and Jesus (1968).

Yields of the same variety differ with environmental conditions (Saran et al 1979); therefore tests should be repeatedly conducted in various sites to get clear results.

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The results we present were obtained from experiments in 1979-80 to evaluate the grain yield of deepwater rice at different plant spacings, seed rates, and fertilizer levels.

1979 WET SEASON EXPERIMENTS

Experiment I was conducted by Sittiyos and Kupkanchanakul (1981) in a Huntra Rice Experiment Station pond where the water level was controlled at 80-cm depth. RD17 was the test cultivar. Three plant spacings and three fertilizer levels were evaluated as shown in Table 1. Three seedlings were transplanted per hill. The results indicated that grain yields of the 2 closer spacings (12.5 × 25 cm and 25 × 25 cm) were not significantly different from each other but were significantly higher than the 25 × 40 cm treatment. Fertilizer treatments showed a minimum 3 t/ha yield of RD17 with no significantly different response to nitrogen. These results suggest that the plant population of rice grown in deep water should be greater than 30 plants/m^2 even when the variety has good tillering capacity as does RD17.

Experiment II determined the grain yield of Pin Gaew 56 (PG56), a traditional floating rice, and the hybrid SPR7297-405 (semi-deepwater line) by comparing pure stand planting with interrow planting of the two varieties. The experiment was also in a Huntra Rice Experiment Station pond with a maximum water depth of 80 cm.

Pin Gaew 56 and SPR7297-405 as pure stand and interrow planting were assigned to 4 m × 4 m plots in a latin square design. Plant spacings were 12.5 cm within rows and 25 cm between rows. Three seedlings were transplanted per hill. Fertilizer (25-25-0 kg NPK/ha) was applied basally (incorporated) 1 day before transplanting. Water was added 30 days after transplanting at a rate of 5 cm/day to a depth of 80 cm. Average grain yields were obtained from 3 m × 3 m areas.

Plant competition between PG56 and SPR7297-405, the lower competitor, completely eliminated SPR7297-405 in the interrow plots and only the PG56 yield was obtained. In pure stands with basal fertilizer, PG56 and SPR7297-405 produced grain yields of more than 5 t/ha — 5.8 t/ha for PG56 and 5.6 t/ha for

Table 1. Grain yield of RD17 grown at 80-cm water depth at various spacings and fertilizer levels. Huntra Rice Experiment Station, Thailand, 1979.

Spacing (cm)	Yield[a] (t/ha) No fertilizer	25-25-0 kg NPK/ha	60-25-0 kg NPK/ha	Spacing mean
12.2 x 25	3.3	3.3	4.0	3.5
25 x 25	3.8	3.3	3.8	3.6
25 x 40	2.4	2.9	3.2	2.9
Fertilizer mean	3.2	3.2	3.7	

[a]LSD (spacing) 0.05: 0.5 t/ha.

SPR7297-405 (Table 2). From the interrow plots, PG56 alone produced 4 t/ha. PG56 might have a potential productivity of 4-5 t/ha if the appropriate stand establishment methods were used.

Experiment III was in a farmer's field at Km 67 on the Asian highway in Ayuthaya province. RD19 and Leb Mue Nahng 111 (LMN 111) were drill-seeded with 25 cm between rows and broadcast-seeded at a rate of 100 kg/ha.

Three main plots (25 m × 56 m) were used. Each plot was divided into subplots for varieties. One main plot was used as a control broadcast (no fertilizer) similar to farmer practices. On the other two main plots 30-37-0 kg NPK/ha was applied basally at seeding. Each subplot was further divided into 2, one-half receiving topdressing of 19 kg N as normal urea/ha and the other half 19 kg as sulfur-coated urea (SCU)/ha about 60 days after seeding as the floodwater began to rise in the field. Yield measurements were obtained by averaging 3 randoom samplings from 2 m × 3 m areas of each plot.

The maximum water depth eventually reached about 120 cm. Good stands were obtained, and there were no serious weed or rat problems. Yield data, summarized in Table 3, showed that RD19 was greatly superior in yield to LMN 111, probably due to RD19's capacity to produce a high number of productive tillers. LMN 111

Table 2. Grain yield of pure and interrow stands of PG56 and SPR 7297-405 at 80-cm water depth. Experiment 2, Huntra Experiment Station, 1979.

Variety	Yield (t/ha)			Mean
	Rep.I	Rep.II	Rep.III	
PG56	5.3	5.8	7.0	5.8
SPR 7297-405	5.7	5.0	6.0	5.6
PG56 + SPR 7297-405[a]	4.2	4.6	3.6	4.1

[a] SPR 7297-405 was eliminated, only the grain yield of PG56 is shown.

Table 3. Yield performance (t/ha) of RD19 and LMN 111 grown in farmers' field under three cultural conditions. Ayuthaya province, 1979 wet season.

Broadcast		Broadcast seeded[a]				Drill seeded[a]			
RD19	LMN 111	RD19		LMN 111		RD19		LMN 111	
No fertilizer		SCU	NU	SCU	NU	SCU	NU	SCU	NU
3.0	1.9	3.7	4.3	1.3	1.8	3.5	5.5	1.9	1.8

[a] Tests received 30-37-0 kg/ha as basal application plus 19 kg N as normal urea (NU) or sulfur-coated urea (SCU) 60 days after seeding.

showed no yield response over the check regardless of the cultural practices used. RD19 exhibited a fertilizer response in both broadcast and drilling. But yield of plots topdressed with SCU averaged somewhat less than those that received normal urea. This suggests that SCU should be tried only as a basal fertilizer in the future.

1980 WET SEASON EXPERIMENTS

Experiment I in 1980 was at the Prachinburi Rice Experiment Station and determined appropriate rates for broadcast seeding RD19, LMN 111, and PG56. A split-plot design with four replications was used. Varieties were assigned to 5 m × 20 m main plots and 4 seed rates (63, 94, 125, and 156 kg/ha) were applied in 5 m × 5 m subplots. Fertilizer was applied basally at 37.5 kg P/ha at broadcasting and 37.5 kg N/ha 30 days after germination. Yield comparisons were taken on a 4 m × 4 m sample in each treatment. A seed rate of 125 kg/ha gave the highest grain yield for all varieties (Table 4). Note that PG56 is not recommended for this area due to its late maturity.

Experiment II, also at the Prachinburi Rice Experiment Station, determined appropriate rates for line-sowing RD19, LMN 111, and PG56. Seed rates, fertilizer, and experiment design were the same as in experiment I.

The seed rate 63 kg/ha produced yields almost as high as 94 kg/ha (Table 5). However, to ensure good stand establishment, 94 kg/ha would be the most appropriate seed rate for a farmer's field.

Experiment III determined the grain yield of RD19, LMN 111, and PG56 at 2 plant spacings at 80-cm water depth in a Huntra Rice Experiment Station pond. Six treatments were assigned as a randomized complete block with three replications. Plot size was 4 m × 5 m for all treatments. Plant spacings, fertilizer application, and water management were similar to experiment I in 1979. Yield measurements were taken on a 3 m × 4 m sample from each plot.

Yield data in Table 6 illustrate that RD19 outyielded LMN 111 and PG56

Table 4. Grain yield (t/ha) of RD19, LMN 111, and PG56 with broadcasting at four different seed rates. Prachinburi Rice Experiment Station, Thailand, 1980.

Seed rate (kg/ha)	Variety yield[a] (t/ha) RD19	LMN 111	PG56	Seed rate mean[b]
63	1.5	1.7	0.9	1.4 b
94	1.8	1.4	1.0	1.4 b
125	1.9	1.7	1.3	1.6 a
156	1.7	1.3	1.1	1.4 b
Variety mean	1.7	1.6	1.1	

[a]LSD (variety) 0.05 = 0.4 t/ha. [b]Means followed by a common letter are not significantly different at the 5% level.

Table 5. Grain yield (t/ha) of RD19, LMN 111, and PG56 with line-sowing at four different seed rates. Prachinburi Experiment Station, Thailand, 1980.

Seed rate (kg/ha)	Variety yield[a] (t/ha) RD19	LMN 111	PG56	Seed rate mean yield[b]
63	2.0	1.6	1.0	1.5 ab
94	2.2	1.6	1.0	1.6 a
125	1.8	1.5	0.9	1.4 bc
156	1.9	1.3	0.8	1.3 c
Variety mean	2.0	1.5	0.9	

[a]LSD (variety) 0.05 = 0.1 t/ha. [b]Means followed by a common letter are not significantly different at the 5% level.

Table 6. Grain yield of RD19, LMN 111, and PG56 at two plant spacings when grown at 80-cm water depth. Huntra Rice Experiment Station, Thailand, 1980.

Spacing (cm)	Variety yield[a] (t/ha) RD19	LMN 111	PG56	Spacing mean
12.5 x 25	2.8	1.6	0.7	1.7
25 x 25	2.1	1.6	0.6	1.4
Variety mean	2.5	1.6	0.7	-

[a]LSD (variety) 0.05 = 0.5 t/ha.

significantly at both plant spacings. Part of this was due to an unidentified disease, which caused severe drying of the leaves of the two floating varieties at flowering. In 1981 the experiment was planted in the field instead of in a pond.

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DISCUSSION

CHAUDHARY: Experiments in 1979 gave better yields than in 1980. What caused this difference?

SITTIYOS: Different environmental conditions, including site, caused the difference. The plant spacing trials in 1979, had no damage by rats, diseases, and insects, but in 1980 there was severe crop damaged by an unidentified disease. Soil fertility at the 1979 site was much better than at the Prachinburi site, which has an acid sulfate soil. It is low in nitrogen and phosphorus as well as low in pH.

KANTER: What was the water depth for the experiment in Table 2?

PRECHACHAT: It was about 1 m at km 67 near Ayuthaya.

FRANCIS: Was the seed rate the same in your trials on different seeding methods? Can lower seed rates be used when the crop is line-sown than when it is broadcast?

SITTIYOS: We used the same seed rates for broadcasting and line-sowing. Seed rates of 63 and 94 kg/ha exhibited good results for line-sowing and 125 kg/ha was appropriate for broadcasting. We need more information on line-sowing to be certain of the feasibility of using a lower seed rate but it appears promising.

RECENT FINDINGS ON CROPPING SYSTEMS IN DEEPWATER RICE AREAS

M. Zahidul Hoque, N. U. Ahmed, Nur-E-Elahi, and M. R. Siddiqui

SUMMARY

Cropping systems in deepwater areas are complex and little research has been reported so far. In a sample deepwater village the average family farm size was 1 ha with 7 members/family; 91% were owner-farmers and 26% were self-sufficient in rice. Fertilizer, seeds, and credit availability and draft power are major farming constraints. Deepwater rice with or without succeeding winter (rabi) crops is the major cropping pattern; 88 to 92% of the fields are double- or triple-cropped. Agroeconomic performance of deepwater rice, jute, and rabi crops (wheat, millet, potato, mustard, sesame, cowpea, chili [hot pepper]) and different cropping patterns are reported. Deepwater rice followed by wheat was the most predominant pattern.

Factors that influence the performance of deepwater rice-based cropping systems are toposequence, rainfall, drought, flood, water depth, cropping technique, deepwater rice varieties, harvest period, insects, and diseases. Comprehensive site-specific cropping systems research in farmer fields is needed to evaluate and improve the existing cropping systems in the deepwater areas.

Deepwater rice, called broadcast aman or B. aman, occupies more than 2 million ha, which constitutes about 25% of the net cropped areas and 20% of the total rice hectarage of Bangladesh. The cropping patterns, farmers' crop management practices, and crop performance in deepwater areas are largely determined by toposequence, rainfall and flooding pattern, and soil type. Deepwater farmers have developed stable cropping patterns, which are often intensive. However, there has been little study of existing cropping systems.

The Bangladesh Rice Research Institute (BRRI) cropping systems program started on-farm survey and research activities in the deepwater rice areas in 1976.

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In addition to deepwater rice research facilities at its three stations, BRRI has research in farmer fields at Daudkhandi, Comilla district. Collaborative research activities also continue with other organizations in other deepwater rice areas.

The general aspects of deepwater rice-based cropping systems of Bangladesh and the initial research findings were presented at the 1978 deepwater rice workshop at Calcutta (Hobbs et al 1979). This paper presents the highlights of recent research.

SURVEY AND EVALUATION OF EXISTING CROPPING SYSTEMS

Initially attention was given to large-scale crop-cut and farm survey studies in the major deepwater rice areas of Bangladesh. These large-scale studies were jointly conducted by the United Kingdom Overseas Development Administration (ODA) Deepwater Rice Project at BRRI, the Agricultural Development Council (ADC), Dacca, and the Division of Rice Cropping Systems, BRRI. The findings of these studies are published in Clay et al (1978), Catling et al (1979, 1980), and Catling and Alam (1981). These surveys enabled IRRI scientists to understand the major factors and constraints determining crop production in the deepwater rice areas.

Farm characteristics

A quick and simple survey of the deepwater rice farms in a village at Daudkhandi was made by BRRI in 1979 (Hoque et al 1980). The survey revealed a farm-size range of 0.09-4.02 ha with a range of 0.06-3.75 ha for cultivated area. Average family size is 7.3 members, out of which only 1.3 members are effective labor. The number of draft animals ranged from 1 to 7/household with an average of 1.5. Seventy-one percent of the farmers rent animals for cultivation and 35% share draft animals. Ninety-one percent of the farmers are owner-farmers and the rest are owner-cum-tenant farmers. Only 26% of the farms reported they were self-sufficient in rice. About 65% of the farm families engaged in nonfarm activities, and 27% had members in government service. In terms of constraints to farming, all farmers had fertilizer constraints, 70% experienced problems of seed availability, 60% suffered from credit constraints, and 30% had draft power problems.

Another small-scale survey on 20 deepwater rice farms was done by the Mennonite Central Committee Cropping Systems team at Kalacha, Habiganj, Comilla District (Saha et al 1981). The average farm size was 0.70 ha and average family size was 8 with 2.9 as effective family labor. Few Kalacha farmers hired permanent farm labor, 55% reported they were using credit, 30% had never used credit, and 15% had previously used credit but stopped. Credit, used for consumption and production, was obtained from banks, private moneylenders, relatives, etc. Terms, conditions, interest, and security for credits differed among sources.

Land use patterns

Farmers do single-, double-, and triple-cropping in the deepwater rice areas. Single-cropping of deepwater rice is usually done in the deeper water and heavy-soil areas where hydrology and residual soil moisture do not favor another crop.

Double-cropping patterns include mixed aus and deepwater rice; deepwater rice followed by winter (rabi) crops; jute followed by rabi crops; and dry season (boro) rice followed by deepwater rice. Triple-cropping patterns include mixed aus and deepwater rice followed by rabi crops; and deepwater rice or jute followed by early and late rabi crops. Usually mustard and potato are used as the early rabi crops. Other rabi crops grown in the deepwater areas include wheat, foxtail millet, finger millet, chickpea, grasspea, lentil, sesame, flax, safflower, watermelon, tobacco, onion, and chili (hot pepper, *Capsicum frutescence*).

Deepwater rice areas are also excellent fishing grounds. Farmers catch a variety of fish, both before and after rice harvest, using traditional fishing techniques. Many deepwater rice areas where rabi crops do not follow deepwater rice are used as grazing lands for cattle in the dry winter months.

Input and crop management practices

Farmer interview and crop-cut studies from 1977 to 1979 throughout the major deepwater rice areas of Bangladesh revealed that 50-66% of fields have a monoculture of deepwater rice (Catling and Alam 1981). Twenty-five to 36% of the deepwater rice fields are mix-cropped with aus rice in shallow-water areas and 6-15% are mixed with other crops such as foxtail millet, sesame, and chili. A mixture of two deepwater rice varieties in the same field was also observed in few cases. In some areas, deepwater rice is now successfully transplanted after a boro rice. Fertilizer is applied to 19-35% of pure-stand fields and to 26-30% of mixed stands. Fertilizer is used most frequently on the Meghna floodplain where the average grain yield was found to be higher. In the direct-seeded deepwater rice fields, farmers do an average of two rakings and two hand weedings to control weeds. No serious disease outbreaks were encountered recently and farmers applied insecticides to less than 1% of the fields (Catling and Alam 1981).

The management practices adopted by farmers for deepwater rice crop and jute and the following rabi crops were monitored in a deepwater rice village at Daudkhandi, Comilla district (Table 1). Farmers seeded deepwater rice at a rate of 83 kg/ha on 10 April after 2 plowings and 2 ladderings. No organic manure or fertilizers were used for the deepwater rice.

Power and labor use

Cattle are the only power source in the deepwater areas. These are used in land preparation, rakings for weed control and mulching, and threshing by trampling. In general, draft power is a constraint in the deepwater areas and farmers sometimes adopt minimum or zero tillage and relay cropping techniques. Sometimes floods kill draft animals. Availability of adequate livestock feeds is also a problem in the deepwater areas.

Most farmers use family and hired labor for weeding and harvesting. Usually, farm laborers are available within the villages. Some farmers (about 18%) have a permanent hired laborer. In some deepwater areas, field operations such as weeding are done on a cooperative basis.

The power and labor requirements for different field operations in farmers' deepwater rice, jute, and following rabi crops are given in Table 2. Deepwater rice

Table 1. Management practices adopted by farmers[a] for different crops in a deepwater rice area, BRRI cropping systems research site at Daudkhandi, Comilla District, Bangladesh, 1980-81.

Management factor	Deepwater rice (40)	Jute (10)	Rabi crops: Wheat (18)	Italian millet (7)	Potato (11)	Mustard (14)	Sesame (12)	Mungbean (5)	Chili (7)
Variety used	Local	Local	HYV	Local	HYV	Local	Local	Local	Local
Plowing-laddering (no.)	2-2	2-2	3-4	3-4	6.7	2-3	3-3	3-4	3-3
Seeding date (day-month)	10-4	28-3	13-12	18-1	7-12	19-11	24-2	12-2	17-1
Seed rate (kg/ha)	83	10	131	9	1530	18	7	10	(TP)
Used organic manure (%)	-	-	-	28	27	-	8	-	14
Organic manure rate (kg/ha)[b]	-	-	-	4783	3421	-	3804	-	8697
Used NPK (%)	-	-	100-94-22	28-14-0	90-90-54	78-71-74	-	40-40-0	42-57-0
$N-P_2O_5-K_2O$ rate (kg/ha)[b]	-	-	77-36-41	25-19-0	234-114-8	63-38-31	-	31-24-0	29-19-0
Weeded once (%)	100	100	100	100	-	-	100	100	100
Weeded twice (%)	68	90	-	100	-	-	58	80	100
Weeded thrice (%)	10	20	-	-	-	-	-	-	-
Field duration (days)	216	114	100	97	76	74	95	76	119

[a]Figures in parentheses are numbers of sample fields monitored. A dash (-) indicates practice not used. [b]Average rate of only those who applied the manure or fertilizer.

Table 2. Power and labor requirements for different field operations in farmers' deepwater rice, jute, and following rabi crops, BRRI cropping systems research site at Daudkhandi, Comilla District, Bangladesh, 1980-81.

Crop	Power requirements for land preparation (paired animal hour/ha)	Labor requirements (h/ha)					
		Land preparation	Seeding or planting	Manure or fertilizer application	Weeding	Harvesting	Total
Deepwater rice	143	133	4		447	215	799
Jute	123	115	6		416	368	905
Wheat	139	143	5	4	225	335	712
Italian millet	140	125	3	6	351	139	624
Potato	225	215	413	18		509	1,155
Mustard	115	143	5	5		207	360
Sesame	97	100	3	2	369	118	592
Mungbean	145	150	5	3	658	182	998
Chili	142	153	213	20	516	260	1,162

required 143 paired animal hours as land preparation power and about 100 man-days of labor.

Crop productivity and profitability analysis

Based on crop-cut studies throughout Bangladesh, deepwater rice yields for 1977-80 ranged from 0.5 to 4.3 t/ha, with an overall mean yield of 2.3 t/ha (Catling and Alam 1981). The years 1977 and 1978 were considered favorable, having early rains and optimum flooding patterns but 1979 (a severe drought) and 1980 (extreme August flood) were considered unfavorable for the deepwater rice crop.

The monitoring data on the agroeconomic performance of different deepwater rice varieties and jute crops in farmer fields are presented in Table 3. On the average the deepwater rice was much more profitable than jute. Returns to labor and power, and the benefit-cost ratio were also higher for deepwater rice than for jute.

The farmers' rabi crops following deepwater rice and jute at the Daudkhandi site were also monitored. Wheat, Italian millet, and potato had average yields of 1.9, 1.1, and 34.5 t/ha, respectively. Seed yields of mustard and sesame were 0.9 and 0.5 t/ha and yields of mungbean and chili were 0.4 t/ha. Total variable costs were $207/ha for wheat, $122 for Italian millet, $782 for potato, $128 for mustard, $90 for sesame, $179 for mungbean, and $237 for chili, with a corresponding net return of $138, $25, $1519, $267, $150, $61, and $326/ha. The benefit-cost ratios were 1.7 for wheat, 1.2 for Italian millet, 2.9 for potato, 3.1 for mustard, 2.7 for sesame, 1.3 for mungbean, and 2.4 for chili.

CROPPING PATTERN PERFORMANCE

Farmers' cropping patterns at the deepwater rice site at Daudkhandi in 1980-81 were monitored by the BRRI cropping systems program. The data are summarized in Table 4. A total of 15 cropping patterns were grown by farmers in a contiguous block of 43 fields. Seventy-five percent of the area in the block was double-cropped and the rest was triple-cropped. Deepwater rice - wheat, the most common pattern, had a total variable cost of $364/ha with a corresponding net return of $415/ha.

The highest net return ($2,283/ha) came from the deepwater rice - potato - sesame followed by deepwater rice - potato - chili ($2,210/ha). The rate of return from total investment was highest in the deepwater rice - mustard - Italian millet pattern. Data in Table 4 clearly indicate a relative economic profitability (net return/pattern) of the farmers' cropping patterns ranging from 60 to 550% (Table 4).

Despite a relatively lower profitability, farmers adopt the deepwater rice - wheat pattern mainly to meet grain requirements for family consumption. The amount of required variable cost, particularly cash requirements, per hectare also determines the adoption rate of the patterns. However, one or two more years' monitoring work are needed to confirm the 1980-81 results.

Farmers' deepwater rice-based cropping patterns at Kalacha were monitored in 1980-81 by the cropping systems program of the Mennonite Central Committee

Table 3. Agroeconomic performance of deepwater rice and jute crops in farmer fields, BRRI cropping systems research site at Daudkhandi, Comilla District, Bangladesh, 1980.

Observation	Deepwater rice variety							Jute
	Kartik-sail	Sada Pankaish	Ijuli Khama	Dulai Aman	Vitali Bajal	Ari Raj	Av	
Samples (no.)	18	8	8	3	2	1	40	10
Yield (t/ha)[a]	2.8	2.7	2.4	2.5	3.0	3.0	2.7	1.6
Gross return ($/ha)	477	430	386	400	480	483	444	267
Total variable cost ($/ha)	175	137	149	193	159	163	162	150
Net return ($/ha)	302	293	237	207	321	320	282	117
Return to material input ($/$ invested)	11.00	11.9	9.4	7.1	10.7	11.2	10.5	33.1
Return to human labor ($/labor hour)	0.5	0.6	0.5	0.4	0.6	0.6	0.5	0.3
Return to animal power ($/paired animal hour)	2.1	2.7	2.0	1.3	1.3	1.8	2.1	1.1
Benefit-cost ratio	2.7	3.1	2.6	2.1	3.0	3.0	2.7	1.8

[a]Exchange rate: US$1 = TK19.

Table 4. Coverage and agroeconomic performance of farmers' deepwater rice-based cropping patterns, BRRI cropping systems research site at Daudkhandi, Comilla District, Bangladesh, 1980-81.

Cropping pattern[a]			Sample field (no.)	Percent of area under pattern	Yield (t/ha)			Total variable cost per pattern ($/ha)[b]	Net return/ pattern		Benefit-cost ratio
DWR/ Jute	Early rabi crop	Late rabi crop			DWR/ Jute	Early rabi crop	Late rabi crop		($/ha)	(%)	
DWR	Wheat	Fallow	16	40	2.6	2.0		364	415	100	2.1
DWR	Fallow	Chili	4	6	2.7		0.5	384	670	161	2.7
DWR	Fallow	Italian millet	3	10	2.5		0.8	265	249	60	1.9
DWR	Mustard	Fallow	2	2	2.7	0.8		289	492	119	2.7
DWR	Lentil	Fallow	2	7	3.1	0.6		257	463	112	2.8
DWR	Potato	Fallow	2	7	2.8	32.2		976	1644	396	2.7
Jute	Potato	Fallow	2	3	1.8	33.4		1007	1371	330	2.4
Jute	Potato	Sesame	1	2	1.4	39.2	0.6	816	1561	376	3.8
DWR	Potato	Sesame	1	5	2.9	38.3	0.6	972	2283	550	3.3
DWR	Potato	Chili	1	3	3.1	29.0	0.5	1039	2210	533	3.0
DWR	Mustard	Chili	1	2	2.8	1.3	0.4	471	1175	283	3.5
DWR	Mustard	Sesame	4	8	2.7	0.9	0.6	405	682	164	2.7
DWR	Mustard	Mungbean	1	3	2.1	0.9	0.4	422	555	134	2.3
DWR	Mustard	Italian millet	1	1	2.9	1.2	0.9	283	877	211	4.1
Jute	Mustard	Italian millet	2	3	1.6	0.7	1.3	372	1124	271	4.0

[a]DWR = deepwater rice. [b]Exchange rate:US$1 = TK19.

(MCC) (Saha et al 1981). Their results are summarized in Table 5. At Kalacha, mixed cropping of short-duration local aus and deepwater rice followed by a rabi crop was the basic cropping pattern. Farmers used different aus and deepwater rice varieties as well as different rabi crops. In most cases, rabi crops were seeded with tillage after harvest of the deepwater rice. In some cases, zero tillage and relay seeding of rabi crops into the maturing deepwater rice were also done.

The total rice production per hectare from the aus + deepwater mixed cropping ranged from 2.0 to 3.9 t/ha (Table 5). The range is attributable to cultivar combination, input use, and other management practices adopted by the farmers. The highest variable cost of production was for aus + deepwater rice - onion, the

Table 5. Agroeconomic comparison[a] of farmers' cropping patterns in a medium deepwater rice area, MCC cropping systems research site at Kalacha, Comilla District, Bangladesh, 1980-81.

Cropping pattern			Sample fields (no.)	Turnaround time (days)	Yield (t/ha)	
Aus	Deepwater rice	Rabi			Aus + DWR	Rabi crop
Aus	+ DWR	- Wheat	6	32	3.4	1.2
Aus	+ DWR	- Millet	4	26	3.1	1.3
Aus	+ DWR	- Mustard	2	11	3.8	0.7
Aus	+ DWR	- Mustard[b]	2	5	2.0	1.0
Aus	+ DWR	- Grasspea[c]	3	-31	3.1	0.7
Aus	+ DWR	- Mungbean	2	47	3.9	0.4
Aus	+ DWR	- Lentil	1	-26	3.6	0.4
Aus	+ DWR	- Cowpea	1	28	3.0	1.6
Aus	+ DWR	- Onion	1	10	2.3	1.5
Aus	+ DWR	- Fallow	2		3.2	

Cropping pattern			Labor cost pattern ($/ha)[a]	Material cost/ pattern ($/ha)	Net return/ pattern		Benefit-cost ratio
Aus	Deepwater rice	Rabi			($/ha)	(%)	
Aus	+ DWR	- Wheat	348	136	240	100	1.5
Aus	+ DWR	- Millet	329	83	267	111	1.7
Aus	+ DWR	- Mustard	355	121	344	143	1.8
Aus	+ DWR	- Mustard[b]	190	129	257	107	1.8
Aus	+ DWR	- Grasspea[c]	252	92	634	264	3.0
Aus	+ DWR	- Mungbean	318	62	512	213	2.4
Aus	+ DWR	- Lentil	155	86	721	300	4.0
Aus	+ DWR	- Cowpea	471	59	865	360	2.6
Aus	+ DWR	- Onion	443	240	758	316	2.1
Aus	+ DWR	- Fallow	151	62	306	128	2.4

[a]Adapted from Saha et al 1981. Exchange rate: US$1 = TK19. [b]In this pattern, Laksmibilash, a poor-performing early deepwater rice variety, was used and mustard was grown with zero tillage after deepwater rice harvest. [c]Rabi crop was relay-seeded in maturing deepwater rice crop with overlaps indicated under turnaround time.

lowest was in the aus + deepwater rice - fallow. The most common cropping pattern, aus + deepwater rice - wheat, gave a net return of $240/ha with a corresponding total variable cost of $484/ha.

FACTORS AFFECTING CROP PRODUCTION IN DEEPWATER AREAS

Distinct interrelationships have been observed among the components of the deepwater ecological system and farming practices and crop performance. Some of the important observations are briefly discussed here.

Toposequence

Most obviously, the relative toposequence in the deepwater basins reflect the hydrological pattern within the basin. The bottom part of the basin is inundated first and drains last. The ridges remain nonflooded during the early rainy months. Land preparation and seeding of deepwater rice must be tuned to the position of the individual field in the toposequence . The toposequence also dictates the deepwater rice variety to be used for best yields and also the monoculture and mixed-cropping practices. Mixed cropping of deepwater rice with aus rice or other crops such as Italian millet and sesame is done mostly on the higher ridges of the deepwater areas. Also, winter rabi crops are grown on the ridges after the harvest of the deepwater rice. During the early growth stages of the deepwater rice crop, grassy weeds and sedges are more predominant in the upper areas in the toposequence than in the lower parts.

Monsoonal rains

Usually the monsoon rains start late March and gradually increase up to August when the highest precipitation occurs. After that the amount of rainfall decreases and actually comes to an end during early November. In 1980 at Daudkhandi, the surface soil showed a 17% soil moisture content in the first week of January which decreased to 10% by the third week of April (Hoque et al 1980).

Heavy rains during March-April interfere with planting of deepwater rice and harvesting of wheat and other rabi crops, and also damage standing rabi crops such as millet, lentil, and mungbean. Rains in November-December sometimes reflood deepwater rice fields and interfere with rice harvesting and cause crop losses. However, if the deepwater rice is already harvested, mild showers in November-December help planting of rabi crops. Rains during the dry months, particularly in January-February, also help restore soil moisture which can significantly increase yields of rabi crops.

Drought

Drought at seeding time causes poor seed germination, which results in sparse plant population. Also, weed problems become serious when a drought period is followed by good monsoon rains.

Floods

Early floods in June-July affect the aus rice in the aus + deepwater rice mixed-cropping areas. If floods come late (later part of July) the aus rice may be safely

harvested, but the deepwater rice growth is adversely affected. Time of flood recession affects deepwater rice harvest and planting of the following rabi crops. If flooding recedes late, farmers have to harvest the rice crop in standing water, sometimes from boats. There have been instances, in cases of early heavy floods in June-July, of farmers diving to harvest ripening panicles of aus rice. Panicles are bundled, bound together, and floated off the field.

Mixed cropping versus monoculture

In the shallow-water areas mixed cropping of aus and deepwater rices reduces the yield of deepwater rice by as much as 12 to 25% (Table 6). Unless the aus rice or other crop yields compensate for that yield loss, such mixed cropping are not profitable. Subsistence farmers in the deepwater rice areas, however, do not always consider this land equivalent ratio criterion. Instead they consider more the risk factor and distribution of food availability over the famine months.

Deepwater rice varieties

Deepwater rices are rather zone-specific in Bangladesh and exhibit considerable variability among themselves in terms of maturity, interaction with flooding pattern, and yield performance. There is a strong need for multisite testing of several top yielding varieties to delineate the possible extrapolation zones for the individual top yielders.

Harvesting period

An attempt was made to determine the effects of harvesting period on the yield of deepwater rice. Of course, most obviously, the effect of harvest period is confounded with varietal characteristics. However, it has been found (Fig. 1) that harvesting period considerably affects the grain yield. The best harvesting period for the deepwater rice in Bangladesh was found to be 1-15 November.

Hydrogeological zones

Deepwater rice areas in Bangladesh are broadly classified in three major floodplains — Ganges floodplain, Jamuna floodplain, and Meghna floodplain. These three broad zones considerably differ from one another in terms of flooding pattern, varietal adaptation, rainfall, and, perhaps, soil fertility. The most rainfall is usually in the Meghna floodplain; farmers there also use more fertilizers. Rains are also early in this floodplain. The water level fluctuates more between years in the Jamuna and Ganges floodplains than in the Meghna.

The grain yields of deepwater rice in 3 hydrogeological zones during the last 4 years are presented in Figure 2. Large-scale appropriate agroecological studies are needed to relate performance of deepwater rice to the prevailing situations in the three broad hydrogeological zones.

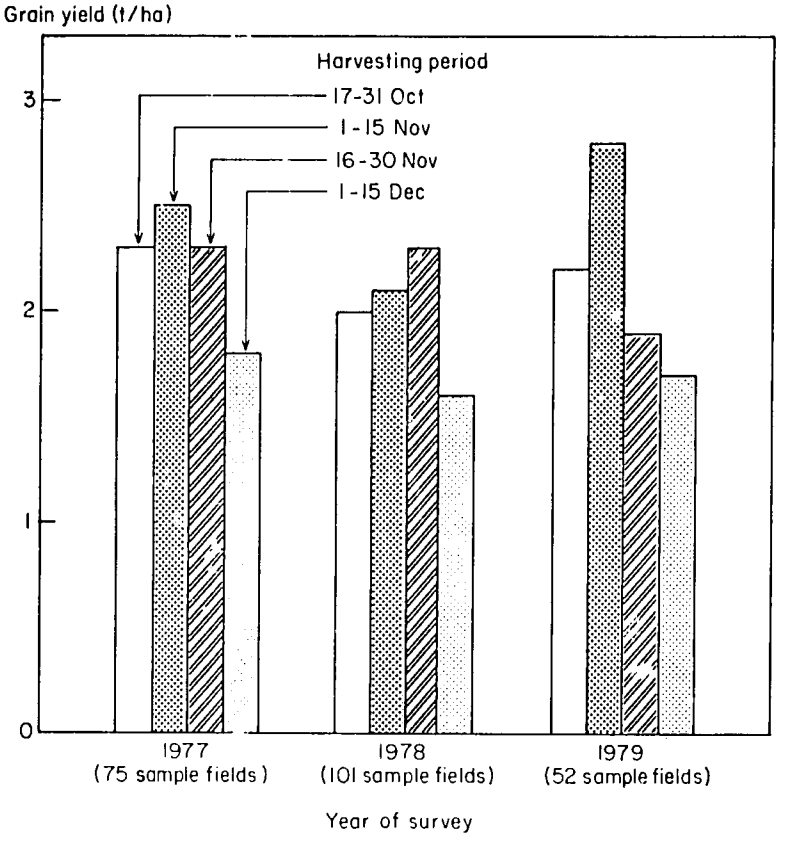
Insects and diseases

The ODA deepwater rice project at BRRI has done considerable work on insect pest and disease problems in deepwater rice areas. Catling and Alam (1981) stated that no serious disease outbreaks were encountered in the recent years but slight ufra nematode damage was observed in 1977 and 1978. Mealybug damage was

Table 6. Mean yields of farmers' deepwater rice crop as influenced by fertilizer application, monoculture, and mixed cropping practices in Bangladesh, 1978-79 (cooperative survey work between British ODA deepwater rice project at BRRI and Division of Rice Cropping Systems, BRRI)[a].

Survey year	Stand type[b]	Observations (no.)	Fields receiving fertilizer application (%)	Mean yield (t/ha)		Av yield of all fields (t/ha)
				With fertilizer	Without fertilizer	
1978	Pure DWR stand	37	35	2.5	2.6	2.6
	DWR + aus rice/other crops	38	26	2.0	2.1	2.1
	Total or mean	75	31	2.3	2.3	2.3
1979	Pure DWR stand	68	31	2.4	2.1	2.2
	DWR + aus rice	27	30	1.7	1.7	1.7
	DWR + other crops	6	17	2.0	2.0	2.0
	Total or mean	101	30	2.2	2.0	2.1

[a]Adapted from Catling et al 1979, 1980. [b]DWR = deepwater rice. Other crops include Italian millet, sesame, chili.



1. Mean yields of deepwater rice as influenced by harvest date in Bangladesh, 1978-80 (adapted from Catling et al 1979, 1980; Catling and Alam 1981).

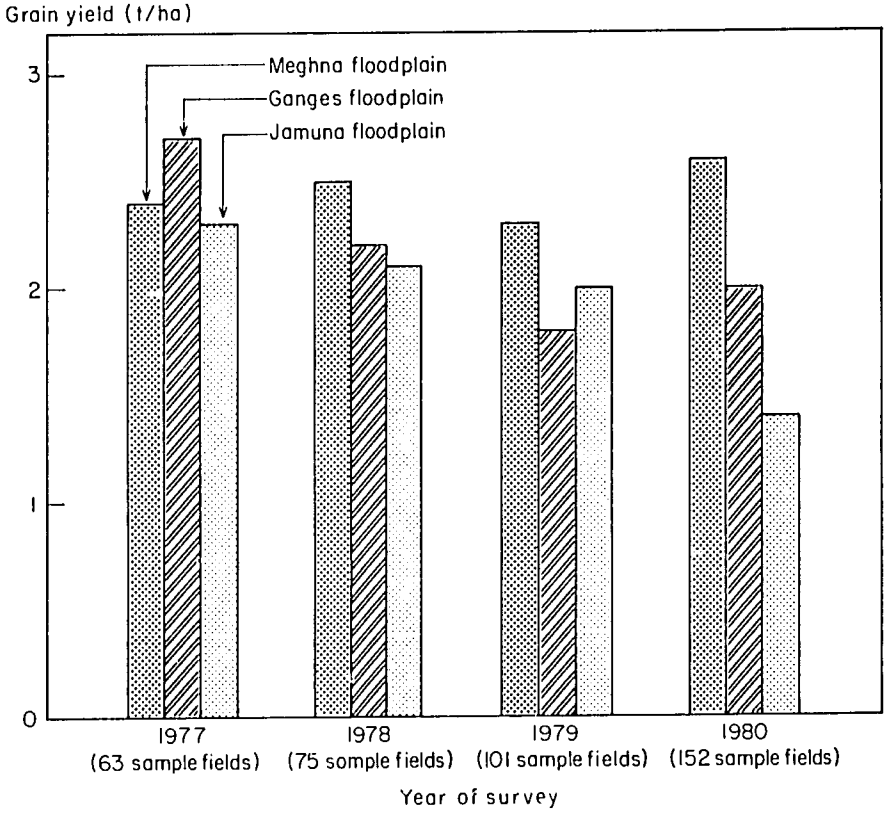
considered severe in 1979, a drought year. Yellow rice borer is considered the major pest of deepwater rice. Rice ear-cutting caterpillar is a problem. Rat damage is usually a serious problem in the deepwater areas. Rats caused serious damages to the deepwater rice crop transplanted after the boro crop harvest in the Dacca-Narayanganj-Demra (DND) irrigation project of Bangladesh Water Development Board (BWDB) in 1979-80 (Hoque et al 1981).

DESIGN AND TESTING OF IMPROVED CROPPING SYSTEMS

Since 1976 attempts have been made to design improved cropping patterns and component techniques for the deepwater areas.

Cropping pattern trials

In the 1976-77 boro season, deepwater rice cropping pattern trials were started in farmer fields at the Jarunbari site, Dacca district (Hoque et al 1977). Deepwater rice was successfully grown after harvesting a boro crop of BR6. The highest total production from the 2-crop pattern was 5.4 t/ha (4.0 t/ha from boro plus 1.4 t/ha



2. Mean yields of deepwater rice in the three hydrogeologic zones in Bangladesh, 1977-80 (adapted from Catling and Alam 1981).

from deepwater rice). It was observed that the production could be increased by another ton per hectare by using higher yielding boro variety such as BR3. However, use of such long-duration boro varieties in the double-cropping system should be confined to higher ridges of deepwater areas, which flood late.

In 1979-80, a cooperative boro - deepwater rice pattern testing was undertaken in farmer fields at Dharmic Para under the DND irrigation project (Hoque et al 1981). Results of those tests are presented in Table 7. The tests confirmed that irrigated boro rice followed by transplanted deepwater rice was a viable system.

In 1980-81 the work on the boro - deepwater rice system was expanded in the DND project (Khan and Hoque 1981). Attempts were also made to try short-duration rabi crops after the boro and deepwater rice crops. The deepwater rice crop after the boro rice gave an additional yield of 2 t/ha (Table 8). The boro - deepwater rice pattern gave 24% higher net return as compared with the farmers' single boro crop pattern at this irrigated site. A short-duration mustard crop between the deepwater rice and boro crop appeared to be highly profitable. Net return could be increased by 107% by adopting intensive cropping patterns thereby replacing the less productive and profitable traditional single cropping pattern in these areas (Table 8). However, financial and technical assistance have

Table 7. Relative productivity of a newly introduced boro-deepwater rice pattern as compared to the existing single boro crop pattern in farmer fields at Dharmic Para site, Dacca-Narayanganj-Demra (DND) irrigation project, Dacca, 1979-80. Cooperative study between Rice Cropping Systems Division, BRRI, and DND Project, Bangladesh Water Development Board (BWDB).[a]

Cropping pattern		Sample	Turnaround	Yield (t/ha)		
Boro rice	Deepwater rice	fields (no.)	time (days)	Boro	Deepwater rice	Total
HYV	Khama	8	37	6.2	1.5	7.7
HYV	Fallow	9	-	5.2	-	5.2
Pajam	Fallow	1	-	4.5	-	4.5

[a]Source: Hoque et al 1980.

to be extended to the farmers so that they can adopt the new improved cropping patterns. Work in the design and testing of improved cropping patterns at other sites is planned.

Component technology studies

Attempts are being made to improve the component technology for the deepwater rice-based cropping systems. Highlights of results are presented here.

To facilitate relay planting of deepwater rice in ripening boro rice, an experiment at Jarunbari compared close (15 cm) paired rows with normal row spacing of 20 cm (Hoque et al 1977). Results indicated that the two spacings produced identical grain yields but the wider spacing between 2 sets of paired rows facilitated relay planting of deepwater rice. The establishment of the deepwater rice was also better in the wider spacing. In another trial, deepwater rice was planted in three methods — transplanting, direct row seeding, and broadcasting into the boro rice fields at flowering and harvesting of boro rice. Broadcasting was better than the two other methods and yields were also higher when deepwater rice was relay-seeded at the flowering stage of the boro crop. Transplanting and direct row seeding were better when done at the harvest stage of the boro crop (Hoque et al 1977).

In another trial, the yields of deepwater rice were significantly increased by adding a topdressing of nitrogen after the boro harvest and before seeding or transplanting deepwater rice.

In 1979-80, a superimposed trial was made in the DND irrigation project to determine the effect of seedbed management (nitrogen, insecticide, seed rate) and seedling age on the yield of deepwater rice following boro rice. Results indicated that better seedbed management and younger seedlings favored yield of deepwater rice (Hoque et al 1980). In 1980-81, a trial at the Daudkhandi site determined the effect of seeding method, seed rate, and straw mulching on the yield of wheat following deepwater rice. Mulch significantly increased wheat yield regardless of seeding method and seed rate.

Table 8. Agroeconomic performance of new intensive cropping patterns and existing farmers' pattern in deepwater rice areas with dry season irrigation, Amulia Site, DND Project, Dacca, 1980-81.[a]

Cropping pattern					Yield (t/ha)			Total variable cost/pattern ($/ha)[b]	Net return/ pattern	
Boro rice	Deepwater rice	Early rabi crop	Sample fields (no.)	Turnaround time (days)	Boro rice	Deepwater rice	Early rabi crop		($/ha)	(%)
				Farmers' pattern						
IR8	Fallow	Fallow	4	250	4.4	-	-	461	496	100
				Newly introduced patterns						
IR8	Lal Khama	Fallow	13	23,77	4.2	2.0	-	743	614	124
IR8	Lal Khama	Mustard (Tori 7)	6	8,12,10	4.4	2.1	0.8	809	888	179
IR8	Lal Khama	Mustard[c] (Tori 7)	5	11,13,3	4.4	2.0	0.5	780	803	162
IR8	Lal Khama	Mustard (TS-72)	1	9,12,4	4.4	2.0	0.8	779	1025	207
IR8	Lal Khama	Red amaranthus	2	10,12,2	4.3	1.8	0.6	772	648	131

[a]Source: Adapted from Khan and Hoque 1981. [b]Exchange rate used: US$1 = TK19. [c]Established with zero tillage after harvest of deepwater rice.

FUTURE RESEARCH DIRECTION

Site-specific cropping systems research in the deepwater rice areas will be continued. Attempts will be made to increase the number of sites so that the major deepwater situations are sampled. Field and whole-farm monitoring will be done at each selected site to adequately describe and analyze the existing cropping systems. Based on the descriptions, improved cropping patterns will be designed and tested in farmer fields. Component technology trials on variety; mixed cropping, intercropping, and relay cropping techniques; fertilizer management; weed control; planting practices; tillage, and other technology areas will also be undertaken. After about 3 years' research at a site, attempts will be made to initiate pilot production program that uses the site-specific research results.

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DISCUSSION

SARAN: Have you tried onion in your cropping pattern trial? Early-maturing deepwater rices like Habiganj Aman I followed by an early-maturing potato variety (like Kufichande-samukhi of India) can be followed by an onion crop.

HOQUE: We have not tested onion in a cropping pattern in the deepwater areas. However, as you will note in Table 4, farmers in certain deepwater rice areas grow onion in their cropping patterns. The onion crop is profitable. We plan to include it as a component crop in the deepwater rice-based cropping patterns at relevant sites.

CHAUDHARY: Is the Irish or sweet potato used in cropping systems?

HOQUE: We used the Irish potato. Farmers usually grow high yielding potato varieties imported from Holland. Potato farmers in the deepwater rice areas around Daudkhandi are advanced. They also have access to government cold-storage facilities to maintain seed stock.

THAKUR: When direct-sown will boro rices in deepwater areas face moisture stress?

HOQUE: Boro rice is grown mainly in irrigated fields. In some low areas with standing water, early-maturing traditional boro varieties may be grown without irrigation. Boro rice is usually seeded in November-December. Now there is a tendency among farmers growing modern boro varieties to transplant the crop somewhat late in February when the cold weather is over. Because the boro crop is grown during the dry winter months, there is always a chance of moisture stress. Usually farmers try their best not to subject the boro crop to moisture stress because the crop gives the highest per-hectare yield among all rice crops in Bangladesh.

BRACKNEY: Because maturity date is important in determining what cropping pattern a deepwater rice fits, discussion pertaining to this should include the variety name. Even within an area of uniform water depth, variety varies widely with cropping pattern.

HOQUE: We have detailed information on each cropping pattern. What has been presented are the summarized data. You are right, deepwater rice varieties used by individual farmers in a specific area vary. We recognize the importance of varietal difference in the patterns. At the Daudkhandi site, for example, Kartiksail, Sada Pankaish, and Ijuli Khama were found more popular than the other varieties.

FRANCIS: In your Table 6, the yield from broadcast aman grown with an aus is about 0.5 t/ha lower than the yield from pure broadcast aman. In the paper that Griffin and I will present later we show total productivity of the aus and aman cropping system will usually yield more than pure broadcast aman. Another point is on the relay sowing. If you are going to establish a relay sowing crop into a boro crop, direct seeding or pregerminated seeding is better than transplanting. However, you have the problem of water coming in quickly. I think the answer to that is to leave as wide a row spacing as you can in the boro crop and to use a high density of transplanted seedlings. Normally you will find you get better stand using germinating seed, but I believe the seedling density that had been used in the past crop was rather low. If we increase seedling density, we can get good yields from relay-transplanting deepwater rice into boro rice.

HOQUE: Definitely the relay transplanting is better than relay seeding. We even found that if we put boro rows close to each other, relay or sequential planting had no effect on the boro yield and we got a good stand of the deepwater rice. But the seed rate is important.

CROPPING SYSTEMS IN DEEPWATER RICE IN THAILAND

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SUMMARY

Cropping systems testing in rainfed fields at a deepwater rice research station started in 1979. Short-maturity dryland crops were grown together with a deepwater rice. Dryland crops were harvested before the soils were submerged and the rice was harvested at the end of the rainy season. Research results are preliminary but provide useful information and conclusions.

Thailand has deepwater rice on about 800,000 ha in 26 provinces. However, the bulk of the deepwater rice is planted on about 582,000 ha in 9 major provinces in the Central Plains. Details on landforms, soils, and rainfall for the Central Plains are given by Prechachat et al (1975), Kaida (1973), and Motomura (1973).

The cropping systems in the deepwater rice areas usually is one crop of rice, but there are places where vegetables and dryland crops like sweet maize, mungbean, and some garden vegetables are planted before the onset of monsoon season. Because these crops are sold in the local markets, their hectarage is not recorded.

There are also deepwater areas where a dry-season broadcast-seeded or transplanted crop is grown with irrigation. The exact double-cropped area is not known.

Rains on the Central Plain start mid-April and farmers prepare their fields mostly by custom plowing by 65- to 80-horsepower tractors. The ideal is the hiring of big tractors (65-80 horsepower) for dryland plowing followed by either 2-wheel or small 4-wheel farmer-owned tractors, which pulverize the soil after the field has received sufficient rain. After seeding, the small machines are used to cover the seeds by light plowing (Chakkaphak and Jackson 1978).

Because early rains are light and soils are not submerged, there is time (3 months) to consider planting dryland crops before the heavy rains start.

CROPPING SYSTEMS EXPERIMENTS

An experiment was started in 1979 to investigate the possibility of intercropping mungbean with deepwater rice. Another experiment tested growing a number of

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dryland crops in the early monsoon and planting deepwater rice a little later than the normal farmer practice.

The two experiments were in rainfed fields at Huntra Rice Experiment Station. Rainfall data are in Table 1. Results of the studies are preliminary and refinements are needed to come up with useful conclusions.

The 1979 experiment studied intercropping of U-Thong 1, a mungbean variety, with Pin Kaew 56, a traditional photoperiod-sensitive deepwater rice variety usually harvested in late December. The experiment had 4 treatments — sole crop of rice, 1 row rice + 1 row mungbean, 2 rows rice + 1 row mungbean, 2 rows rice + 2 rows mungbean.

The rice and mungbean were sown 8 May in a randomized complete block with 4 replications. Basal fertilizer of 125 kg 16-20-0/ha was applied. Seeding rates were 63 kg rice/ha and 25 kg mungbean/ha. Row spacing was 33 cm. Yields are shown in Table 2.

Rice yield was considered low compared with the normal station yield of about 2.8 t/ha for deepwater rice. Mungbean yield was low compared with the average yield of 1.2 kg/ha at a field crop station. However, the mungbean yield was considered reasonable for a rainfed paddy with normal management.

In 1980 the experiment was repeated but drought at the early part of the growing season and late heavy rains at the late stage of mungbean growth damaged the mungbean crop. Mungbean yield was low and rice yield averaged 0.8 t/ha.

Table 1. Monthly rainfall records, Huntra Rice Experiment Station, Thailand, 1956-81.

Year	Monthly rainfall (mm)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1956-1978	10	23	32	107	161	171	161	187	333	192	41	6
1979				79	225	207	281	178	327			
1980			13	197	64	261	137	108	260	250	12	
1981			20	146	193	108	175	215	239	62		

Table 2. Grain yield of deepwater rice (PG 56) and mungbean (U-Thong 1) in a rainfed experiment at Huntra Rice Experiment Station, Thailand, 1979 wet season.

Cropping pattern	Grain yield rice + mungbean (t/ha)
Sole crop of rice	1.4
1 row rice + 1 row mungbean	1.6 + 0.4
2 rows rice + 1 row mungbean	1.2 + 0.3
1 row rice + 2 rows munbean	1.3 + 0.4

In 1981, the experiment was modified to accommodate six treatments, namely:
- sole crop of rice,
- 1 row rice + 1 row mungbean,
- 2 rows rice + 1 row mungbean,
- 1 row rice + 2 rows mungbean,
- 2 rows rice + 2 rows mungbean, and
- sole crop of mungbean.

The crops were planted 15 May 1981 in a split-plot design with 3 replications. Yield data for mungbean are in Table 3. The rice crop harvest will be in late December 1981. A slope of the field of this experiment contributed to water damage and variations in yield. Plots of the highest yielding treatments were in better positions than the other plots.

Another experiment was started in 1981 to study cropping pattern testing in rainfed fields at Huntra:
- rice (RD25) — rice (Pin Kaew 56),
- mungbean (U-Thong 1) — rice (RD25),
- white sesame (local var.) — rice (RD17), and
- sweet maize — rice (RD 19).

The first crop was planted 15 May 1981 in a randomized complete block design with 3 replications. Yield data of the first crops are presented in Table 4.

Table 3. Mungbean yield in a rainfed intercropping experiment with rice, Huntra Rice Experiment Station, Thailand, 1981.

Cropping pattern	Mungbean yield (t/ha)
Sole crop of rice	
1 row rice + 1 row mungbean	1.0
2 rows rice + 1 row mungbean	0.3
1 row rice + 2 rows mungbean	1.9
2 rows rice + 2 rows mungbean	0.4
Sole crop of mungbean	0.3

Table 4. Yield of the first crop in cropping pattern tests at Huntra Rice Experiment Station, Thailand, 1981.

Cropping pattern	Yield (t/ha)
Rice - rice	1.6
Mungbean - rice	1.2
White sesame - rice	0.9
Maize - rice	21,100 marketable ears

Yield performance of the first crop was considered encouraging. High yields could have been due to less than normal rain in June and July, which coincided with the period when the tested crops were approaching maturity. It was observed that time from the start of planting until harvest of the first crops should not exceed 2.5-3 months. The time of harvest of the first crops approached the onset of heavy rains. This limits the choice of crops to be selected. The rice variety for a first crop must be photoperiod insensitive and early maturing.

More research is needed to test alternatives and technical competence in farmer field situations.

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CROP ESTABLISHMENT PRACTICES FOR DEEPWATER RICE IN BANGLADESH

P. Francis and G. Griffin

SUMMARY

Agronomic trials, superimposed trials, and farmer observations were conducted over a 2-year period to gain an idea of how a farmer's establishment techniques could be improved, and collect economic data on existing practices.

Land preparation was influenced by soil moisture and previous cropping. On silt loam soils, winter cropping with nonrice crops, although it often delayed the planting of the deepwater rice, facilitated land preparation for rice. Farmers have developed modifications to the normal seeding method to accommodate different soil moisture conditions. Where flooding depth allows, farmers plant a mixture of aus (summer rice) and broadcast aman (deepwater rice) in a 2-4 ratio. Overall yields of more than 3 t/ha were recorded from farmers' fields.

Line-sowing has been tried experimentally as an alternative to broadcasting. Line-sowing is limited to lighter (silt loam) soils and gives little yield advantage, but offers seed savings and more efficient weed control.

Transplanting is becoming more popular with Bangladeshi farmers as cropping intensity increases. Relay transplanting of deepwater rice into a maturing boro (winter) crop offers a bonus yield of 1-1.5 t/ha.

Responses to fertilizer application were measured at several sites, significantly in the aus of the aus and broadcast aman mixture and in aman trials that were transplanted.

In some areas in Bangladesh land preparation and sowing of the deepwater rice crop tend to be late in the season. This tendency has developed during the last few years, due possibly to intensification of agriculture, particularly with the introduction of new and higher-yielding varieties of rabi (winter crops) such as wheat and

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mustard. Because of more intense cropping, many farmers tend to use fertilizer on the photoperiod-insensitive aus (spring) rice crop and broadcast aman (B. aman or deepwater) rice crop to ensure a good stand of B. aman rice quickly. The farmers are also varying planting systems.

Two years of agronomic trials have been planted in many deepwater rice areas as part of a pest management project for deepwater rice. The trials were mainly on farmers' fields in randomized complete blocks with 8- × 8-m plots and 4 replications. Area harvested was generally at least 16 m^2. We sought better stands and yields of deepwater rice by better agronomic practices, including establishment techniques.

Griffin and Suter (1981) made a detailed survey of the agronomic and economic aspects of deepwater rice and nonrice-crop cultivation in Kalacha Union, Comilla District. Yields were estimated based on 4 random 2- × 2-m crop-cuts taken following the BRRI cropping system methodology. Also, some fertilizer trials were superimposed on farmers' fields using 8- × 8-m plots with 5 replications. We have used data from the surveys and superimposed trials for a greater understanding of the effect of various levels of farmers' management inputs and varieties on yields of deepwater rice in the area.

LAND PREPARATION

Land preparation remains a major obstacle to increased deepwater rice yields in areas where the soil has high clay content. At Kalacha, which has a silt loam soil and where a rabi crop precedes the deepwater rice crop, the growing of a late rabi crop of mungbean or millet before the deepwater rice crop allowed farmers to reduce the time required for land preparation from 3-6 days to 1-3 days. The mungbean or millet was completely uprooted at harvest and the aus and B. aman seed mixtures were sown directly into the broken soil and followed by plowing and laddering. For other winter crops, extra plowing and laddering were done before sowing.

Where rabi crops are not grown, the land is prepared as early as late January or even immediately following the harvest of the previous season's crop, while the soil still has some moisture.

Land preparation is tied to the soil moisture content, and rains in the middle of the dry season in January or February assist the task greatly. At Kalacha in 1980, when there were several rain showers during land preparation an average of about 3 plowings and 5 ladderings were necessary. In 1979, a much drier year, the corresponding figures (based on farmers' recall) were about 5 plowings and 9 ladderings.

Improved plow designs, which are gradually becoming available in Bangladesh, may greatly speed dryland preparation but essentially the best solutions to land preparation problems are timely land preparation — when there is still some soil moisture — on the heavier soils and the growing of a rabi crop on the lighter soils.

BROADCAST SEEDING

Broadcast seeding is still the principal method of sowing deepwater rice in Bangladesh. In 1981, three different broadcast seeding methods were observed at

Kalacha. For the early planted aus and aman mixed crop, dry seed was sown into a well-plowed and laddered soil, then covered by an additional plowing and laddering. This is the method practiced by most farmers.

However, there was exceptionally heavy rainfall during the second and third week of April, which prevented the usual land preparation. Because of high-moisture soil conditions, farmers either planted presoaked (12-24 hours) seed into land plowed once and covered the seed using shallow plowing or raking, or they sowed pregerminated seed (soaked 24-36 hours followed by incubation) onto a puddled field prepared by laddering only.

Using these modifications, farmers can establish a good stand quickly, which partially compensates for late planting. However, there is a greater risk of losing young shallow-rooted seedling if drought occurs. Also, the weed population remains much higher than with the normal broadcast seeding. Even with the normal method there is a severe problem of weed control in deepwater rice.

At Kalacha the average number of hand weedings was 1.1. Aus and B. aman combinations, including the higher-yielding aus variety Dharial, required a significantly higher number of weedings (1.7) possibly because of its earlier planting. Regression analysis showed no significant correlation between hours of weeding and yield, suggesting that each farmer weeded adequately.

The first weeding — a light hand weeding — is preceded by 1 raking at 2-3 weeks after planting. It loosens the soil surface and removes young weeds and some rice seedlings.

The second hand weeding has a much higher labor input and is done 5-6 weeks after seeding. It mainly removes sedges and grasses from the rice stand. Weeding operations of the crop at Kalacha incurred 29% of the total variable costs, greater than that required for land preparation (27%) or harvesting (20%).

Broadcast seeding has resulted in the buildup of high populations of wild rice (probably *Oryza nivara*). Because of high populations of wild rice and volunteer rice seedlings in farmers' fields, broadcast seed rate trials have rarely shown any significant difference between treatments. In a 1979 trial at Manikganj similar yields were obtained from seeding rates ranging from 75 to 105 kg/ha (Francis 1980).

The seeding rate used universally by farmers is 92 kg/ha. It allows for considerable loss of the rice plants during successive rakings and hand weedings and for considerable mortality of tillers during flooding.

Where the aman rice is mixed with an aus rice the typical ratio of aus to aman seed is about 2:1. At Kalacha the aus seeding rate was 80 kg/ha and aman was 44 kg/ha. Depending on flood depth at flowering and harvest the aus yields in this mixture can be highly variable. The aus yield at Kalacha in 1980 was high (1.6 t/ha) with a high yield of 2.1 t/ha for Dharial (Table 1). This aus yield was significantly higher than those of other aus varieties where several samples were taken (BRRI crop-cut methods) but not significantly better compared to single samples.

The mean total aus and aman yield at Kalacha was 3.2 t/ha. In this area, about half of the combined yield came from the aus component. In other yield studies of aus and aman mixtures the main component of total yield usually came from the aman component.

Table 1. Agronomic performance of aus varieties (summer crop broadcast seeded on dry soil) in aus and broadcast aman (deepwater rice) mixture in farmers' fields observed at Kalacha, Bangladesh, 1980.

Variety	Plot (no.)	Mean date of planting	Mean date of harvest	Mean field duration (days)	Mean grain yield (t/ha)[a]
Dharial	5	8 Apr	20 Jul	103	2.1 a
Jail faita	1	18 Apr	7 Jul	80	1.6 ab
Bondesar	19	23 Apr	22 Jul	90	1.5 b
Faita	1	20 Apr	21 Jul	92	1.5
Sorgamug	1	22 Apr	27 Jul	96	1.4 ab
Matichak	3	19 Apr	22 Jul	94	1.2 b

[a]Figures in a column followed by a common letter are not significantly different at the 5% level.

Crop-cut studies made in the whole deepwater rice growing area by Clay et al (1978) and Catling et al (1979, 1980) and Catling and Alam (1981) showed that the yield of aman, sown in a mixture with aus, was lower than that of the aman sown alone. The difference was 0.4 t/ha in 1977, 0.5 t/ha in 1978, and 0.6 t/ha in 1979. However, the extra yield due to the aus crop was estimated (by farmers) to be 1.1 t/ha in 1978 and 1979. Thus, even in an unfavorable year for the aus crop, the total aus and aman yields should exceed those of the aman crop.

LINE-SOWING

On the lighter soils, line-sowing is becoming increasingly popular with crops such as wheat and jute. However, on the clay soils, producing a fine enough tilth requires considerable extra effort and it is unlikely that line-sowing will ever be widely used. Fields for line-sown agronomic trials in Manikganj in 1979 required an extra two plowings and ladderings (over what would have given a tilth for broadcasting).

Our experience with line-sown experimental plots has been that weed control tends to be poorer initially because of lack of interrow cover by the line-sown crop. However, once canopy closure takes place, few weed problems occur because of the uniformity of the line-sown stand. Weed removal during the normal growth period was noticeably more efficient with less damage to the crop than in the broadcast stand. Hand weeding of broadcast experimental plots was 14% longer than hand weeding of line-sown plots.

Significant yield differences between different line-sown seeding rates in farmers' fields are difficult to demonstrate because of volunteer seedlings and wild rice in the rows. In a trial at Daudkhandi 1980 no marked response to different line-sown seeding rates could be shown (Table 2). There was, however, a significant response to fertilizer.

Table 2. Effect of seed rate and fertilizer level on the grain yield (t/ha) of Habiganj Aman IV, Daudkhandi, Bangladesh, 1980.

Fertilizer level	Seed rate (kg/ha)				Mean
	30	50	70	90	
40 kg N and 17 kg P/ha	1.8	1.7	1.9	2.0	1.9 a
No fertilizer	1.4	1.5	1.5	2.0	1.6 b
Mean	1.6	1.6	1.7	1.9	1.7

[a]Figures in a column followed by a common letter are not significantly different at the 5% level. Maximum water depth: 2.6 m; CV (%) = 24.

With line-sowing, a greater proportion of the seeds germinate and lower seeding rates give a stand equal to that obtained by broadcasting. This was demonstrated in several trials where line-sowing at 75 kg/ha and broadcasting at the normal rate of 92 kg/ha gave similar yields from Habiganj Aman IV (Francis 1981).

Line-sowing of deepwater rice is unlikely to be widely adopted in Bangladesh. However, on the lighter soils in areas of shallower flooding depths the advantages of the methods are better germination, lower seeding rate, and more efficient weeding which may result in more widespread adoption of the method.

TRANSPLANTING

More and more Bangladesh farmers are increasing use of transplanting for planting deepwater rice. This has come about as a result of intensification of cropping systems in many areas and because of the need to establish a deepwater rice crop following the harvest of boro crop. Some areas are now growing longer-duration and late rabi crops such as cowpea, millet, and mungbean, which delay the time of establishment of the deepwater rice crop.

There are several advantages of transplanting the crop. The regularity and uniformity of the line-sown crop are there, and problems of land preparation and weed control are virtually eliminated. Although transplanting requires a fairly high labor input, it eliminates the labor needed for weeding. The main advantage is that it ensures a uniform tiller stand at a fairly advanced stage of growth and plants can elongate shortly after establishment if there is sudden water rise. The stand does not suffer from weed competition, damage due to weeding, and from unnecessary production of weak tillers, which have a high mortality rate when submerged.

The use of closer spacing and a lower number of seedlings transplanted/hill to encourage tillering have resulted in increased yields in agronomic trials. At Joydebpur, in a deepwater tank flooded to a 2-m depth, closer hill spacing (Table 3) gave significant yield responses. In another trial, increasing seedlings/hill (at the same initial seedling population) gave a slight, although insignificant, yield increase (Francis 1981).

Table 3. Effect of hill spacing and seedling number in a hill on the yield (t/ha) of Habiganj Aman IV in a deepwater tank, Joydebpur, Bangladesh, 1980.

Hill spacing (cm)	Seedlings (no./hill)[a] 4	8	Mean[a]
23 x 15	2.7 a	2.7 ab	2.7 a
23 x 23	2.2 c	2.6 ab	2.4 b
Mean	2.5	2.7	

[a]Figures in a column followed by a common letter are not significantly different at the 5% level. Flooding depth: 2.0 m; CV (%) = 7.8.

Over several seasons, crop-cuts in the Narsingdi area from fields where the local variety Gilamyt was transplanted produced more than 3 t/ha (Catling et al 1978). Replicated observational plots at Gilamyt in the same area, with 15- × 15-cm spacing, 3 seedlings/hill, and fertilized with 40 kg N/ha, yielded 3.2 t/ha.

In certain areas of Bangladesh yields of 3 t/ha can be obtained with good management of a transplanted crop. Results of a fertilizer response trial with a transplanted crop are presented later in the section on fertilizer use.

Relay cropping

An extension of the normal transplanting practice is to transplant deepwater rice seedlings into the preceding crop as it matures to gain time for establishment before flooding. This can be carried out best if a space for seedlings is left in the preceding crop (Fig. 1).

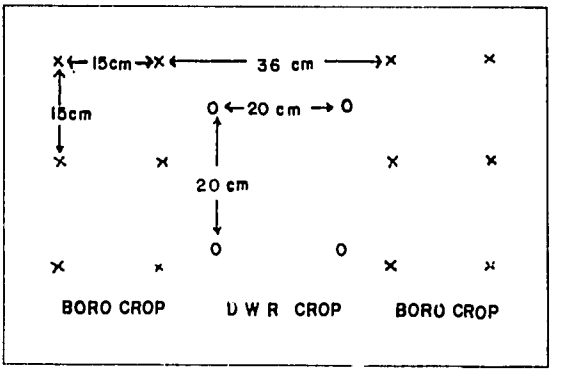
An experiment at the Habiganj regional station in 1979 showed that 50-cm spaces could be left between paired boro rows without any significant reduction in yield. Mean boro yields were 4.3 t/ha, deepwater yields were 0.8 t/ha (Francis 1980).

FERTILIZER USE IN CROP ESTABLISHMENT

The use of fertilizer on deepwater rice in Bangladesh is localized. The two major factors involved in increased fertilizer use are the increased intensity of cropping, including boro cropping, and the local hydrogeologic factors such as silt deposition and rainfall.

Crop-cut surveys between 1978 and 1980 showed that many of the farmers were using fertilizer of some kind (Clay et al 1978). In 1977 19% of the farmers used fertilizer; in 1978, 31%. Fertilizer use was more extensive on the Meghna floodplain, which has a higher rainfall and less silt deposition than the rest of the deepwater areas.

We found fertilizer use more common on those areas where cropping was fairly extensive, e. g. where a rabi crop was followed by an aus and b. aman mixture. In



1. Hill spacing layout for deepwater rice relay transplanted into a boro rice crop.

Kalacha, where 100% of the farmers grew this mixture, 70% used fertilizer of some kind. Where phosphorus was applied it was as a basal application of triple superphosphate (mean level 14 kg P/ha). Nitrogen was usually applied as urea (mean level 23 kg/ha) 50-60 days after seeding and following hand weeding. Statistical analysis of yield from different fertilizer uses by farmers showed no significant difference. Superimposed fertilizer trials on farmers' fields showed that a significant increase in yield was obtained in the aus crop but not in the aman crop (Table 4) with nitrogen and phosphorus. Some trials harvested in July this year with various mixture of aus and aman showed a consistent aus yield improvement with fertilizer use (Table 5).

Yield increases from fertilizer use in deepwater rice are usually not large and

Table 4. Fertilizer response[a] in a superimposed trial in farmers fields, Kalacha, Bangladesh, 1980.

Treatment	Aus yield (t/ha)	Aman yield (t/ha)	Total yield (t/ha)
NPK[b]	2.02 a	1.82 a	3.84 a
NP	2.02 a	1.90 a	3.92 a
PK	1.93 ab	1.92 a	3.85 a
NK	1.87 ab	2.09 a	3.96 a
0	1.66 b	1.83 a	3.49 a
Farmers' level[c]	1.78 ab	1.99 a	3.76 a
Mean	1.88	1.92	3.80
CV	21	12	11
LSD	.26		

[a]Figures in a column followed by a common letter are not significantly different at the 5% level. [b]NPK = 60 kg N-26 kg P - 33 k/ha. [c]In farmers level there was variability among different farmers. Three farmers used zero fertilizer, one used 21 kg P_2O_5/ha and 21 kg N/ha as a topdress and one farmer used only 12 kg N/ha as a topdress.

Table 5. Yields of aus (broadcast-seeded summer rice) and broadcast aman (deepwater rice) mixtures in farmers' fields at Mirjapur, Tangail, Bangladesh, 1981.

	Yield (t/ha)				Mean[b]
	40[a]	50[a]	60[a]	100[a]	
		50-17 kg N-P_2O_5/ha			
Line-sown	0.28	0.39	0.35	0.93	0.48 a
Broadcast	0.28	0.35	0.43	0.82	
		No fertilizer			
Line-sown	0.17	0.33	0.25	0.57	0.35 b
	0.12	0.26	.42	0.62	

[a]Indicates % aus in the aus and broadcast aman mixture.
[b]Means followed by the same letter are not significant at the 1% level.

thus are difficult to demonstrate in farmers' fields. In 1980, yield increases were obtained in six fertilizer trials in farmers' fields but only two of the increases were significant (Rajbari and Daukhandi). Nevertheless, the mean increase in yield over the 6 fertilizer trials was 21% (Francis 1981).

Some work has been done with different sources of nitrogen for the transplanted crop. At Rajbari, Joydebpur, during the 1980 season a transplanted trial tested different forms of urea at three rates. There was no significant yield difference among the different forms (Table 6). The highest yield (2.9 t/ha), a 33% increase

Table 6. Response of transplanted Habiganj Aman IV to rates and forms of urea, Rajbari, Bangladesh, 1980.[a]

Rates (kg N/ha)	Yield (t/ha)[b] Prilled urea	Sulfur-coated urea	Urea supergranules	Mean
0	-	-	-	2.1 bcde
27	2.7 abc	2.0 e	2.1 de	2.3 c
54	2.7 ab	2.9 a	2.4 abcde	2.1 a
87	2.3 bcde	2.5 abcde	2.6 abcde	2.5 ab
Mean of 3 N levels ns	2.6	2.5	2.4	2.5

[a] Flooding depth: 2.2 m ; CV (%) = 14.4. [b]Figures in columns followed by a common letter are not significantly different at the 5% level.

over the control, was obtained from sulfur-coated urea at 54 kg N/ha. Prilled urea at 27 kg N/ha gave significantly higher yields than the other forms at that level.

Research at BRRI (1979) on survival of seedlings of deepwater rice after flooding have shown that the use of nitrogen fertilizer helps seedlings elongate after submergence. Hence the use of fertilizer in situations where there is danger of the crop being drowned due to late establishment would appear to be advisable. In such situations, where there will be little time for much tillering before water rise, the optimum tiller population would perhaps be best achieved by the use of close spacing of the seedlings at transplanting which, as has been shown, can result in higher yields.

CONCLUSION

With the general intensification of cropping in Bangladesh, farmers have had to make some modifications to their traditional methods of establishing a deepwater rice crop. Perhaps due to increased winter cropping main modifications observed are increased fertilizer use together with more varied systems of establishing the crop at a late date, e.g. by transplanting and relay cropping. A large percentage of the farmers in the shallow-flooded areas are planting aus (summer crop) and B. aman (deepwater rice) mixtures which are capable of total grain yields of more than 3 t/ha and which offer a greater likelihood of avoiding complete crop loss in a year when flood damage is high.

Experimental work on the transplanted crop has shown that high yields are obtainable with this method although care must be taken to use optimum spacing and adequate fertilizer levels. Transplanting eliminates weed problems and facilitates double-cropping with aman (wet season crop) relayed into the boro (dry season) crop, but there is increased risk of losing the crop with quick rising floodwaters.

Deepwater rice yield increase with nitrogen fertilizer application can be obtained both in formal trials and superimposed treatments on farmers' fields. Higher soil fertility is beneficial in producing a large number of healthy tillers which will survive and be productive under deep flooding. This may be especially important in the later-planted fields which have a shorter period of establishment before flood comes.

Some experimental work has been carried out on line-sowing as a new method for establishing the deepwater rice crop. There should be some saving of seed with this method but yield advantages are difficult to show because of volunteer rice problems in farmers' fields. However, on the lighter soils, the better, quicker, and more efficient weeding possible with this method may result in increased use of this method in the future.

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PLANT PROTECTION

WEEDS, WEED PROBLEMS, AND WEED CONTROL IN DEEPWATER RICE AREAS

S. K. De Datta and M. Zahidul Hoque

SUMMARY

Many weeds in deepwater rice fields cause substantial yield reduction. Most weed competition is during the stand establishment and early to mid-vegetative stages when deepwater rice grows as a dryland crop. Some shift in weed species occurs when flooding starts. Predominant weeds in deepwater rice areas in Bangladesh, India, Thailand, and Mali are listed.

Farmers in deepwater rice areas use tillage, raking, manual and mechanical weeding, blocking devices to prevent entry of floating and aquatic weeds to rice fields, and spot spraying with phenoxy herbicides to control weeds. Wild rice species with submergence and elongation capacity are causing concern in Asia, more so in West Africa.

Current research results are inadequate to suggest integrated control of weeds in deepwater rice.

Weeds are a major problem of all types of rice cultures. Weed competition, however, is most serious where rice is seeded and grown on a dry soil. Because deepwater rice is seeded primarily on dry soils and the field remains dry anywhere from 6 weeks to 3 months, weed problems differ greatly from those in any other rice culture.

Minimizing competition from weeds at early stages of rice growth largely determines how well deepwater rices would tolerate stresses due to flooding at later stages. Aquatic weeds upon flooding cause less problems when stand establishment is good and tillering of rices is adequate than when early weed competition is unchecked.

To suggest appropriate weed control measures for deepwater rice areas we classify weeds into:

- weeds that are harmful when rice is grown as a dryland crop, i.e. before flooding,
- weeds that are harmful after flooding, and
- weeds that are harmful both before and after flooding.

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We summarize information on weeds and weed problems in deepwater rice areas, control measures that are followed by the farmers, and weed control technology under testing.

WEEDS AND WEED PROBLEMS IN DEEPWATER RICE

The agroecology in the deepwater rice areas undoubtedly determines the plant associations and as such the incidence of harmful weeds. Even after 4-5 months flooding in deepwater rice fields, a number of weeds offer serious competition.

In all deepwater rice areas in Asia, weeds such as *L. hexandra*, *H. pseudo-interrupta*, *H. aristata*, *S. articulatus*, and the wild rices (*Oryza* spp.) that grow in dryland soils are affected by flooding. On the other hand, weeds such as *E. crassipes* and *N. stellata* move into the fields after flooding occurs in deepwater rice areas (Moody 1981).

Bangladesh

The graminaceous weeds and the sedges affect the deepwater rice before the advent of the flood (Zaman 1975). Some of these weeds die after flooding but others continue to grow and compete with the rice crop. Also, new weeds emerge after flooding. Ahmad (1975) claims that most of the aquatic weeds germinate and grow after flooding and generally in a considerable water depth. He explains that the clarity of water and the intensity of sunlight penetrating may be the major factors that contribute to the germination and subsequent growth of the aquatic weeds. A list of weeds found in the deepwater rice fields in Bangladesh is presented in Table 1 and a brief discussion of those follows.

Among the weeds of deepwater rice, the wild rices are considered among the most serious. The systematic position of all the endemic wild rices is still in confusion (Ahmad 1975). They are known as *Oryza perennis* Moench, *O. rufipogon* Griff., *O. spontanea*, and *O. sativa* var. *fatua* Prain, with the latter most commonly referred to.

O. sativa var. *fatua* possesses highest flood tolerance among the wild rices and produces few tillers and small panicles with 10-15 spikelets (Zaman 1975). The spikelets shatter easily, even before full maturity, which aids dispersal of this weed. The highly dormant seeds possess long awns, which help wider dispersal.

Most of the wild rices are perennial and form a woody root stock that remains viable for many years. Thus, the wild rice propagates through the awned seeds and root stocks and can quickly infest an area. Other deepwater rice varieties cannot produce well in an area heavily infested by wild rice (Zaman 1975).

Scirpus articulatus L. is submergence tolerant and grows with the rice in rising flood to cause considerable damage to the crop.

Sesbania aculeata Poir. and *Sesbania paludosa* Jacq. cause harm to the deepwater rice crop both before and after flooding. Although these plants are sometimes useful in protecting the rice fields from floating masses of water hyacinth [*Eichhornia crassipes* (Mart.) Solms] and are capable of atmospheric nitrogen fixation, they can in abundance cause considerable damage to the rice crop. However, farmers usually make good use of the *Sesbania* sticks for domestic purposes.

Leersia hexandra Sw. is one of the most common and obnoxious weeds in the medium deepwater areas. It reproduces by seeds and root stocks and, therefore,

Table 1. Weed species found in deepwater rice fields in Bangladesh.

Weed species	Botanical family	Period when considered harmful to deepwater rice crop[a]
Oryza sativa var. *fatua* Prain	Gramineae	BF, AF
Scirpus articulatus L.	Cyperaceae	BF, AF
Sesbania aculeata Poir.	Leguminoseae	BF, AF
Sesbania paludosa Jacq.	Leguminoseae	BF, AF
Leersia hexandra Sw.	Gramineae	BF, AF
Hymenachne pseudo-interrupta Muell.	Gramineae	BF, AF
Hygroryza aristata (Retz.) Nees	Gramineae	BF, AF
Eichhornia crassipes (Mart.) Solms	Pontederiaceae	AF
Monochoria vaginalis (Burm. f.) Presl	Pontederiaceae	AF
Vossia cuspidata (Roxb.) W. Griff	Gramineae	AF
Pistia stratiotes L.	Aroideae	AF
Chamaeraphis gracilis Hack.	Gramineae	AF
Nymphaea stellata Willd.	Nymphiaceae	AF
Ipomoea aquatica Forsk.	Convolvulaceae	AF
Echinochloa colona (L.) Link	Gramineae	BF
Eleusine indica (L.) Gaertn.	Gramineae	BF
Echinochloa crus-galli (L.) Beauv.	Gramineae	BF
Cyperus rotundus L.	Cyperaceae	BF
Cyperus iria L.	Cyperaceae	BF
Cyperus difformis L.	Cyperaceae	BF

[a]BF = before the rice fields are flooded; AF = after the rice fields are flooded.

cannot be easily controlled. Zaman (1975) observed that among the graminaceous weeds of deepwater rice, *L. hexandra*, *Hymenachne pseudo-interrupta* Muell., and *Hygroryza aristata* (Retz.) Nees are most harmful. These weeds elongate with flooding and offer competition to the rice crop. Submergence by floodwater may kill some of these weeds.

Water hyacinth, *E. crassipes*, is considered the most obnoxious water weed (Alim 1956) and can completely destroy a deepwater rice crop. Masses of water hyacinth are usually carried to rice fields by water currents or strong winds. Once in the fields, the hyacinth masses completely damage the crop within a few days by suffocating the rice plants. In sparsely populated rice fields, as well as in nearby noncultivated fields, water hyacinth population may gradually build up and ultimately take over.

Monochoria spp. is one of the most common weeds of deepwater rice (Chowdhury and Zaman 1970). This weed is harmful particularly at the early stage of flooding.

Vossia cuspidata (Roxb.) W. Griff. is a gigantic floating grass usually found in the deeper areas. It usually grows in thick masses in vacant fields and in sparsely

populated rice fields. It is widely used as feed for horses and cattle.

Pistia stratiotes L. is a small floating weed that occurs in masses in most of the deepwater rice areas. However, it is not found in densely populated deepwater rice fields.

Chamaeraphis gracilis Hack. is a floating aquatic grass (Alim 1956). It is harmful after flooding and found mainly in the deeper areas of the deepwater rice basins.

Nymphaea stellata Willd., the national flower of Bangladesh, competes with the deepwater rice crop. However, it grows mainly in vacant fields and sparsely populated rice fields. It can tolerate prolonged submergence, and grows with the rising water level. In Bangladesh, its stem and seed are eaten as a vegetable.

Ipomoea aquatica Forsk., also used as a vegetable, can grow in sparsely populated deepwater rice fields and in open spaces from where it may intrude on rice fields and cause some damage.

Before the advent of flooding, the deepwater rice crop may be heavily infested by *Echinochloa colona* (L.) Link, *Eleusine indica* (L.) Gaertn., and *Echinochloa crus-galli* (L.) Beauv. These weeds may also cause considerable damage to the rice crop even during the early stage of flooding. Farmers usually uproot these weeds and feed to the cattle, even when the deepwater rice plants are about a meter tall. Sometimes, these weeds are sold in bundles as green fodder.

In the higher ridges of deepwater areas, such as in the summer rice (aus crop in Bangladesh and India) and deepwater rice mix-cropped fields, *Cyperus rotundus* L., *C. iria* L., and *C. difformis* L. are common.

India

Many papers summarize problems of deepwater rice areas in different states of India (For Assam: Barroah and Uzir 1962, Borthakul 1971; for West Bengal: Mukherji 1970, 1975; Mukhopadhyay and Ghosh 1979; for Bihar: Chatterji 1951, Saran 1977). However, few papers actually summarize information on weeds and weed problems in deepwater rice in India.

For West Bengal, Mukhopadhyay and Ghosh (1979) list *E. crassipes*, *Ipomoea* sp., and *Scirpus* sp. Other weeds mentioned are *Monochoria vaginalis* (Burm. f.) Presl, *Sagittaria sagittifolia* L., and *C. iria* during early flooding (15-20 cm). Algal weeds are also mentioned to be present in the districts of 24-Parganas, Howrah, and Midnapore.

For Assam, grassy weeds (Mukherji 1970), particularly wild rice similar to that in Bangladesh, cause serious problems in deepwater areas.

Because deepwater rice water regime is in continuum from rainfed wetland to floating (De Datta 1981), some of the weed species overlap.

Among the common noxious aquatic weeds in India, *E. crassipes* is most serious, reported from 98 districts (Table 2). How many of these weeds actually cause damage in deepwater rice in India is not clear, however.

Thailand

In Thailand, grasses, sedges, broadleaf weeds, and aquatic weeds cause serious problems in the period before flooding of deepwater rice (Suwatabandhu 1950, Kittipong 1982).

The principal weeds in deepwater areas are *Echinochloa stagnina* (Retz.) Beauv., *E.*

Table 2. Ten most common noxious aquatic weeds in India, arranged in order of decreasing importance on the basis of assessment of relative preponderance of individual species in different districts (Varshney and Singh 1976).

Weed species	Nature of weed	Districts	
		Actual distribution in (no.)	Causing concern in (no.)
Eichhornia crassipes (Mart.) Solms	Free-floating	98	92
Nymphaea stellata Willd.	Rooted-floating.	85	83
Nelumbo nucifera Gaertn.	Rooted-floating	86	79
Hydrilla verticillata Presl	Rooted-submerged	87	83
Typha sp.	Emergent	69	65
Lemna sp.	Free-floating	77	46
Vallisneria sp.	Rooted-submerged	71	40
Potamogeton sp.	Rooted-submerged	66	37
Pistia stratiotes L.	Free-floating	78	41
Salvinia sp.	Free-floating	60	19

picta (Koen.) Michael, *Ischaemum rugosum* Salisb., *Leptochloa chinensis* (L.) Nees, *L. panicea* (Retz.) Ohwi, *Aeschynomene aspera* L., *Pentapetes phoenicia* L., and *Melochia concatenata* L. (De Datta 1980).

Flooding in deepwater rice areas generally starts in mid-September and water depth will vary from 0.75 to 1.5 cm for about 2 months. During flooding aquatic weeds predominate and some of the major weeds that are not killed by the rising flood continue to grow. Weeds and degree of infestation in Thailand's deepwater areas are given in Table 3.

Mali

In Mali, the most troublesome weeds, according to farmers, are *Oryza longistaminata* Chev. and Roehrich and *O. barthii* A. Chev. (Toure 1979). A list of important weed species in floating rice fields is presented in Table 4. Farmers do not regard *Oryza glaberrima* Steud. as a weed and do not remove it during weeding. Other weeds mentioned as important are *Sacciolepis* sp. (15.6%), *Brachiaria* sp. (7.8%), *Echinochloa* sp. (1.6%), and broadleaf weeds (3.1%). Cyperaceae weeds are not considered important because of their early vegetative cycle (WARDA 1978a).

Although *O. longistaminata*, *O. breviligulata* Chev. and Roehrich, and *O. glaberrima* are prevalent in Mali, only *O. longistaminata* is difficult to control. Other weeds suggested as important are *Panicum anabaptistum* Steud., *Brachiaria* sp., and *Sacciolepis cymbiandra* Stapf. The most noxious broadleaf weeds are *Melochia corchorifolia* L., *Aeschynomene sensitiva* Sw., *Sesbania sesban* (L.) Merr., and *Ipomoea aquatica* Forsk.; noxious sedges are *Cyperus*, *Eleocharis*, and *Pycreus* species. Floating weeds are *Neptunia oleracea* Lour., *Nymphaea lotus* L., and *Nymphoides* sp. (WARDA 1979a).

Table 3. Weeds and degree of infestation in deepwater rice in Thailand (Kittipong 1982).

Weed species	Degree of infestation[a]
Pentapetes phoenicea L.	**
Aeschynomene indica L.	*
Alternanthera philoxeroides (Mart.) Griseb.	*
Cyanotis axillaris (L.) D. Don.	**
Ipomoea aquatica Forsk.	*
Melochia concatenata L.	*
Commelina diffusa Burm. f.	*
Echinochloa colona (L.) Link	**
Panicum cambogiense Balansa.	**
Leptochloa chinensis (L.) Nees	**
Echinochloa crus-galli (L.) Beauv.	**
Paspalum scrobiculatum L.	**
Ischaemon barbatum Retz.	**
Cyperus pulcherimus Willd. ex Kunth	*
Fimbristylis littoralis Gaud.	*
Cyperus rotundus L.	*

[a] * = common, ** = most common.

Germination and growth habits

Basic studies on various weeds in the Mopti, Mali, areas suggest that compared with *Oryza stapfii* Roshev. (80% germination 5 months after harvest), *O. barthii* (maximum germination, 51%) and *O. longistaminata* (maximum germination, 16%) were highly dormant indicating the difficulty of controlling these rice weeds (WARDA 1980).

E. stagnina is an annual or perennial species distributed in tropical Asia and in Africa (Bor 1960). Perennial strains have been collected in Assam and West Bengal, India, and in Burma, Thailand, Sri Lanka, and West Africa. The perennial strains have creeping stems, and easily sprout or root from the nodes (Yabuno 1982). They are also self-pollinated and reproduce by seed. The interior of the stem of the perennial strains is spongy and suitable for thriving underwater growth. These strains can elongate with rise in floodwater and float (Yabuno 1966). For these reasons they are locally considered troublesome weeds. Plants of the West African perennial *E. stagnina* with floating habit are much larger and grow more vigorously under water than the Asian floating strains.

Stoloniferous perennial *E. stagnina* distributed in the floating rice areas in Southeast Asia and tropical West Africa, and rhizomatous perennial *E. pyramidalis* (Lam.) Hitchc. & Chase distributed in tropical Africa have floating habits. These two species have various cytotypes and their taxonomy is not yet fully described (Yabuno 1982).

CROP LOSSES IN DEEPWATER RICE DUE TO WEEDS

Few experiments on crop losses due to weeds in deepwater rice are reported. However, it has been observed that deepwater rice may suffer from severe weed

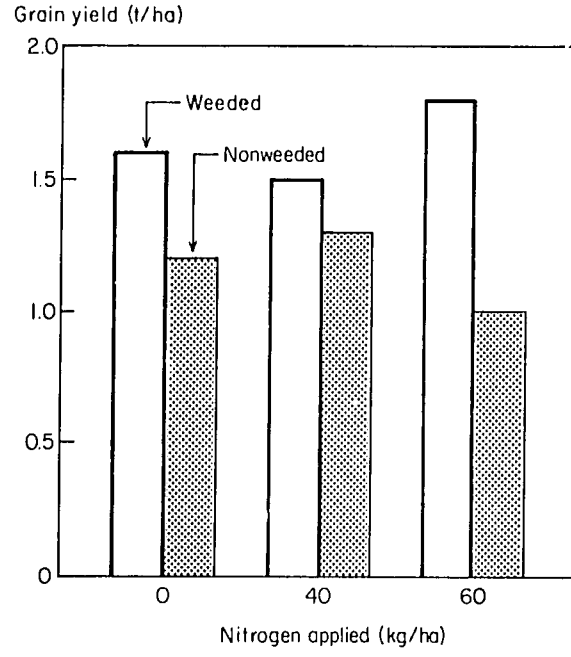
Table 4. List of important weed species in floating rice fields in Mali (WARDA 1981).

Weed species	Family
Brachiaria sp.	Gramineae
Echinochloa stagnina (Retz.) Beauv.	Gramineae
Echinochloa lelievrei (Cheval.) Berhaut	Gramineae
Oryza barthii A. Chev.	Gramineae
Oryza glaberrima Steud.	Gramineae
Oryza longistaminata Chev.	Gramineae
Oryza stapfii Roshev.	Gramineae
Paspalum scrobiculatum L.	Gramineae
Sacciolepis cymbiandra Stapf.	Gramineae
Vossia cuspidata (Roxb.) W. Griff.	Gramineae
Cyperus sp.	Cyperaceae
Eleocharis plantaginea R. Br.	Cyperaceae
Scirpus praelongatus Poir.	Cyperaceae
Pycreus sp.	Cyperaceae
Aeschynomene sensitiva Sw.	Papilionaceae
Sesbania sesban (L.) Merr.	Papilionaceae
Achyranthes aspera L.	Amaranthaceae
Alternanthera sessilis (L.) R. Br. ex Roth.	Amaranthaceae
Melochia corchorifolia L.	Sterculiaceae
Corchorus fascicularis Lam.	Tiliaceae
Ipomoea aquatica Forsk.	Convolvulaceae
Neptunia oleracea Lour.	Mimosaceae
Nymphaea lotus L.	Nympaheaceae
Nymphoides sp.	Nenyanthaceae
Caperonia sp.	Euphorbiaceae
Utricularia stellaris L.	Lentibularieae
Borreria filifolia (S. & Th.) K. Schum	Rubiaceae
Polygonum mildbredii	Polygonaceae

infestation during the preflood period if no weeding is done. Weed problems increase when low seeding rates are used and stand establishment is poor due to drought. Weed growth during the preflood period reduces the growth and tillering of the rice plants. Fortunately, however, flooding and subsequent submergence kill most of the grasses and sedges that germinate before flooding. But if flooding is below normal these weeds, if not removed, may cause crop failure.

An experiment with the deepwater rice variety Dudlaki at the BRRI Habiganj Deepwater Rice Research Station, Bangladesh, determined the effect of weeding and basal nitrogen application rates on the grain yield (BRRI 1980). In the weed-free treatment, the plots were kept weed free by hand weeding until flooding. The results are presented in Figure 1. Weeding gave an average grain yield of 1.6 t/ha as compared to 1.3 t/ha from the nonweeded check, a significant difference at the 1% level. There was no significant effect of basal nitrogen application rate on the grain yield.

In another BRRI trial with the variety Habiganj B. Aman IV, it was found that if



1. Grain yield of deepwater rice (variety Dudlaki) as influenced by weeding at three levels of nitrogen application, Habiganj Deepwater Rice Research Station, Bangladesh, 1979 (adapted from BRRI 1980).

weeds are not controlled before flooding, the grain yield may be reduced as much as 32% (Table 5).

In deepwater rice in West Bengal, India, even at shallow flooding, yield losses due to weeds including water hyacinth are heavy (Mukhopadhyay and Ghosh 1979).

In Thailand, weeds such as *Cyperus pulcherimmus* Willd. ex Kunth, *Echinochloa crus-galli* (L.) Beauv., *Ischaemum barbatum* Retz., *L. chinensis, Setaria* sp., *Alternanthera philoxeroides* (Mart.) Griseb., *A. aspera, M. concatenata,* and others provide severe competition to deepwater rice especially during stand establishment and vegetative stages (Prechachat and Jackson 1975).

At Mopti, Mali, competition due to weeds such as *O. longistaminata, P. anabaptistum,* and *M. concatenata* causes severe yield reduction. In 1 study, yield of deepwater

Table 5. Effect of weed control treatments on the yield of the deepwater rice variety Habiganj B. Aman IV. Joydebpur, 1980.

Weed control treatment	Grain yield t/ha[a]		%
Weed free until flooding by hand weeding	2.5	a	100
Premergence herbicide Oxidiazon at 1 kg a.i./ha	2.2	ab	92
Not weeded (check)	1.7	b	68

[a]Yields with a common letter are not significantly different at the 5% level, DMRT. Source: BRRI 1981.

rice was reduced 33%. When weeding was delayed until 60 days after seeding (DS) the traditional method of 1 weeding during flooding did not control those weeds effectively (WARDA 1979b). Farmer field studies on yield losses due to weeds revealed a significant yield difference between weeded and nonweeded plots — the percentage loss ranged from 9 to 82% (WARDA 1979b).

WEED CONTROL PRACTICES OF FARMERS

Deepwater rice farmers in Bangladesh and India recognize weeds as a major constraint to rice yields. Traditional methods of weed control include raking and hand weeding.

In Bangladesh, a 3-year survey in the major deepwater rice areas revealed that at least 95% of the farmers weed their fields yearly (Table 6). Based on data for 3 years, an average of 97% of the farmers in Bangladesh do some kind of weed control in deepwater rice. This clearly indicates the importance of weeding in the deepwater areas and the value attached to it by the farmers.

Control measures before flooding

Deepwater farmers' traditional methods of weed control are raking and hand weeding. Some farmers use herbicides.

Raking. Farmers rake dry deepwater rice fields with bullock-drawn wooden rakes. Raking is more convenient in the light-textured soil areas. In the heavier-textured soils clods make the operation somewhat difficult. Raking breaks the soil crust formed by monsoonal showers, forms a dry soil mulch, thins the deepwater rice population, and uproots many weeds. Bangladesh farmers do about two rakings/field (Table 6).

In some cases, farmers do laddering (dragging a ladder-like device) before raking to make raking easier. Laddering and raking undoubtedly damage the deepwater rice crop but reduce hand weeding and help farmers control weeds on a large-scale basis. Raking and laddering are done when rice seedlings are 10-15 cm tall.

Hand weeding. Hand weeding is the most common and most effective method of weed control by deepwater farmers. Preflood hand weeding range from 1 to 3. The

Table 6. Intensity of farmers' weed control practice in deepwater rice crop in Bangladesh, 1977-79.[a]

Observation	1977[b]	1978	1979
Sample fields (no.)[c]	63	74	71
Fields weeded (%)	98	95	97
Average no. of hand weeding/field	2.0	1.9	1.8
Average no. of rakings/field	-	1.9	1.8
Average no. of weeding after flooding field	-	0.4	0.3

[a]Source: Catling et al 1979, 1980. [b]Dash indicates data not collected. [c]Surveys covered major deepwater rice growing areas of Bangladesh. Sample numbers in this table represent only those from which information on weed control were used.

3-year field survey in Bangladesh (Table 6) revealed that farmers apply almost 2 hand weedings. During the first, and sometimes a second, hand weeding, Bangladesh farmers use a small hand hoe, which helps uproot the weeds and breaks the crust on the soil surface. In most second, and all third, hand weedings, farmers weed by hand pulling.

In 1980, farmers' weed control at the BRRI deepwater rice-based cropping systems research site at Daudkandi was monitored (Hoque et al 1981b). On the average, single, double, and triple hand weedings were practiced by 22, 68, and 10% of the farmers (Table 7). The average timing of the 1st, 2d, and 3d hand weedings were 33, 51, and 75 DS. Three hand weedings were used in the popular varieties Kartiksail and Sada Pankaish. A small number of farmers grew the varieties Vitali Bajal and Ari Raj and applied only 1 hand weeding either at a delayed (58 DS) or early (11 DS) date but within the time of the first flush of weeds after the initial rains.

The labor and costs for different field operations, including hand weeding, in farmers' 1980 deepwater rice crop in Bangladesh were also monitored (Hoque et al 1981a). A total of 447 hours/ha are spent in hand weeding (Table 8) — 56% of the total labor requirements for the different field operations in deepwater rice. On the basis of the 1980 study, it was calculated that farmers spent US$60/ha for weed control, 52% of the total labor costs for all field operations. The total cost of deepwater rice production in the study area was about US$162/ha and about 37% of that spent for weed control alone. Farmers, however, mostly use available family labor for hand weeding.

In Thailand hand mowing of rice plants and weeds before flooding is common. The weeds and rice are then fed to water buffalo (Kittipong 1982).

Herbicides. In Thailand, 2,4-D (2,4-dichlorophenoxy acetic acid) is applied as a spot treatment, but farmers seldom apply herbicides to their entire fields. Recently, there have been increasing reports of wild rice causing considerable problems, which is now attributed to shift in primary tillage from animal-drawn plow to large tractors. At present, there is no practical method to control wild rice (Prechachat and Jackson 1975).

Phenoxy acid herbicides are used by Thai farmers to control difficult weeds such as rice teaweed (*M. concatenata*), jointvetch (*Aeschynomene indica* L.), and morning glory (*I. aquatica*) because they are strong competitors and can survive in deep water (Kittipong 1982).

Control measures after flooding

Weed control after flooding is mainly by hand. Some farmers erect barriers to prevent weed from entering fields.

Hand weeding. Some farmers attempt to remove the weeds, particularly the water weeds, from the fields even after flooding (Table 6). But such weeding is difficult. Farmers sometimes use indigenous boats and floats, such as one made of banana trunks, to remove weeds in deep water. Such an operation is particularly attractive when the farmers can feed the collected weeds to livestock.

Border crops. Farmers in some areas grow a strip of *S. aculeata*, *S. paludosa*, *A. aspera*, or even jute (*Corchorus capsularis* L.) along the border of deepwater rice fields to prevent the entry of water hyacinth and other weeds.

Table 7. Frequency and timing of farmers' hand weeding (HW) in 1980 deepwater rice crop, BRRI cropping systems research site at Daudkandi, Comilla district, Bangladesh.[a]

Deepwater rice variety	Samples (no.)	Seeding date	Farmers practicing (%)			Time of HW (DS)[b]			Maturity (DS)
			1 HW	2 HW	3 HW	1st HW	2nd HW	3d HW	
Kartiksail	18	9 Apr	11	72	17	27	49	73	215
Sada Pankaish	8	11 Apr	24	63	13	30	55	89	221
Ejuli Khama	8	15 Apr	12	88		21	44		206
Dulai Aman	3	2 Apr	33	67		35	54		230
Vitali Bajal	2	30 Mar	100			58			230
Ari Raj	1	26 Apr	100			11			201

[a]Source: Hoque et al 1981b. [b]DS = days after seeding.

Table 8. Labor and cost requirements for different field operations in farmers' deepwater rice crop in Bangladesh, 1980.[a]

Field operation	Labor requirements		Cost of labor	
	Hr/ha	%	US$/ha	%
Land preparation	133	17	18	16
Seeding	4	0.5	<1	<1
Weeding[b]	447	56	60	52
Harvesting	215	27	36	32
Total	799	100	113.59	100

[a]Adapted from Hoque et al 1981a. [b]Total cost of production was US$162.26/ha.

Artificial barricades. Sometimes farmers make barricades with bamboo poles and bars to prevent entry of water weeds into the fields. The barricades also prevent the floating rice crop from being moved from the field by wind or water current.

Removal of wild-rice seed. The wild rices, in most cases, shatter before full maturity. The medium- and long-duration deepwater rice varieties mature after such shattering of wild rices. In some areas of Bangladesh, the grains of the wild rice are harvested before they shatter. Villagers find this job rewarding, particularly in cases of heavy wild rice infestations. This practice provides an extra amount of food and helps prevent dispersal of wild-rice seed.

Other management practices

Other management practices to consider for weed control are crop rotation, stubble burning, and wet seeding and transplanting.

Crop rotation. Farmers in the higher ridges of deepwater areas in Bangladesh grow a crop of jute after one or more deepwater rice crops. The jute crop helps eradicate wild rice and other weeds in deepwater rice fields.

In some cases, farmers sow seeds of deepwater rice variety Maliabhangar at a high rate of 100 kg/ha. Maliabhangar seedlings have dark purple vegetative parts and are easily distinguished from the green seedlings of wild rice (Zaman 1975). This helps a farmer weed out wild-rice seedlings in the deepwater field.

Burning of stubble. Deepwater rice farmers in many areas burn the rice stubble during the dry season. Burning destroys wild rice and many other weed seeds, root stocks, and other vegetative parts, thereby reducing the weed problems for the next season. Burning also destroys ufra nematode populations and the larvae and pupae of rice stem borers that are in the stubble (Zaman 1975).

Wet seeding and transplanting. In some negligible areas, farmers wet-seed or transplant deepwater rice. In those fields puddling reduces weed infestation to a considerable extent. However, wet seeding or transplanting of deepwater rice is possible only in limited areas where adequate surface water is available. Moreover, if those areas have early flash floods, transplanting involves a great risk of crop failure.

Although most of the observations and studies reported here are from Bangladesh, farmer practices for weed control are similar in northeastern India.

In Mali, farmers use hand weeding after flooding to minimize competition due to *O. longistaminata* and *O. barthii*. Perennial *E. stagnina* is also removed by hand wherever feasible (Yabuno 1982).

In Mali, a survey showed that 7% of the farmers weed their rice fields mechanically by plowing at the end of the cropping season (between January and April) to control rhizomatous wild-rice weeds. Plowing is done early so that the rhizomes are exposed to the sun as long as possible (WARDA 1981).

RESEARCH ON WEED CONTROL IN DEEPWATER RICE

Research on weed control in deepwater rice is at its infancy. Studies to date are scattered and not widely reported.

In West Bengal, India, Mukhopadhyay and Ghosh (1979) reported that 1-2 kg a.i. 2,4-D/ha at the 4-6 week stage of rice growth controlled water hyacinth, *Ipomoea* sp.,

and *Scirpus* sp. Mukherji (1970) reported that a number of herbicides, including nitrofen (2,4-dichloro-4'-nitrodiphenyl ether) and a zinc ethylene bisdithiocarbamate compound, controlled algae as weeds. Nitrofen also contributed to some grass and broadleaf control. If herbicides are used after flooding commences, a boat-mounted sprayer can be used (Catling et al 1980).

Extensive studies are being done by West African Rice Development Association scientists to control weeds in West Africa's deepwater rice areas. Major efforts are focused on the control of *O. longistaminata*. In one trial paraquat (1,1'-dimethyl-4,4'-bipyridylium ion) and glyphosate [*N*-(phosphonomethyl) glycine] at different rates were compared. Results suggest that only glyphosate at 1.1 kg a.i./ha was effective (WARDA 1978b, 1980).

In a WARDA weed control trial with 15 treatments only propanil (3',4'-dichloropropionanilide) at 3.24 kg a.i./ha gave the same grain yield as hand weeding (WARDA 1978b). The weeds present were *Heteronychus oryzae, P. anabaptistum, M. concatenata, A. sensitiva, I. aquatica,* and a wild rice, *O. barthii.*

In a study at Mopti, Mali, the effects of some cultural practices and chemical methods were evaluated to control wild rice (*O. longistaminata*). Most herbicide treatments, with or without cultural practices, reduced wild rice population 90% (Table 9). Another study to control *O. barthii* showed that paraquat at 2.4 kg a.i./ha and glyphosate at 1.9 kg a.i./ha controlled the weed but affected the germination of rice (WARDA 1979b).

Table 9. Efficiency of some methods of controlling *O. longistaminata*, 1978-79 (WARDA 1979b).

Treatment	*O. longistaminata* (no.)/m² Before treatment	After treatment	Reduction in weed population (%)
Mowing under water (twice)	812	53 b	94 ab
Plowing just before flood	840	273 c	68 c
Plowing just before flood + mowing under water once	791	49 c	92
Glyphosate, 2 kg a.i./ha, + moving under water once	938	21 ab	97 ab
Glyphosate, 3 kg a.i./ha	985	42 ab	94 ab
Glyphosate, 4 kg a.i./ha	911	46 b	94 ab
Glyphosate, 5 kg a.i./ha	966	10 a	99 a
F-test	ns	*	*
CV	16%	20%	4%

FUTURE CONSIDERATIONS

Weeds are, undoubtedly, a serious problem in the deepwater rice areas. The controls used are laborious and expensive and a single method cannot be effective in the deepwater areas. For example, chemical or hand weeding (Table 5) may be effective only before flooding; there is still a need to protect the crop from other water weeds after flooding. A combination of methods and techniques is needed.

Research results available so far are negligible and should be intensified. Therefore, all the pertinent factors that affect weed problems in the deepwater areas should be taken into consideration and alternative weed control measures developed. The factors that need consideration include:

- monitoring of present weed problems,
- preseeding tillage operations,
- seeding rates,
- fertilization practices,
- flooding patterns,
- postharvest field operations, and
- cropping patterns.

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DISCUSSION

FRANCIS: We have observed several years that the flowering date of wild rice is a few weeks earlier than that of cultivated rices. Removal of the wild-rice panicles at this stage (when they are easily identifiable) would be an easy method of cleaning up the fields of wild rice.

DE DATTA: That is a good technique if labor is available. However, we should attempt to do it at the early stage of stand establishment.

SARAN: In India and other countries growing deepwater rice, shattering is a common character among many wild rices. Do you have plans to work on the population that grows from the shattered grains?

DE DATTA: We would collaborate in studies of how the wild rice population can be minimized by control during stand establishment. We do not have any interest in research on the population that grows from shattered grains.

KARIM: What is the possibility of using specific bacterial inoculum to control weeds in deepwater rice?

DE DATTA: If somebody can show how to do it, why not?

WAHAB: We can suggest that deepwater-rice farmers plow their land somewhat earlier. If there is heavy rainfall before the 3d or 4th plowing, or if it is possible to add water in the field, that will encourage the wild rice and other weeds to germinate. If the farmers plow the land again after germination of weeds and keep the land fallow 2-3 days, the weeds will die.

DE DATTA: I guess if rain initiates germination of weeds following plowing, subsequent plowing can and does control weeds, including perennials and especially wild rice. However, I do not think irrigation to initiate germination of weeds in deepwater rice is feasible.

SCREENING BANGLADESH DEEPWATER RICES FOR YELLOW RICE BORER RESISTANCE

H. D. Catling and Z. Islam

SUMMARY

Deepwater rices at the stem elongation stage were screened for resistance to natural populations of the yellow rice borer *Tryporyza incertulas* (Walker) in Bangladesh farmer fields. No definite sources of resistance were found in 57 indigenous varieties and 15 advanced breeding lines. Thirteen indigenous varieties with <5% damaged stems need to be retested to confirm possible resistance. Raja Mondal was the best susceptible check variety.

The screening method, which requires the individual dissection of large numbers of elongated stems, is laborious and costly. The succulence, nutritive value, and anatomy of the elongating stem appear to favor the penetration and development of yellow rice borer larvae. The search for sources of resistance should continue. Natural plant resistance should be maintained in new breeding lines by retaining, or increasing, the aquatic tillering ability.

With the emergence of yellow rice borer, *Tryporyza incertulas* (Walker), as the major pest of deepwater rice, a program was initiated in 1978 to screen Bangladesh germplasm for sources of resistance. Major attention was given to varietal reaction in the particularly susceptible stem elongation phase. This is believed to be the first attempt to screen elongating deepwater rice for rice borers.

METHODS

Field sites were selected at the Habiganj Experiment Station (120 km northeast of Dacca) and in farmer fields at Agrakhola (10 km west southwest of Dacca) and Manikganj (3 and 8 km west of Dacca). Standard agronomic practices were

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followed — 1-2 hand weedings, 90 kg/ha seeding rate, and no fertilizer or pesticide. Reduction of volunteer rice was attempted by thorough land preparation. A pigmented marker variety was used along plot boundaries. The germplasm included Bangladesh indigenous varieties of different growth duration and plant type, several foreign varieties, and advanced breeding lines.

Standard field screening was at four sites in 1978 and at three sites in 1979. Plot size was 30-32 m^2. An aggressive negative screening (ANS) experiment was done at Agrakhola in 1979 with single 12-m^2 plots of each entry. In addition five selected Bangladesh indigenous varieties were replicated three times to identify standard susceptible and resistant varieties. Entries that showed high or moderate insect damage in the negative screening were rejected and those with low incidence retested to confirm the results.

All plots were exposed to naturally occurring populations of yellow rice borer. Borer activity was assessed just before flowering by dissecting 100 stems removed systematically from each plot. (Dissection is necessary because deadhearts are a poor indicator of larval damage in elongating deepwater rice.) A threshold level of <5% damaged stems was used to indicate resistance. Counts for deadhearts in the preflood stage were made in 1979 using a 0.25-m^2 quadrat placed 6 times in each plot. Stem diameters were measured with calipers at several sites.

RESULTS

Sixteen entries (10 Bangladesh indigenous rices, 1 Rayada strain, and 5 advanced breeding lines) were screened in 1978 at two sites near Agrakhola village and two sites at Habiganj. At Agrakhola and the deeply flooded site at Habiganj, the advanced breeding lines were adversely affected by hand weeding and rapid floodwater rise. By July the yellow rice borer had attacked every plot and at late elongation stage the indigenous entries averaged 17% (9-25%) damaged stems; the advanced breeding lines had 25% (13-29%) damaged stems. The heaviest damage (mean of 25% damaged stems for the four replications) was recorded at Raja Mondal. Entries with thicker stems tended to be more severely damaged. Catling (1979) provides a more detailed description of these first screening experiments.

In a small, unreplicated trial in a tank at Joydebpur (Dacca) natural yellow rice borer populations caused an average of 53% damaged stems to the Bangladesh varieties Nowla, Khama, Sarsari, and Raja Mondal, and attacked 38% of the stems of three BR lines.

Twenty-one entries were screened at three sites in 1979 (Table 1). Poor stands developed for several advanced breeding lines, particularly at Habiganj. Rice borer activity was low in the preflood period with 0.4% and 2.9% deadhearts counted at deeply flooded sites, and 0.6% deadhearts at the shallow site (means not statistically significant). The flooding regime was similar at both deeply flooded sites and yellow rice borer was the predominant insect pest species. Because the borer populations did not build up until August, only the upper stem sections were significantly infested; lower stem sections escaped serious damage. The highest infestation levels were in Mura Bajal and BR222-B-358. Eight entries averaged between 10 and 20% and 11 entries had less than 10% damaged stems. None of the

Table 1. Reaction of 21 Bangladesh indigenous deepwater rice varieties and advanced breeding lines to natural populations of rice borers at three sites in Bangladesh, 1979.

Entry	Damaged stems (%)			
	Deeply flooded sites,[a] mainly yellow borer			Shallow site,[b] yellow and dark-headed borers
	Habiganj	Manikganj	Mean	
Kartiksail	7.2	2.0	4.6	16.8
Shulpan	7.5	2.0	4.8	8.7
Chota Bawalia	5.6	4.8	5.2	13.5
Lakshmidigha	6.7	3.8	5.3	11.2
Buna Jota	7.6	3.5	5.6	14.7
Khama	4.3	6.9	5.6	13.7
Puiatipari	9.8	4.0	6.9	8.1
Habiganj Aman II	7.8	5.9	6.9	15.7
Sarsari	6.0	11.0	8.5	15.4
Yodaya	9.7	8.1	8.9	13.6
BR 117-3B-37	6.6	11.5	9.1	10.3
Raja Mondal	7.3	13.0	10.2	15.2
Habiganj Aman VIII	9.8	10.8	10.3	3.3
Pankaish	9.6	11.8	10.7	8.0
BR 116-3B-28	10.8	-	10.8	2.2
Badal 106	11.4	11.1	11.3	5.6
Chamara	21.5	6.9	14.2	13.1
BR 222-B-323	22.6	9.3	16.0	1.9
Balam	26.1	12.1	19.1	7.7
BR 222-B-358	31.6	14.8	23.2	3.7
Mura Bajal	30.4	16.0	23.2	4.7

[a]Maximum water depth is 200 cm at Habiganj and 227 cm at Manikganj.
[b]Maximum water depth is 65 cm.

entries were consistently below the 5% economic threshold level, indicating possible resistance. Unlike in 1978, there was no indication of a positive correlation between stem thickness and percentage of damaged stems.

At the shallow-water site, significant stem damage was caused by yellow rice borer and dark-headed borer *Chilo polychrysa* (Meyr.). The overall level of damage was similar to that at the deeply flooded sites but no entries had more than 20% damaged stems (Table 1). However, due perhaps to the much shorter stems and different growth habit of the plants, and greater activity of dark-headed borer, varietal reaction was different from that in the deeply flooded sites.

Sixty-one Bangladesh indigenous rices, 8 foreign varieties, and 20 advanced breeding lines were screened in single plots at Agrakhola in 1979. Severe drought, followed by the normal floodwater rise in July, resulted in poor stands for many entries, especially among the advanced breeding lines. Although the stands had improved by the time of flowering, there were insufficient stems for dissection in

38 of the plots. In some other plots, removal of stems for dissection was further hampered by volunteer rice. As at the deeply flooded Habiganj and Manikganj sites, rice borer damage was mainly confined to the upper half of the stems and the yellow rice borer was responsible for 80-90% of the damage. Of the 51 entries successfully screened, 39 were rejected as susceptible. Twelve were below the 5% threshold for damaged stems and were retained for rescreening (Table 2). A variable reaction was recorded with the five varieties being considered as standard checks. Their mean differences were not significant — 5 and 9% damaged stems for Puiatipari and Chota Bawalia and 16-17% damaged stems for Habiganj Aman II, Khama, and Raja Mondal.

Sources of resistance

Varietal reaction was extremely variable in almost all entries included several times in the screening. Although some varieties tended to be less infested than others, the differences were not statistically significant (Table 3). This also applied to the set of possible standard check varieties when all observations were summed.

Raja Mondal appeared to be the most susceptible check. Although the overall mean level was not significantly higher (Table 3), this thick-stemmed Bangladesh variety was usually more heavily attacked than other varieties.

A list of deepwater rice germplasm screened during 1978 and 1979 is given by

Table 2. Reaction of 51 deepwater rice entries to natural populations of yellow rice borer at Agrakhola, Bangladesh, 1979.

Damaged stems (%)	Entry
0-5	Balam, Bahdoia, Dholadigha, Guda, Habiganj Aman VIII, Hijaldigha, Jhaolath, Kala Aman, Kalaharsal, Keora, Phul Kani, Shulpan
6-10	Azladigha, Bawalia, Bhabani, BR 228-B-153, Chamara, Dudh Lakhi, Gayaba, Gilaymit, Gowai 84, IR7732-1-109, Matia Goral, Moral, Raj Bawalia, Shuli
11-15	Bawalidigha, Beguamon 349, BR 222-B-233-6, BR 222-14-B-358, BR 223-B-8, BR 226-B-204-1, Dinkao Baleo, Dudh Bajal, Dulai Aman, Gabura, Habiganj Aman IV, Kartik Khama, Mago, Nowla, Pankaish, Sailkotha, Shada Aman
16-20	Badal, BR 229-B-88, Lakshmidigha, Saran Kraham, Sonnadigha
21-25	Gorcha, Khali Gorcha
>30	Karkati 87

Table 3. Reaction of Bangladesh indigenous varieties to natural populations of rice stem borers (predominantly yellow rice borer); varieties with 8 observations or more in 1978 and 1979.

Variety	Observations (no.)	Damaged stems (%)	
		Mean[a]	SD
Habiganj Aman VIII	8	9.4	5.7
Puiatipari	10	10.6	8.8
Chota Bawalia	10	10.9	7.9
Habiganj Aman II	11	11.8	7.5
Chamara	8	13.6	7.4
Khama	11	14.5	12.2
Sarsari	8	18.0	16.7
Raja Mondal	11	21.1	14.6

[a]Not significant by analysis of variance.

Catling (1981). The list consisted of 72 entries: 7 Bangladesh pureline selections, 45 Bangladesh indigenous varieties, 5 foreign varieties, and 15 advanced breeding lines (2 from Thailand). Data on the varietal reaction of 26 other Bangladesh indigenous varieties from stem dissections made during surveys for rice borer incidence in farmer fields from 1977 to 1980 are also available (Catling 1981). Of the entries screened more than once, only Shulpan, with a mean of 4.5% (4 observations), was below the 5% threshold level. Nine entries screened once in the ANS experiment were below the 5% level but 4 of those were rejected because the same variety was heavily infested in the surveys for rice borer incidence mentioned above. Thus, 6 varieties were identified with possible resistance: Bhadoia, Hijaldigha, Jhaolath, Kala Aman, Kalaharsal, and Shulpan. Seven varieties (with only one observation each) — Barracha, Bashi Raj, Dudh Moni, Guda Lokhi, Haroli, Horigachi, and Kusta Bawalia — were below the 5% damage level in the insect pest surveys. The 13 varieties mentioned above need to be screened again but it is expected that most will be rejected when the 5% level threshold is applied.

DISCUSSION AND CONCLUSIONS

In most, if not all, seasons, natural populations of yellow rice borer are high enough to effectively screen elongating deepwater rice in Bangladesh fields. All plots were attacked in 1978 and 1979 and prior to flowering, stem infestation levels higher than 30% were common. However, field screening is costly and laborious because large numbers of stems have to be removed from flooded fields for individual dissection to determine borer infestation. At Habiganj in 1979 the removal of 2,100 stems took 12 hours and dissection a further 88 hours. A rapid screening technique is urgently required so that the germplasm can be screened more quickly.

Several indigenous varieties showed <5% infested stems in field tests, but their reaction should be confirmed. The search for resistance should continue for the remaining several hundred indigenous varieties in Bangladesh. It is clear from their general vegetative vigor under attack, especially their ability to produce compensatory aquatic tillers, that many of the indigenous varieties possess valuable tolerance for yellow rice borer.

Many of the advanced breeding lines were attacked by the yellow rice borer despite the use of TKM6 (an accepted source of moderate resistance) in the original crosses of the Bangladesh deepwater rice breeding program. During the genetic advance of these breeding lines it is not usual for the material to be exposed to yellow rice borer, and the segregating material is not purposefully selected for resistance to this insect. Thus, with a greater appreciation of the yellow rice borer it is proposed that breeders routinely reject obviously susceptible materials and maintain the vegetative vigor and aquatic tillering ability of new deepwater rice breeding lines. Screening methods should concentrate on the susceptible elongating stem, which differs greatly from the shorter stem of ordinary wetland rice.

Many of the plant characters known to favor attack by yellow rice borer (Israel 1967, Manwan 1975) are typical of the elongating deepwater rice plant:

- Long, wide, healthy leaves are favorable for egg laying.
- Young stem tissue is produced continuously for 6-8 weeks and is probably favorable for the penetration and nutrition of borer larvae. The first-instar larva is a critical stage in the life history of all stem borers. Fang (1977) found rice stems in continuously irrigated plots more succulent (larger sheath *groove* and lower percentage of dry matter) than stems from well-drained plots. Larval penetration was almost three times higher in the irrigated plots and larval weight was also increased.
- Thick stems with a large lumen (for easy larval movement) are usually favorable for larval development.
- Typically, susceptible varieties have thinner, less lignified hypodermis, smaller vascular bundles, and large air sacs in the parenchyma. Our preliminary examinations revealed a weak hypodermis and small vascular bundles. A high proportion of air passages and poor development of sclerenchymatous tissue was reported in elongating deepwater rice by Chowdhury and Zaman (1970) and Datta and Banerji (1979). A detailed study of the plant characters involved in the response of deepwater rice to rice borers is an important field for future research.

Progress in resistance breeding for rice borers has been limited in shallow-water rice and is negligible in deepwater rice. The basis for borer resistance is polygenic and suitable groups of genes are often difficult to incorporate into breeding lines. Moreover, plant characters associated with resistance, for example, thin stems, are not necessarily desirable agronomically. Nevertheless, there is an obvious need to identify and incorporate yellow rice borer resistance into the new generation of deepwater rices.

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DISCUSSION

HILLERISLAMBERS: You say that breeding materials should be exposed to stem borer. I want to know at what generation you recommend this, because with stem borer incidence as erratic as it is, you may not want to lose promising early-generation materials to unreliable tests.

CATLING: We want breeders to take note of reactions to stem borers in any generation. We emphasize not to take measures to avoid stem borers, and as far as we are concerned any lines attacked by stem borers can be rejected. This is the whole theory of aggressive negative screening.

DURVASULA: Is chemical control for stem borer in deepwater rice effective and, if so, economical?

CATLING: We do not believe it is effective in the flooding period. It is also dangerous to use insecticides during that period.

THE PROBLEM OF YELLOW RICE BORER IN ASIAN DEEPWATER RICE

H. D. Catling and Z. Islam

SUMMARY

The yellow rice borer *Tryporyza incertulas* (Walker) is a major pest of flooded deepwater rice in Bangladesh. More than 40% of the rice stems are consistently damaged and yield losses are 20-40%. Preliminary surveys suggest that the borer is also an important pest of deepwater rice in Thailand, India, and Burma. The pest is closely associated with Asian rice and may have originated in the deepwater rice areas of India and Bangladesh.

Yield loss to yellow stem borer is caused by an erosion of plant stand during the flooding period, a reduction in panicle weight, and production of whiteheads. High population densities of the borer develop in deepwater rice, mainly because of the long growth duration of the plant, the favorableness of the elongating stem for larval penetration and nutrition, and the general adaptability of the insect to an aquatic environment.

The status of yellow rice borer should be immediately confirmed in the other deepwater rice areas of the region. Work should continue on identifying varieties resistant to the insect during the elongating stage, and new but environmentally safe methods of chemical control are urgently required. Efforts should be made to develop cultural control methods such as effective crop residue treatments.

The yellow rice borer *Tryporyza incertulas* (Walker) is a major rice pest in Asia and thus one of the most damaging insect pests of mankind's food. It was recently cited as a major pest in Pakistan, India, Bangladesh, Thailand, Burma, Malaysia, Vietnam, Indonesia, Philippines, Taiwan, South China, and Japan (Commonwealth Agricultural Bureaux 1980). In Bangladesh, it was first listed as a major deepwater rice pest in 1975 (Alam 1975) but it was not until the initiation of the first systematic pest survey in elongating deepwater rice in 1977 that its true status was discovered (Catling and Islam 1979a).

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INCIDENCE OF YELLOW RICE BORER

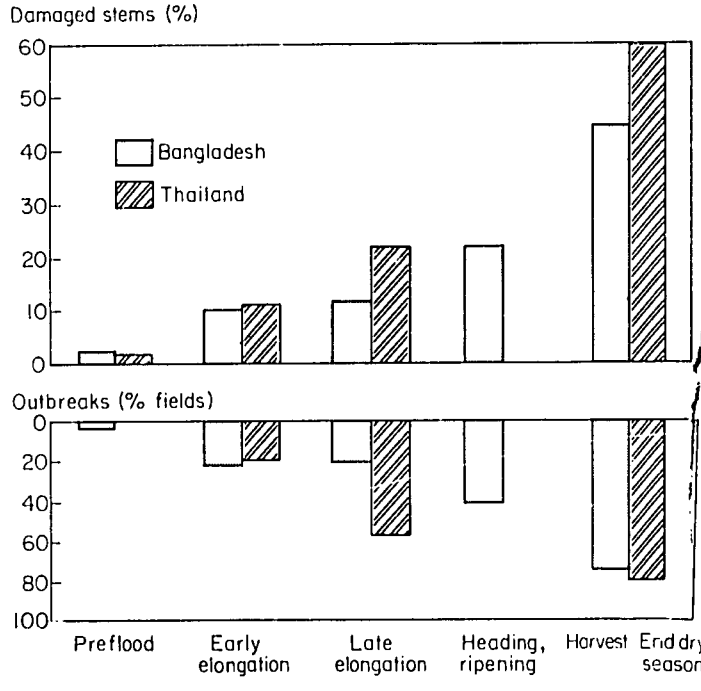
We discuss the status of yellow rice borer by drawing on the results of several unpublished field studies in Bangladesh from 1977 to 1980 and on preliminary pest surveys in Thailand, India, and Burma.

Bangladesh

Farmer fields in the main deepwater rice areas of Bangladesh were intensively surveyed for rice borer incidence from 1977 to 1980 (Catling and Islam 1979a; Catling 1980, 1981). In the preflood period, borer activity was based mainly on counts of deadhearts. During the flooding period and at harvest, a minimum of 100 stems were removed from each sample field for dissection. At harvest a 5-m^2 area of collapsed plant canopy was sampled for whiteheads using a 0.25-m^2 quadrat. More than 56 local varieties were sampled.

The activity of rice borers was low during the preflood period (April to mid-June) with a mean of 2% damaged stems (Fig. 1). Minor outbreaks (> 5% deadhearts) occurred in less than 5% of the fields. Other rice borers in the fields were the pink species, *Sesamia inferens* (Walker), and the darkheaded species, *Chilo polychrysa* (Meyrick).

During the long flooding period (mid-June to October) the proportion of damaged stems increased to 10% in the elongation phase and exceeded 20% at heading and at early ripening (Fig. 1). At those stages the deadheart symptom is usually a poor indicator of stem damage (Catling and Islam 1979a). For the 4-year study, the deadhearts-damaged stem ratio was 1:8. During the elongation phase



1. Incidence of stems damaged by rice borers (predominantly yellow rice borer) in deepwater rice fields in Bangladesh (1977-80) and Thailand (1977-81, preliminary). For Bangladesh, number of fields sampled was 114 at preflood, 47 at early elongation, 59 at late elongation, 47 at heading and ripening, and 36 at harvest. Means for damaged stems among periods were significant in ANOVA at the 1% level (F = 31.53; CV = 25.7%). For Thailand, number of fields sampled was 20 at preflood in 1981, 14 at early elongation in 1977-78, 9 at late elongation in 1979, and 5 in the 1981 dry season. Outbreak thresholds were 5% deadhearts at preflood, 29% damaged stems at flooding period, and 40% damaged stems at harvest.

about 20% of the fields were at outbreak level; by the early ripening stage this had increased to 40% (Fig. 1). The yellow rice borer was totally dominant during the flooding period every year, with 98% of the stem damage attributable to that species.

By harvesttime the proportion of damaged stems increased to a mean of 45% (SD 14.0), two-thirds of the fields at outbreak level (Fig. 1). Whitehead incidence varied from a mean of 3.8% in 1980 to 5.4% in 1979. Whiteheads were also a poor measure of rice borer activity — the whiteheads-damaged stems ratio was 1:8 from 1977 to 1979 and 1:13 in 1980. The two other rice borer species were more common in ripening deepwater rice, but yellow rice borer remained dominant.

Thailand

Preliminary results of short field surveys by Catling in the Central Plains of Thailand from 1977 to 1979 and of detailed observations in April 1981 indicated a pattern of stem damage similar to that in Bangladesh (Fig. 1). In 1979, 22% of the stems were damaged by rice borers at the late elongation stage, and more than half of the 9 fields examined were at outbreak level. At the end of the 1980-81 dry season, borer damage was recorded in 60% of the dry stubble removed from 5 deepwater rice fields. Yellow rice borer was the predominant species during the flooding period. There were indications that *Chilo* spp. may sometimes be more active in Thailand's prolonged preflood period.

India and Burma

Rice borer incidence in several deepwater rice fields in India and Burma were examined by Catling in 1977 and 1980. Yellow rice borer was the predominant species during the flooding period, and the number of damaged stems tended to exceed 20% toward the end of the elongation phase (Table 1).

CROP INJURY AND YIELD LOSS

The yellow rice borer larva enters the lumen (cavity) of the stem and chews irregularly into the parenchyma layer along the internode. Feeding is seldom deep enough to reach the inner ring of the vascular tissue. In many stems the larva attacks more than 1 internode (sometimes 4 or 5 in the thin-stemmed plants) after boring through the nodal septum. Damage to the parenchyma may interfere with cell division and elongation, thus affecting the extension of the stem. It will also affect the nutrient supply and water conduction of the vascular system, the effect being much greater where the septum is eaten through (E. L. Leafe, Grasslands Research Institute, England, 1979, pers. comm.). Before pupating, the mature larva bores a hole through the stem wall for the eventual exit of the moth. Because the feeding is not concentrated at a single point and is usually far below the growing point, few deadhearts are usually produced, especially during rapid stem elongation.

Although elongated plants attacked by yellow rice borer often produce compensatory aquatic tillers, there is a continuous erosion of stems during the flooding period as the weakened stems decay or are covered by rising floodwater. Experi-

Table 1. Incidence of stems damaged by rice borers (predominantly yellow rice borer) in deepwater rice fields in India and Burma, 1977 and 1980.

Site	Date	Growth stage	Fields sampled (no.)	Damaged stems (%)	Outbreaks[a] (% fields)
India: Bihar, W. Bengal	Aug 1977	Early elongation	4	9.3	25
Burma: Maubin	Aug 1977	Early elongation	3	5.3	0
India: Bihar	Oct 1980	Late elongation	4	21.2	50

[a]Outbreak threshold = 20% damaged stems.

ments showed that heavy infestations reduced stem density 10-20%. In pot experiments the panicles borne by compensatory tillers were 27-30% lighter in weight (Catling and Islam 1979b), and the mean weights of all the panicles on attacked plants lower, than those of unattacked plants (Catling 1981). There is a direct yield loss from whiteheads.

A series of crop loss assessments comprising experiments in farmer fields and with potted plants showed that yellow rice borer can cause 20-40% yield loss. In the pot experiments, a 30-40% yield loss was associated with rates of 22-45% damaged stems at harvest. In field experiments a 20-30% yield loss was related to 33% damaged stems (Catling and Islam 1979b, Catling 1981). Thus the damaged stems-yield loss ratio was about 1:1.

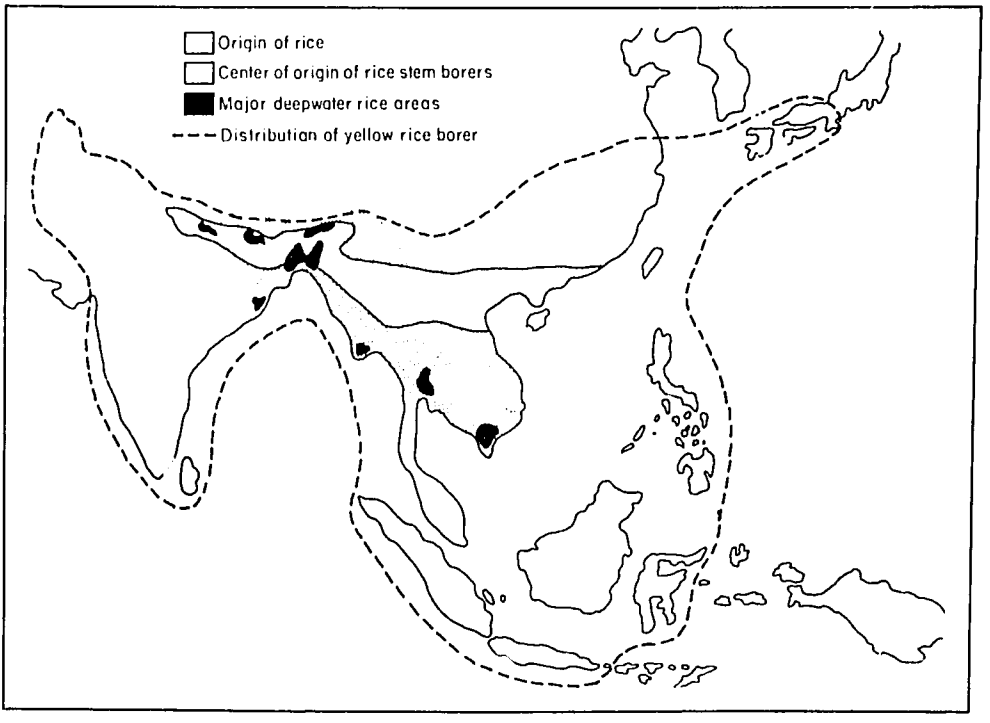
Borer attacks in the early elongation stage appeared to produce greatest yield loss. Economic thresholds for rice borers in the vegetative stage of nondeepwater rice are usually put at 5-10% damaged stems or deadhearts (Dyck 1977), but no comparable data are available for elongated deepwater rice. Conservative outbreak thresholds are used in this paper — 5% deadhearts at preflood, 20% damaged stems at flooding, and 40% damaged stems at harvest (Fig. 1).

ECOLOGICAL NOTES

Yellow rice borer is mainly or exclusively restricted to Asian rices (*Oryza* spp.), and has probably been associated with cultivated rice for thousands of years (Yasumatsu 1976). Thus, it probably originated somewhere within the broad belt starting in northern India, stretching eastward through Bangladesh, Burma, Thailand, and southern China, where rice is endemic. The insect is now distributed from the tropics to the southern parts of the East Asian temperate zone (Fig. 2). Because rice is aquatic or semiaquatic the intimate insect-plant association suggests that the yellow rice borer is inherently adapted to, and probably originated in, an aquatic environment (Yasumatsu 1976). Moreover, because the major deepwater rice areas are within the center of origin for rice borers, and those in India and Bangladesh are near the area of origin for rice, an ancestral deepwater rice may well have been the original host plant of the yellow rice borer.

There is strong evidence that the yellow borer has high moisture requirements. It prefers poorly drained areas, and the larvae always bore downward toward the roots (Yasumatsu 1976). It was one of the few rice insects found to be highly adapted to deeply flooded rice in Bangladesh (Catling 1981). Conversely, high temperature and low humidity before flooding severely lower yellow rice borer populations by reducing egg laying and causing high mortality to egg masses by desiccation. In the tropics, aestivating larvae are dried out and killed during the dry season.

Yasumatsu (1976) contends that rice borer populations are low near the center of origin for rice, with highest densities occurring away from these endemic areas, especially where pesticide use is high. This does not hold for Bangladesh, however, densities of brood 3 and 5 larvae and pupae often exceeded 0.1 million/ha, and in some years approached 0.5 million/ha in flooded deepwater rice (Catling 1981). Population data also indicated that in August and September large numbers of



2. Centers of origin of rice and rice stem borers, major deepwater rice areas, and distribution of yellow rice borer in Asia (sources: Chang 1976, Yasumatsu 1976, Commonwealth Institute of Entomology 1968).

moths from the deepwater rice areas moved into the adjacent transplanted aman crop causing greater damage in it.

Several reasons are given for the extremely high densities of yellow rice borer in flooded deepwater rice:

- The aquatic environment is generally favorable; high humidity and moderate temperature increase egg laying and egg hatch.
- The elongating stem is probably favorable for the penetration of the first-instar larva and the nutrition of all larval stages. Fang (1977) found that the penetration rate and total weight of the larvae were significantly higher on succulent, continuously irrigated plants than on tougher, intermittently watered plants.

In Bangladesh, larval density increased about fourfold from brood 3 to 5 during the flooding period.

- The long growth duration of deepwater rice (180-200 days) enables the development of 4-5 borer generations. Evidence of successive generations was sometimes observed within single stems.
- The developing stages may be less accessible to many parasites once the larvae are inside the long stems.

CONCLUSIONS AND RECOMMENDATIONS

Yellow rice borer is a major pest of deepwater rice in Bangladesh and probably causes significant yield losses in other parts of Asia where rice is deeply flooded for

long periods. The status of this insect should be confirmed immediately in other parts of the region by thorough field surveys. Simultaneously, crop loss assessment studies should be made on several local varieties because extent of yield loss may be strongly influenced by plant type. For instance, the more erect, thicker-stemmed Thai varieties may respond differently to borer attack than the Bangladesh varieties.

Although as yet, no sources of varietal resistance to yellow rice borer are known in the deepwater rices (see companion paper by Catling and Islam, this vol.), the search should continue and be expanded. Breeders must recognize the probable regional status of the yellow rice borer and should guard against the development and release of new varieties that may be less tolerant of rice borer than those presently grown by farmers.

The yellow rice borer is not easily controlled by conventional insecticides. Despite 22 spray applications at 6-day intervals, 9-14% of the stems were damaged at harvest in 3 separate field experiments in Bangladesh (Catling 1981). In another trial, high rates of carbofuran applied at planting failed to give protection in the flooding period. There is also the danger that insecticides could disturb the beneficial fauna and cause fish mortality. However, selective materials or imaginative methods of application may yet be found to assist in controlling the insect.

It is unlikely that the effectiveness of the existing complex of natural enemies can be improved. Thus, at the present time, any control strategy will depend largely on cultural methods and the careful use of insecticides.

The cultural approach is being adopted by the Bangladesh Rice Research Institute where the feasibility of severely reducing the overwintering populations of yellow rice borer is being investigated. In December and January the entire population is confined to stubble in the field (Catling 1981). If this crop residue is burned or trampled by cattle, pest numbers should be drastically reduced, making populations much lower the following season. Because the moth can fly several kilometers, and farmer fields are small and fragmented, this control method requires the concerted action of large groups of farmers. In some places it may also be feasible to combine large-scale trapping with several other cultural methods as has been reported for rice borer control in China (Chiang 1977).

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DISCUSSION

DURVASULA: If stem borers have been long associated with deepwater rice in the region that is the center of origin of rice, why is there no natural selection for resistance?

CATLING: It is possible that the vigorous aquatic tillering of many deepwater rices has evolved partly as a response to sustained borer attack over hundreds of years. We believe that yellow rice borer has been associated with flooded rice for a very long time.

PUCKRIDGE: What is the mechanism of infestation by rice borers? Does this have relevance to morphology and resistance of rice varieties?

CATLING: This is an important aspect, which needs immediate attention. The behavior of first-instar larvae from hatching to complete entry into the stem is the basis for research on resistance breeding and chemical control.

PETPISIT: There are several other kinds of stem borer. Why are yellow ones predominant in the deepwater rice area?

CATLING: The yellow rice borer is the only one well adapted to deeply flooded rice.

WAHAB: On the basis of your study can we suggest control measures for farmers? If you think so, at which stage of the crop can they take the control measure?

CATLING: The destroying or thorough trampling (by cattle) of field stubble will lower the overwintering population and should assist in reducing the borer population in the following season.

SCREENING FOR RESISTANCE TO UFRA DISEASE (*DITYLENCHUS ANGUSTUS*) IN DEEPWATER RICE

L. Rahman and I. McGeachie

SUMMARY

Four hundred and thirty-two deepwater rice entries were tested at BRRI for ufra disease resistance. Seedlings in standing water were inoculated by placing nematode-infested plant materials at their bases. This method of inoculation is simple, fast, and convenient for inoculating a large number of rice varieties at one time. A thorough evaluation of BRRI germplasm collection indicated that it may be possible to identify sources of ufra resistance.

Ufra disease, caused by the rice stem nematode *Ditylenchus angustus* (Butler 1981) Filipjev 1936, is a serious disease of deepwater rice in Bangladesh. Of the eight recognized major pests of deepwater rice in Bangladesh, ufra ranks second based on yield loss (Catling 1980). Ufra occurrence is frequently catastrophic, mostly in the southern regions of the country (Cox and Rahman 1980). Yield loss due to ufra depends on the severity of infection but may reach 100% (Miah and Bakr 1977a). A yield loss of 4% of Bangladesh's total deepwater rice yield due to ufra has been estimated (Catling et al 1979).

Ufra control by phytosanitary methods such as stubble burning, crop rotation, alternate drying, and deep plowing has been recommended. For socioeconomic reasons these methods have not been adopted in Bangladesh. On the other hand, the use of chemicals is not economical or feasible because of limitations imposed by the agroecological conditions of deepwater rice areas. There is a need for ufra-resistant varieties, but no highly resistant variety has been found (Miah and Bakr 1977b, Sein 1977, Hashioka 1963). However, by screening large numbers of varieties from the germplasm collection it may be possible to locate sources of ufra resistance.

Several methods can be adopted for inoculating rice plants with ufra nematodes (Buangsuwon et al 1971, Hashioka 1963, Miah and Bakr 1977, Sein 1977, Rahman 1980). We describe a method of inoculation used for varietal screening for ufra resistance in a specially designed deepwater tank.

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MATERIALS AND METHODS

A culture of the rice stem nematode was maintained on potted BR3 seedlings and used as the source of inoculum. Forty-eight 1 m × 1 m plots with a high levee around each were laid out in the deepwater tank. Levees were plastered with mud to maintain 8-10 cm stagnant water in the plots during the seedling stage. A 50-cm space was left between the plots.

Four hundred and thirty-two deepwater rice entries from the BRRI germplasm bank and breeding lines were screened. On 30 March 1981 10 entries/plot were dry-seeded separately in 10 lines with a 10-cm spacing between lines. Khama, a traditional, ufra-susceptible deepwater variety, was used as a check and sown in the first line of each plot. Two weeks after germination the plant stands were thinned to 20-30 plants/line.

At 25 days after seeding the seedlings were inoculated by spreading nematode-infested materials from the BR3 culture into each plot. For this purpose, 5 infested plants bearing about 30,000 nematodes of all stages were teased longitudinally, cut into small pieces of about 2-3 cm, and spread uniformly over each plot. A water depth of 7-8 cm, to submerge up to half of the leaf bases at inoculation, was maintained for 7-10 days after inoculation. Care was taken to prevent drainage of water from the plots during this period. As the plants started to elongate, the tank was flooded to keep the water level at the uppermost node of the plants. About 30 days after inoculation, 2 live ufra-infested plants were also transplanted in each plot to ensure an adequate level of infestation.

Frequent observations of plants for any visual ufra symptoms were made. We observed faint and chlorotic discoloration (a diagnostic ufra symptom at the vegetative stage) at the leaf base on a few plants 3-4 weeks after inoculation. This symptom became more evident about 7 weeks after inoculation. At this time plants of each entry were examined closely for ufra symptom *in situ*. Entries with visible symptoms were considered as primarily infested and five tillers from them were sampled randomly for subsequent examination in the laboratory.

In the laboratory, plants were dissected to the innermost tender leaf, cut into pieces about 0.5 cm in length, and placed in a *bijou* bottle; 2 ml tapwater was later added. Bottles were left undisturbed at room temperature overnight. At the end of the overnight incubation, a 1-ml suspension from each bottle was examined under a stereomicroscope (15 ×) using a 1-ml Peter's counting slide. Total and average number of nematodes per plant and percentage of infestation for each entry were calculated.

Three weeks after the first sampling, we made a sampling of entries showing ufra symptoms not visible during the first sampling. Processing of plant samples in the laboratory was done as with the first samples. Irrespective of ufra symptoms, the remaining entries were sampled and examined again 10 days after the second sampling.

Based on both the average number of nematodes per tiller and the percentage of infestation, test entries were classified into four broad groups — highly resistant, resistant, intermediate, and susceptible (Table 1). The resistant group (R) was classified into plants infested but not showing symptoms (R^1) and plants infested

Table 1. Four broad groups of test entries based on number of nematodes and percentage of plants infested. BRRI, 1981.

Group	Nematodes (no./tiller)	Infestation (%)
Highly resistant	0	0
Resistant	1-100	01-20
Intermediate	101-300	21-60
Susceptible	>300	61-100

and with visible symptoms (R^2) (Table 2). Some entries did not show any consistent relationship between the average number of nematodes per tiller and the percentage of infestation and were left as unclassified.

The air temperature and relative humidity pertaining to the experimental period were 27 ± 5° C and 81 ± 12%, respectively.

Entries showing highly resistant and resistant reactions to ufra are listed in Tables 3 and 4. The most susceptible entries (100% infestation) were Kalamon, Kalimikri 860, Kalimikri 402, Matiamon 73/10, Laki-2, Bazail-9, BR523-3-1, BR232-2B-3-4/A, and BR516-46-2, with a high nematode population per tiller (about 1,000). Some of the test materials found highly resistant and resistant to ufra in this experiment have also been reported to have drought resistance and good stem elongation ability (Gomosta and Kanter, this volume).

Other work on varietal screening against ufra done at BRRI (S.A. Miah, BRRI, pers. comm.) used metal troughs and incorporated infested stubble with the soil at transplanting. Of the 37 varieties tested, 6 were resistant, 9 intermediate, and the rest susceptible. The resistant ones were Habiganj Boro II, IV, and VI, Lalchiken, Lohagor, and Monolata. Habiganj Aman II and V were highly susceptible.

Table 2. Test entries showing different resistance reactions[a] to ufra, BRRI, 1981.

Condition	Nematode population (no./tiller)	Infestation (%)	Resistance reactions	Entries (no.)
No disease symptom	0	0	HR	116
	1-100	1-20	R^1	7
With disease symptom	1-100	1-20	R^2	62
	101-300	21-60	I	81
	>300	61-100	S	57
	variable	variable	uc	77

[a]HR = highly resistant, R = resistant (R^1 = plants were infested but did not show symptoms, R^2 = plants were infested but there were no visible symptoms), I = intermediate, S = susceptible, uc = unclassified.

Table 3. Varieties with resistance reactions[a] to ufra in tests at BRRI, 1981.

Variety	Resistance reactions	Variety	Resistance reactions
A.C. x VIII	HR	Dhuliaman 38/13	R
Ashkol Boron	HR	-39/2	R
Badal 64/1	R	-51/4	HR
-106	HR	-55/20	HR
-724	HR	-64/3	HR
-734	HR	-142	HR
-745	R	-153/5	R
-744/1	HR	-584	R
-814	HR	-662	R
-613	R	-719	R
Bagdar 1	HR	-746	R
-2	HR	-1015	R
-127	R	Ejuli Khama	HR
Balam	HR	Fulkari-2	R
Beguaman 109	HR	-3	R
Biruin 519	HR	-4	HR
Bodershor	R	-7	HR
Baishbish	R	-8	HR
Chamara	HR	-9	HR
Chota Bawalia	HR	Ghira aman	HR
Cula	HR	Goda danga	HR
Gowai 50/9	HR	Karkati 161	HR
-131/55	HR	-420	HR
-279	HR	Kartik Khama 14	R
-476	HR	Khama 55/22	HR
-812	HR	-361	HR
-842/1	HR	-359	HR
-846	R	-384	R
Habiganj Aman IV	R	-574	R
-VIII	R	-501	R
Kala aman 21/7	R	-583	HR
-38/9	HR	-851	HR
-74	R	-954	HR
-129	R	-1066	HR
-223	R	-1073	R
-243	R	-1165	R
-737	R	-1180	R
-1074	HR	-1183	HR
Kalimikri 119	HR	-1192	R
Kalaray	HR	-1193	R
Kartiksail	HR	Kusta Bawalia	HR
Karia	HR	Laki -544	R
Laki - 9	R	-578	HR
-21	HR	-643	HR
-22	HR	Lakshmidigha-11	R
-25/3	R	Lal aman-648	R
-26	HR	Laijan	R
-39/3	HR	Mati aman 62/2	HR
-56/2	HR	Molladigha 10	HR

Continued on opposite page

Table 3 continued

Variety	Resistance reactions	Variety	Resistance reactions
-117	R	Murabazal	HR
-126	HR	N.C. Khama-3	R
-133	HR	-6	R
-135	R	Pankaish	R
-137	HR	Pankiraj 1171	R
-140	HR	Pathkhola	HR
-142	HR	Rajboalia	R
-146	R	Rajamandol	HR
-182	HR	Shuliboron	HR
-192	HR	Sonadigha 1	HR
-194	HR	Shulpan	R
-461	HR	Sailkota	HR
-492	HR	Shada pankaish	HR
Sitpwa	HR		

[a]R = resistant, HR = highly resistant.

RESULTS AND DISCUSSION

Close visual observations of the ufra-infested rice plants revealed that chlorotic discoloration at the leaf base (a typical ufra symptom during the vegetative stage) may appear about 1 month after inoculation. When tillers of different entries showing this type of symptom were processed in the laboratory, numbers of nematodes recovered from different individual tillers varied. The average number of nematodes per tiller ranged from 2 to 3,120. Similarly, a 16-100% variability in tillers infested with the nematode occurred among different test entries. Based on both the average number of nematodes per tiller and the percentage of infestation, resistance reactions of the entries to ufra were grouped as seen in Table 2.

Of the 432 entries tested, 116 showed an apparent resistance reaction to ufra because neither visible ufra symptoms (chlorosis) nor nematode infestation was detected in these entries. The entries included in group R^1 did not show any visible ufra symptom but had 1-100 nematodes, while entries included in group R^2 yielded 1-100 nematodes/tiller and had 1-20% infestation. The entries belonging to the R groups ($R^1 + R^2 = 69$) are considered resistant because they had a low level of nematode population and low number of infested tillers with or without symptoms.

CONCLUSION

We do not conclude from one season's research that those deepwater rice entries that showed apparent resistance in a deep water tank would also be resistant in the field. Therefore, these entries will be tested in an ufra-infested field in the next season. However, this preliminary experiment suggests that:

- Sources of ufra resistance may be available and further evaluation of the germplasm in the deepwater tank is indicated.
- The seedling-based inoculation method for nematode, which simulates field

Table 4. Advanced breeding lines with resistance reactions[a] to ufra in tests at BRRI, 1981.

Designation	Resistance reactions	Designation	Resistance reactions	Designation	Resistance reactions
Bhadoia/IR8/Habiganj Aman I	HR	BR308-B-2-2	HR	BKN6986-173-5	HR
BR222-B-161-10-2-1	R	BR359-20	HR	BKN6990-63	R
BR308-B-2-3	HR	BR516-11-2	HR	Chenab gel-64-117	R
BR311-B-5-4	HR	BR516-37-4	R	CNL 31	HR
BR224-2B-2-5	HR	BR516-121-3	HR	CNL 241	HR
BR222-B-236-6	R	BR523-11-4	HR	CNL 539	HR
BR306-B-3-2	HR	BR523-93-4	R	CNL 319	HR
BR308-B-2-9/A	HR	BR523-168-3	R	DWCB-2B-6	HR
BR116-3B-28	HR	BR523-193-3	HR	DWC(T)-2B-81-2	R
BR116-3B-133	HR	BR516-11-2	HR	DWC(T)-2B-109	HR
BR223-B-3	HR	BR524-11-1	R	DWC(T)-B-283	R
BR223-B-1	HR	BR524-56-1	HR	DWC(T)-B-285	R
BR307-B-1-1	R	BR324-B-30-513	R	IR424/Habiganj Aman II	HR
BR308-B-2-1	R	BR223-B-1-4-1	R		

[a]R = resistant, HR = highly resistant.

conditions, is the most effective and the easiest method of inoculation for fast screening a large number of rice varieties against ufra.

- Because healthy appearing plants may also have nematode infestation, plants not showing ufra symptoms should also be sampled for evaluation of resistance reaction.
- A standard scoring system for evaluating resistance reactions of rice varieties to ufra either at the vegetative or the reproductive growth phase of the rice plant should be developed.

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DISCUSSION

CATLING: It is interesting that among your highly resistant and resistant varieties in the ufra screening experiments, three of them — Shada Pankaish, Khama, and Kartiksail — were the highest yielders in the Meghna floodplain in our crop-cut studies.

RAHMAN: That is a nice comment. Along with the comment I must mention that some varieties — Chamara and Baishbish — had good elongation ability as well. However, the highly resistant varieties are going to be tested in a farmer's field next season. After the field test we can transfer the varieties to the breeders to incorporate the ufra resistance characters with other agronomic traits.

BRACKNEY: Have the materials you identified as resistant to ufra been screened enough so that you are sure all are truly resistant?

RAHMAN: This is the preliminary screening test. From this year's experiment I will not conclude that they are truly resistant. They will be retested next season. Environmental conditions, either macro or micro, were the same for all varieties in all plots, there is no question of escaping infection. But if it happened, why? Is it due to morphological, physiological, or biochemical characters associated with respective varieties? We are searching for sources of resistance by spreading nematodes in a simulated field condition.

DURVASULA: We heard here that ufra is the most serious pest in deepwater rice in Vietnam and this is true in other deepwater areas as well. So it is heartening to note the improved screening technique as well as resistant varieties for ufra. I would strongly suggest nomination of those resistant lines to the IRTP deepwater nurseries for testing in different countries and thus making available the resistant sources to the various breeders involved in deepwater rice varietal improvement.

RAHMAN: I fully agree and it would be really interesting to test these varieties in different countries.

DELAYED PLANTING OF DEEPWATER RICE: A NEW APPROACH FOR UFRA CONTROL

I. McGeachie and L. Rahman

SUMMARY

The length of the overwintering period of the stem nematode, the causal organism of ufra disease in deepwater rice, is a critical factor in its survival from one season to another. Prolonging that period, either by delaying sowing or by transplanting, is suggested as a method of ufra control. In 1980 plots were sown or transplanted with a local deepwater rice variety susceptible to ufra, at 4 dates starting from the farmer's usual time for sowing. During the vegetative growth the earlier two plots had the highest level of infestation. At harvest, later establishment was found to significantly decrease ufra incidence and increase yield. Results to date may help in formulating an optimum strategy for ufra control.

Ufra, a rice disease caused by the rice stem nematode, *Ditylenchus angustus* (Butler 1913) Filipjev 1936, was first reported in Bangladesh in 1913. It is a serious rice disease in some deepwater areas and can cause as much as 100% loss in small fields characteristic of Bangladesh.

Ditylenchus angustus reproduces on rice plants throughout the growing season, feeding mainly on soft tissues such as leaf sheaths and developing panicles. After flowering, ufra effects can be seen clearly because panicles of infested plants often neither fail to emerge, emerge partially but are spirally twisted, or emerge fully but have mostly empty grains. The ufra nematode can infest most types of rice but the broadcast aman crop, which is grown in the wettest areas and has a long growth period during the wettest part of the year, is particularly prone to infestation.

Boro (winter) rice crops in areas with ufra can also be infested and, although not severely damaged, can provide a source of inoculum for subsequent broadcast aman crops. Before harvest, the broadcast aman plants ripen and dry and ufra nematodes on them coil and enter a cryptobiotic state — one which is reversed by providing water.

Nematologist, and plant pathologist, ODA/BRRI Deepwater Rice Pest Management Project, BRRI, Joydebpur, Bangladesh.

Although nematodes may survive in an active state on volunteer rice, wild rice, or on some weed species, infested crop residues are the primary source of ufra inoculum in deepwater rice (Cox and Rahman 1980a).

Cox and Rahman (1979) and, more recently, we studied the factors that influence the overwintering state of *D. angustus*. Our studies showed a decline in the viability of the coiled nematodes over the dry winter period. In endemic areas the survival rate is normally just sufficient to ensure infection of the spring-sown crop. The length of the winter phase is a critical factor in determining the survival of the disease from one season to the next. This may explain the uneven distribution in ufra areas. For example, in 1979 spring rains were delayed and, subsequently, ufra was either absent or was at a low level in many areas (Cox et al 1980). If the length of the winter phase is critical, then any method of prolonging it, for example, by sowing later or by transplanting the crop would result in some degree of control.

The feasibility of deliberately delaying planting as a control measure against ufra was investigated in 1980-81.

MATERIALS AND METHODS

In 1980 and 1981, fields with a history of ufra in Chor-niloki, Matlab Bazar, were studied. Chor-niloki is a deeply flooded area where ufra is always present in the broadcast aman crop.

In 1980, a 1,400-m^2 field was divided into 8 equal plots. These were planted on four dates to a local variety, Hassi Aman, which is susceptible to ufra. The seed was broadcast-seeded on the first two plots 19 February (T_1), the usual date for sowing in the area. The next two plots were planted 6 March (T_2), another two on 21 March (T_3), and the last two on 16 April (T_4). In T_2 and T_3, seed was broadcast but in T_1 2-month-old seedlings grown in a noninfested seedbed at Joydebpur were transplanted in a randomized design because of the threat of flooding.

The 1981 treatments were basically the same as the 1980 treatments. A different field in the same area was chosen. This time a 2:1 mixture of aus (variety: Lohagar) and aman (Hassi Aman) seed was sown on 3 plots allocated to T_1, T_2, and T_3. In T_4 only broadcast aman seedlings were used. The seed was sown on a strip of land adjacent to the experimental field at the same time T_2 plots were sown. Planting dates of the 4 treatments were 5 March, 15 March, 26 March, and 20 April.

In T_1 urea was applied at 30 kg N/ha before transplanting. Planting was at 10- × 15-cm spacing at 2-3 plants/hill.

An experiment at Chor-niloki in 1980 compared different methods of establishing deepwater rice, using the local aman varieties Jattra Muluk and Habiganj Aman VIII. The establishment methods were broadcasting, drilling, and dibbling (all 29 February) and transplanting on 8 May.

During vegetative growth several random samples of rice stems were taken at 2-week intervals starting from 15 July in 1980 and 11 June in 1981. Tillers were counted to compare the stand in the different treatments.

Stems were processed in the laboratory to estimate nematode population per tiller. Each tiller was dissected to the innermost leaf sheath, cut into small pieces, and placed in a *bijou* bottle with 2 ml of tapwater. Stoppers were placed in the

bottles and the samples stored overnight at room temperature. The suspension in each bottle was examined using a Peters 1-ml counting slide, and the number of *D. angustus* per tiller was estimated.

At harvest in 1980, 4-m^2 crop-cuts were taken to estimate yield and extent of ufra infection in the different treatments. The total number of panicles, the number with ufra symptoms, and the number of whiteheads and healthy panicles in each cut were counted. Panicles showing ufra symptoms were classified as:

- ufra I (no panicle emergence),
- ufra II (panicles emerged partially), and
- ufra III (panicles emerged totally, but most grains were unfilled).

The proportion of panicles in a defined area classified as ufra II has been found useful as a disease index.

Grain was sundried, threshed, and winnowed and yield weights were adjusted to 14% moisture content.

RESULTS AND DISCUSSION

The greatest number of infested stems was in T_1 until 23 August 1980 when T_1 and T_2 were the same (Table 1). However, the average nematode population per infested tiller was always highest in T_1. This could be because of the longer time for reproduction, or because these were fewer nematodes in the late-sown rice. However, the 1981 results (Table 2) were contradictory because T_3 had the most infested plants. Although diseased plants were present in the field, few were sampled. This suggests that either the sampling design should be modified, or another method should be sought to give reliable information about the disease during the vegetative growth stage of the host.

Table 1. The effect of delaying the sowing or transplanting deepwater rice on ufra, Chor-niloki, Matlab Bazar, Bangladesh, 1980.

Treatment[a]	Date of sampling[b]							
	% infested stems[c]				Av nematode population[d] (no./infested stem)			
	1	2	3	4	1	2	3	4
				Broadcast				
T1	20	24	52	24	1372	1422	470	328
T2	8	2	52	34	80	50*	27	100
T3	2	2	22	2	8*	3*	159	112*
				Transplanted				
T4	0	0	16	0	0	0	41	0

[a]Sowing dates T1, 19 Feb; T2, 6 Mar; T3, 21 Mar; and T4, 16 Apr. [b]Sampling dates (1-4) were 15 July, 7 and 23 August, and 15 September respectively. [c]Random samples of 25 stems were collected from each plot 50/treatment. [d]*indicates only one infested stem.

Table 2. The effect of delaying sowing or transplanting deepwater rice on ufra, Chor-niloki, Matlab Bazar, Bangladesh, 1981.

Treatment[a]	Date of sampling[b]											
	% infested stems[c]						Av nematode population[d] (no./infested stem)					
	1	2	3	4	5	6	1	2	3	4	5	6
Broadcast												
T1	2	12	3	3	0	3	96	123	108	552	0	42
T2	0	0	0	2	0	0	0	0	0	72	0	0
T3	0	3	2	0	1	1	0	30	24	0	36	24
Transplanted												
T4	0	2	0	0	5	7	0	36	0	0	40	1378

[a]Sowing dates: T1, 19 Feb; T2, 6 Mar; T3, 21 Mar; and T4, 16 Apr. [b]Sampling dates (1-6) were 11 and 26 June, 9 and 23 July, and 14 and 18 August respectively. [c]20 stems/plot, 60/treatment at sampling dates 1-4; and 25 stems/plot, 75 treatments at dates 5-6. [d]*indicates only one infested stem.

The question of whether reduction in the amount of primary infestation influences the amount of loss that occurs at harvest remains. Perhaps other factors such as spread of nematodes from adjacent infested plots by movement of water might compensate for lack of initial inoculum.

At harvest, plots that were sown or transplanted later had a significantly higher yield and less ufra than those sown at the farmer's usual time (Table 3). This confirms that primary infestation is important in determining the final amount of damage by ufra.

The results of the 1980 establishment method trial at Chor-niloki again showed that the time of planting was the critical factor for ufra. The plots that were transplanted roughly 9 weeks after the 3 other treatments were established had a significantly lower percentage of panicles with ufra symptoms than crops sown earlier. This was true in both varieties broadcast and dibbled. The latter had an average of 65% ufra-infested panicles for Jattra Muluk and 68% for Habiganj Aman VIII; transplanting gave 16.6% and 17.9% for the 2 varieties. The yields were not significantly different but the stands in the transplanted plots were poor because of insufficient time for establishment before flooding.

In the 1981 establishment trials aus was included in the first three treatments, because this could be an important consideration in determining the optimum procedure. Seedlings in the transplanted plots were spaced 10 × 15 cm apart. The plots were also fertilized to improve establishment and plant stand. When the plots are harvested and the results obtained and analyzed, it may be possible to take all the factors into account and suggest the optimum procedure for ufra control.

Table 3. The effect of different times of establishment of deepwater rice on ufra incidence and yield,[a] Chor-niloki, Matlab, Bangladesh, 1980.

Treatment[b]	Ufra[c]	Yield (t/ha)[d]
	Broadcast	
T1	53 a	1.0 c
T2	37 b	1.4 bc
T3	38	1.9 ab
	Transplanted	
T4	19 c	2.3 a
CV (%)	23	21

[a]In a column, means followed by the same letter or letters do not differ significantly (p = 1%). [b]Sowing dates: T1, 19 Feb; T2, 6 Mar; T3, 21 Mar; T4, 16 Apr. [c]Total percentage of panicles in each crop cut showing any ufra symptom. The figures are the averages of six crop cuts. The data were transformed by arcsin transformation before analysis. [d]Av of six crop cuts. Figures are correlated to 14% moisture content.

IMPLICATIONS FOR FUTURE WORK

There are several implications for future research:

- Prolonging the overwintering period by sowing or transplanting at a later date has significantly reduced ufra and increased yield in 1980 but more trials are needed to confirm this.
- Spread of nematodes by water dispersal from adjacent fields may occur. This source of inoculum may be important. Control measures in a single field may be adequate because of spread of ufra from other fields. Some thought should be given to the problem of how to measure the contribution of secondary ufra infection by water dispersal to total disease expression and yield loss at harvest.
- In addition to our experiments on ufra control, quantitative assessment of the efficiency of the traditional control by stubble burning and straw removal is needed. Perhaps in some situations of low disease pressure these may be sufficient for control. Improved methods of burning and perhaps chemical treatment of crop residues could also be assessed. These studies will increase understanding of the field situation and the factors there which determine the extent of ufra. Such knowledge ultimately can only aid us in finding suitable controls for this disease.
- Ufra may occur in other cropping patterns; for example, where boro rice is grown in irrigated fields followed by broadcast aman, or where infested materials along with rice stubble are not destroyed because they are left as mulch for a crop such as watermelon. Work on this aspect is being carried out. Control methods included timing of nematicide applications, and destruction of crop residues and younger seedlings.

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DISCUSSION

NASIRUDDIN: There are reports that ufra is not a serious problem in Thailand where deepwater rice is seeded in May-June, which is late compared to Bangladesh. This delayed seeding may be the reason why there is no ufra in Thailand.

McGEACHIE: Workers from Thailand have reported no ufra. This late sowing may well

be the reason why it is not a serious problem, but another reason may be the dryness of the preflood period. The nematode must have proper moisture. A dry spring in Bangladesh in 1979 greatly reduced ufra incidence and severity except in deep, wet, endemic areas.

SUKAPANPOTHARAM: Regarding ufra in Thailand, we have not found the presence of ufra yet in deepwater rice areas but there was a report about 15 years ago of ufra incidence in southern Thailand. It seems to have disappeared.

TOURE: Delaying planting is a known weed control practice. The problem is that delaying planting is risky because the flood may come at any time.

McGEACHIE: This risk must be compared with the chance and extent of crop loss due to ufra, and the best procedure selected to minimize the risks.

WAHAB: In Bangladesh deepwater rice farmers start seeding in March-April. If they seed later their crop may be lost because of lack of establishment of the crop before flooding. It is not at all wise to suggest that farmers seed their crops 6 weeks later.

McGEACHIE: We agree it carries heavy risks. We believe that transplanting of the broadcast aman crop is more promising. Perhaps aus and aman could be transplanted so there is also an aus crop. Transplanting is perhaps costly in terms of labor, seedbed, costs, and the need for fertilizer for establishment. There would be a saving, however, in time needed for weeding, amount of seed needed, and the increased fallow would perhaps permit the growth of a nonrice winter crop. I must, however, emphasize that we are not yet sure that this delaying planting is effective, and we must await more results.

PETPISIT: Is the decrease of nematode infestation in the delayed planting plot due to the nematodes moving to the plots nearby or due to the nematodes that died because of starvation?

McGEACHIE: It is difficult to test such a thing, without somehow totally isolating a field, or plot in a field, as a control (i.e. no water spread). Because there must have been a spread as water movement between plots was unimpeded, we would suggest that this reduction in yield loss was due to loss of primary inoculum from infected panicle material.

PRELIMINARY INSECTICIDE TESTS AND OBSERVATIONS FOR PREFLOOD CONTROL OF YELLOW RICE BORER IN DEEPWATER RICE

B. Taylor, Md. Badiul Alam, and Q. Md. A. Razzaque

SUMMARY

Starting with the hypothesis that insecticides could reduce the year's second brood of yellow rice borer, *Scirpophoga incertulas* (Walk.), and thus reduce the late season population potential in deepwater rice, trials of insecticides were made and a preliminary report of their efficacy is given. Stem dissections were made during the insecticide trials and the results, taken together with data from other trials and earlier work of the ODA/BRRI Deepwater Rice Pest Management Project, are used to examine the population structure of the yellow rice borer and to postulate a population dynamics model.

The existing evidence on rice yield loss due to yellow rice borer is re-examined and it is suggested that the most critical period of attack may be before flooding when basal and primary tillers are the only targets available for the pest.

The Deepwater Rice Pest Management Project, jointly funded by the Government of Bangladesh, through the Bangladesh Rice Research Institute (BRRI) and the Overseas Development Administration of the Government of the United Kingdom, entered a second phase in 1981 and aims to build on knowledge acquired or confirmed during 1977-80. Much of the first-phase work on stem borers, principally the yellow rice borer (or yellow stem borer), *Scirpophaga incertulas* (Walk.), was described by Catling and Islam (1979) and subsequently by Catling (1980, 1981).

During the first phase, relatively little work was done on actually controlling the yellow rice borer. Catling and others used basal applications of carbofuran at sowing time in 1979 but found that these gave little or no protection into the flooding period and there were no differences in yield between treated and untreated plots.

ODA/BRRI Deepwater Rice Pest Management Project, BRRI, Joydebpur, Bangladesh.

In 1978, the same workers attempted to compare the effect of intensive insecticide use with a no-treatment regime (Catling et al 1980). Although some 22 applications of insecticide (carbofuran granules twice before flooding and then 20 sprays of diazinon at intervals of 6-7 days) did not give total protection from yellow rice borer attack, stem infestation at harvest was only 9.0% in the treated area compared with 33.2% in the nonsprayed area. The yield from the treated area was 26.7% higher than that from the control area. In 1979, a similar experiment (with only 20 sprays of diazinon and no carbofuran) resulted in 33.2% infestation in the nonsprayed control area and 13.5% in the treated area. The yield improvement, however, was only 15.4%. Catling concluded that the trials showed the futility of trying to control yellow rice borer with insecticides alone (Catling 1981).

Much information was acquired, however, about the incidence of yellow rice borer, its importance as the major pest of deepwater rice in Bangladesh, and its population dynamics (Catling 1981). Catling postulated that there are six broods, or generations, of yellow rice borer each year. The first infestation of deepwater rice is by brood 2 in the preflood period (May to mid-June). Brood 3 tends to coincide with the onset of flooding (mid-June to the end of July). Brood 4 is at the height of flooding (August to late September), and brood 5 infests the rice at the heading stage, as the floods subside (late September to the end of October). The seasonal patterns, however, were variable in terms of density of infested stems and in numbers of larvae and pupae. In general, from Catling's conclusions, a typical year has a fairly high infestation in brood 3, a decline in the numbers in brood 4, and a peak in brood 5. The incidence of natural enemies of yellow rice borer, both predators and parasites, is highest in brood 5, relatively low in brood 3, and depressed probably by the onset of flooding in brood 4.

After reviewing Catling's findings, we decided that there could be scope for depressing brood 2 and, maybe, brood 3, and thus lower the late-season population potential. The use of insecticides in the early season would avoid the possible major problems of logistics and of contamination in spraying deeply flooded rice. Such a timing was also expected to have a minimal effect on the natural enemies of yellow rice borer.

A literature search showed that there has been little evaluation of insecticides for yellow borer control and almost none in deepwater rice areas. As a first step, we tested a range of insecticides to see which would control yellow rice borer. Particular emphasis was on trying to establish the effects on the egg and first-instar stages.

MATERIALS AND METHODS

The following insecticides were obtained:

Active ingredient	*Manufacturer's suggested dose (a.i./ha)*	*Trade name*
formothion (OP)	336-560 g	Anthio 25 EC
monocrotophos (OP)	250 g	Azodrin 40WSC

diazinon (OP)	1000-1500 g	Basudin 60 EC
dicrotophos (OP)	300-500 g	Bidrin 24WSC
dicrotophos (OP)	500-1000 g	Carbicron 50 WSC
propenofos (OP)	500-750 g	Curacron 50 EC
quinalphos (OP)	250-375 g	Ekalux 25 EC
methomyl (Carbamate)	250-500 g	Lannate 24 WSC
fenthion (OP)	500-1000 g	Lebaycid 50 EC
dimethoate (OP)	240 g	Perfekthion 40 EC
cypermethrin (Pyr.)	50-100 g	Ripcord 102 EC
fenvalerate (Pyr.)	100-200 g	Sumicidin 20 EC
fenitrothion (OP)	300-1000 g	Sumithion 100 EC
(experimental product)	750 g	G 24'480 EC

(OP) = organo-phosphorus; (Pyr.) = synthetic pyrethroid

The rates used were in the range suggested by the manufacturer — lower rates on young plants, higher rates as the tiller density increased. The spray volume used throughout was 600 liters/ha, applied with a knapsack sprayer.

Insecticide trial at Bastia, Manikganj

An insecticide trial was carried out in a farmer field in an area visited for population dynamics studies (Catling 1981). The field usually floods to a depth of 2-3 m. Stem infestation by yellow rice borer in 1977 and 1978 was more than 40% by the onset of flooding and reached 40-60% by late season in the four seasons 1977-1980.

The field was broadcast-seeded in early March with the deepwater variety Digha. Overall field dimensions were about 90 m × 30 m with a nearly rectangular shape, which made it convenient to make 36 plots 15 m × 6 m. Twelve treatments, including a nonsprayed control with three replicates of each, were possible.

The first insecticide application was made 13-14 May, when plant height was about 45 cm. Average tiller count on 13 May was 374 tillers/m^2.

Subsequent applications were on 27-28 May, 10-11 June, and 24-25 June. Plant height was about 50 cm on 27 May, and 110-125 cm on 24 June. Average tiller count on 4 June was 270/m^2.

Stem sampling by taking 34 stems from each plot, with the sampler moving along the diagonals of the plot and taking care to keep away from the edges, was done 21 May, 4 June, 17 June, and 1 July. On the last date flooding had started and there was about 30 cm of water in the field.

Following the practice adopted by Catling and Islam (1979), stem dissection was the main method of assessment. Stem samples were taken to the laboratory and each stem was split and examined for larvae, pupae, and evidence of infestation (frass, exit-holes). Deadhearts also were recorded. Table 1 presents data from stem dissections.

Insecticide trial in a deepwater tank, Joydebpur

Another trial was put in a 20 m × 20 m deepwater tank at BRRI, Joydebpur. The

Table 1. Results of stem dissections from insecticide trial at Bastia, Manikganj, Bangladesh, 1981.

Treatment[a]	Assessment dates	No./100 stems with Dead-hearts	No./100 stems with Frass or borer holes	Live stages found per 100 stems: Larval instars I	II	III	IV	V	VI	Pupae	Pupal skins
Control	22 May	18	19	0	0	3	2	2	2	1	0
	4 Jun	4	11	0	0	0	0	0	3	4	0
	17 Jun	2	6	0	0	0	0	0	0	0	5
	1 Jul	3	9	0	0	0	0	0	0	1	4
Anthio	22 May	7	11	0	0	1	2	1	1	1	0
	4 Jun	5	8	0	0	0	0	0	1	1	0
	17 Jun	5	10	0	0	0	0	0	1	0	4
	1 Jul	0	5	0	0	0	0	1	0	0	2
Azodrin	22 May	6	6	0	0	2	0	0	0	0	0
	4 Jun	1	3	0	0	0	0	0	0	2	0
	17 Jun	3	5	0	0	0	0	0	0	0	1
	1 Jul	0	1	0	0	0	0	0	0	0	1
Basudin	22 May	8	8	0	0	2	0	2	1	0	0
	4 Jun	2	2	0	0	0	0	0	1	0	0
	17 Jun	3	9	0	0	0	2	0	0	0	2
	1 Jul	0	2	0	0	0	0	0	0	0	1
Bidrin	22 May	10	13	0	0	1	0	0	3	0	1
	4 Jun	5	13	0	0	1	0	1	3	5	1
	17 Jun	1	6	0	1	0	0	1	0	0	1
	1 Jul	0	3	0	0	0	0	0	0	0	2
Cabicron	22 May	8	8	0	0	1	1	0	2	0	0
	4 Jun	1	2	0	0	0	0	0	0	1	0
	17 Jun	1	3	0	0	0	0	0	0	0	2
	1 Jul	0	4	0	0	0	0	0	0	0	1

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Table 1 continued

Treatment[a]	Assessment dates	No./100 stems with Dead-hearts	No./100 stems with Frass or borer holes	Live stages found per 100 stems: Larval instars I	II	III	IV	V	VI	Pupae	Pupal skins
Curacron	22 May	6	9	0	0	0	0	1	2	0	1
	4 Jun	1	2	0	0	0	0	0	0	0	1
	17 Jun	3	7	0	0	0	0	0	0	0	3
	1 Jul	1	2	0	0	0	0	0	0	0	3
Ekalux	22 May	2	5	0	0	0	0	1	2	0	0
	4 Jun	0	1	0	0	0	0	0	0	1	0
	17 Jun	1	1	0	0	0	0	0	0	0	0
	1 Jul	0	0	0	0	0	0	0	0	0	0
Perfekthion	22 May	4	5	0	0	0	0	2	4	0	0
	4 Jun	2	8	0	0	0	0	0	2	2	0
	17 Jun	3	5	0	0	0	0	0	0	0	2
	1 Jul	0	7	0	0	0	0	0	1	0	5
Ripcord	22 May	8	11	0	0	1	0	3	6	0	0
	4 Jun	3	7	0	0	0	0	0	1	3	0
	17 Jul	2	6	0	0	1	0	0	0	0	2
	1 Jul	0	5	0	0	0	0	0	1	0	1
Sumicidin	22 May	4	5	0	0	2	0	1	0	0	0
	4 Jun	4	4	0	0	0	0	0	0	1	1
	17 Jun	3	6	0	1	0	0	0	0	0	2
	1 Jul	0	3	0	0	0	0	0	0	0	2
Sumithion	22 May	8	11	0	0	0	0	2	1	0	0
	4 Jun	1	2	0	0	0	0	0	0	2	0
	17 Jun	3	7	0	0	0	0	0	0	0	5
	1 Jul	1	8	0	0	0	0	0	0	0	5

[a]Treatment dates: 13-14 May, 27-28 May, 10-11 June, 24-25 June.

tank was divided into 36 plots 3 m × 3 m and each plot individually bunded to prevent water movement between plots. Because of delays in land preparation, only 3 blocks were planted: Raja Mondal was planted in two blocks and Habiganj Aman IV in one block. These were not flooded and served as a simple insecticide trial with no possibility of yield data. As at Bastia, 12 treatments were arranged randomly within the blocks. Each treatment was replicated three times.

The first applications started 16 July but heavy rain interrupted work and the spraying was not completed until 19 July. Subsequent applications were made on 25 July, 5 August, 15 August, 29 August, and 9 September.

Sample of 20 stems/plot were taken 23 July, 7 August, 17 August, 22 August, 1 September, and 11 September. Data from stem dissections are in Table 2.

DISCUSSION AND CONCLUSIONS

Insecticide evaluation

We emphasize that the experiments we reported are not complete. For instance, we have not harvested the plots at Bastia and this may add considerably to the value of this season's work. Similarly, our results should not be taken as an endorsement or condemnation of any insecticide used.

A crude assessment, taking into consideration the number of live stages and the changes in stem infestation, suggests that the insecticides worth further evaluating are Azodrin, Basudin, Carbicron, Curacron, Ekalux, and Sumithion. Lannate was underdosed and a decision on it cannot be made until the season is complete.

While we agree with Catling that insecticides alone are unlikely to be the whole solution (Catling 1981) our 1981 results indicate that there may well be a genuine place for insecticide use in deepwater rice. The major questions are what product and when it should be used.

Observations on population dynamics

A side benefit of the regular dissections of stem samples during the two trials was the opportunity to analyze the population structure of the yellow rice borer during each year. Figure 1 shows the composition of the stem borer juvenile population on each date of our observations; additional points on the graph were derived from two sets of dissections of stem samples from agronomy trials, and from survey data obtained in previous years (where the latter showed a high enough infestation for analysis). The composition of the population on any one date is expressed as the percentage of the total juvenile stages, which falls into one of the six larval instars, pupae or pupal skins (the last possibly can be deceptive because pupal skins, unlike the other stages, tend to persist as relics).

Our first 1981 observations were on 22 May, whereas for 1977-1980 no data were obtained, at least not from the rapid surveys, prior to late June. In general, our summary of the population structure coincides with the thinking of Catling. The timing of the peak maturity in each brood, we feel, may be somewhat earlier than suggested by Catling (1981) especially brood 4. The population structure of brood 3 seems less clear than for broods 2 and 4. This is possibly because stem dissections in the middle of the growth and development cycle are liable to reveal a

Table 2. Results of stem dissections from insecticide trial in a deepwater tank at BRRI, Joydepbur, Dacca, Bangladesh, 1981.

Treatment[2]	Assessment dates	No./60 stems with Dead-hearts	No./60 stems with Frass or borer holes	Live stages found per 60 stems: Larval instars I	II	III	IV	V	VI	Pupae	Pupal skins
Control	23 Jul	2	4	2	0	0	0	0	0	0	0
	7 Aug	6	20	0	1	0	4	0	0	0	0
	17 Aug	8	10	0	0	0	0	0	1	2	0
	22 Aug	2	10	0	0	0	0	0	3	2	1
	1 Sep	2	17	0	0	0	0	0	0	0	10
Anthio	23 Jul	2	3	0	0	0	0	0	0	0	0
	7 Aug	6	21	0	0	0	0	2	2	0	0
	17 Aug	4	16	0	0	0	0	0	5	4	0
	22 Aug	0	13	0	0	0	0	0	0	2	2
	1 Sep	1	9	0	0	0	0	0	0	0	3
Azodrin	23 Jul	3	4	0	0	0	0	0	1	0	0
	8 Aug	1	5	0	0	0	0	0	1	0	0
	17 Aug	0	7	0	0	0	1	0	1	1	0
	22 Aug	0	3	0	0	0	0	0	0	0	0
	1 Sep	1	5	0	0	0	0	0	0	0	2
Basudin	23 Jul	2	5	0	0	0	1	1	0	0	0
	7 Aug	1	5	0	0	0	0	0	1	0	0
	17 Aug	1	3	0	0	0	0	0	0	0	1
	22 Aug	0	1	0	0	0	0	0	0	0	1
	1 Sep	1	1	0	0	0	0	0	0	0	0
Carbicron	23 Jul	3	6	0	1	0	1	0	0	0	0
	7 Aug	6	18	0	0	0	3	3	3	0	0
	17 Aug	2	3	0	0	0	1	1	0	0	0
	22 Aug	0	2	0	0	0	0	0	0	0	0
	1 Sep	0	2	0	0	0	0	0	0	0	2
Curacron	23 Jul	3	4	0	0	0	0	0	2	0	0
	7 Aug	2	6	0	0	0	0	0	1	0	0
	17 Aug	3	8	0	0	0	0	0	0	1	0
	22 Aug	0	1	0	0	0	0	0	0	0	0
	1 Sep	0	4	0	0	0	0	0	0	0	0

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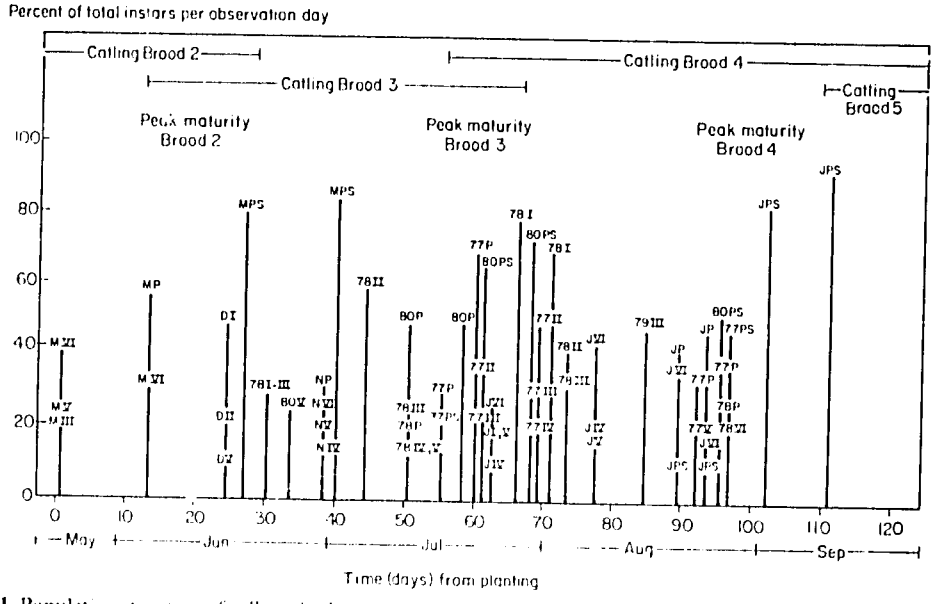
Table 2 continued

Treatment[a]	Assessment dates	No./60 stems with Dead-hearts	No./60 stems with Frass or borer holes	Live stages found per 60 stems: Larval instars I	II	III	IV	V	VI	Pupae	Pupal skins
Lannate	23 Jul	2	5	0	0	0	0	1	1	0	0
	7 Aug	4	16	0	0	1	0	0	6	0	0
	17 Aug	2	7	0	0	0	0	0	1	1	0
	22 Aug	0	5	0	0	0	0	0	1	2	0
	1 Sep	0	6	0	0	0	0	0	1	0	1
	1 Sep								0	1	0
Leybacid	23 Jul	2	5	1	0	0	0	1	1	0	0
	7 Aug	2	9	1	1	0	0	0	1	0	0
	17 Aug	0	6	0	0	0	0	0	0	0	3
	22 Aug	0	2	0	0	0	0	0	0	0	0
	1 Sep	1	10	0	0	0	0	0	1	1	2
Ripcord	23 Jul	1	2	0	0	0	0	0	0	0	0
	7 Aug	2	12	0	1	1	1	0	1	1	0
	17 Aug	4	10	0	0	0	0	1	4	0	1
	22 Aug	1	9	0	0	0	1	0	0	1	0
	1 Jul	2	7	0	0	0	0	0	0	0	2
Sumicidin	23 Jul	3	3	1	0	0	0	0	0	0	1
	7 Aug	2	14	0	0	0	0	2	3	2	0
	17 Aug	2	13	0	0	0	0	1	0	2	0
	22 Aug	1	8	0	0	0	0	1	0	2	0
	1 Sep	3	12	0	0	0	0	1	0	1	0
Sumithion	23 Jul	1	1	0	0	0	0	0	0	0	0
	7 Aug	0	4	0	0	0	0	1	0	0	0
	17 Aug	1	9	0	0	0	0	0	1	5	0
	22 Aug	1	5	0	0	0	0	0	0	0	0
	1 Sep	0	3	0	0	0	0	0	0	0	1
G24,480	23 Jul	2	5	0	0	0	0	1	0	0	0
	7 Aug	2	7	0	0	0	1	0	0	0	0
	17 Aug	1	6	0	0	0	0	0	2	2	0
	22 Aug	0	5	1	0	0	0	0	0	2	0
	1 Sep	1	2	0	0	0	0	0	0	0	1

[a]Treatment dates: 16-19 July, 25 July, 5 August, 15 August, 29 August.



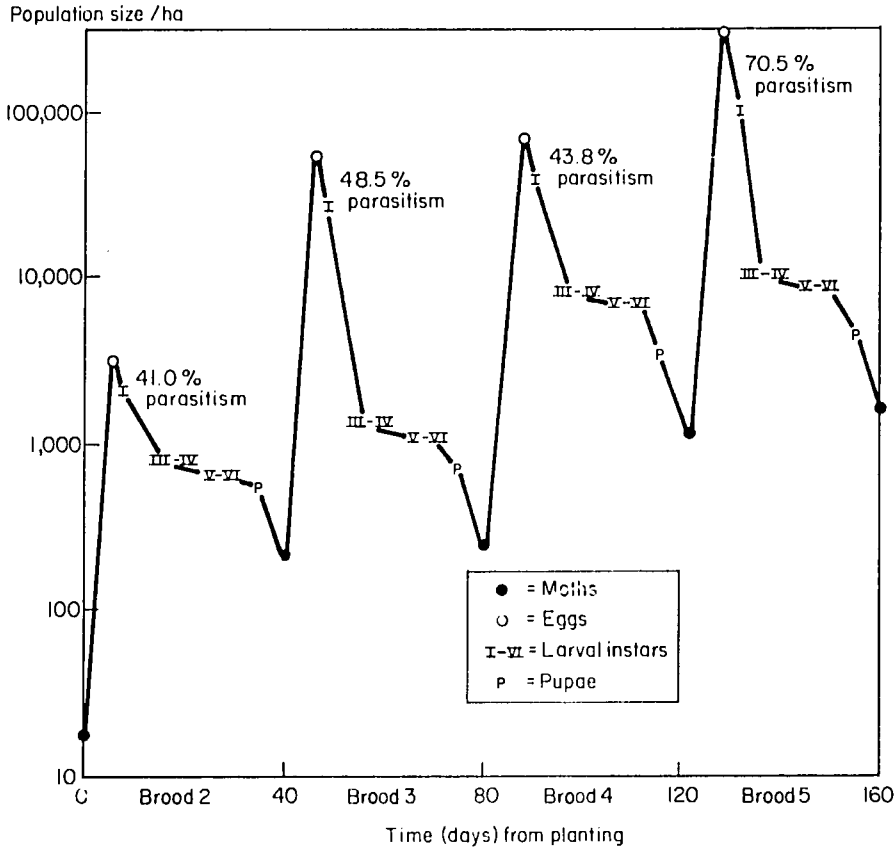
1. Population structure of yellow rice borer during the deepwater rice season in Bangladesh. Key: M Bastia, Manikganj, 1981; N Narsingdi, 1981; D Daudkandi, 1981; J Joydebpur (deepwater tank), 1981. 77, 78, 79, 80 results from rapid survey dissections in 1977 to 1980. I-VI larval instars; P pupae; PS pupal skins. Instars forming less than 10% of the total per observation day have been omitted. Catling Broods 2 to 5, after Catling (1981).

range of larvae of slightly different ages. Thus, on any one day there may be three instars present. Alternatively, it is conceivable that the so-called brood 3 actually does not exist and what is observed is late brood 2 individuals and the onset of brood 4. This would help to explain the anomaly between Catling's (1981) statement "Populations of yellow rice borer are always low before flooding (late June-early July)" and the fact that his light-trap catches showed no decline in numbers of adult moths at that time.

Timing of insecticide use

One of the difficulties that we faced in assessing the effectiveness of the insecticides used in the trials was that the numbers of live stages in the nontreated control appeared to decline with the passage of time, especially at Bastia (Table 1). One reason may have been replacement of infested stems by new tillers, thus altering the stem population being sampled. This was reflected in the apparent drop in stem damage. Another, possibly more important, reason is that, unlike many other insect pests, which have much shorter generation times or less well-defined broods, or both, the yellow rice borer populations can increase only at the start of a fresh brood — at four distinct points in each deepwater rice season.

Catling (1981) gave a good deal of information on moth numbers and egg parasitism. If his data are combined with the report by Rothschild (1970) on the mortality of different stages from egg to pupa, a model of the yellow rice borer population cycle can be derived. Figure 2 shows such a model. The numbers of



2. A population model for yellow rice borer in deepwater rice in Bangladesh.

moths are taken from Catling's data from light trapping; the number of eggs per moth is taken as 300, which, like the level of egg parasitism, is derived from Catling's studies. The intermediate mortalities are from Rothschild (with some adjustment to fit the egg to adult figures). The gross mortalities for the broods are 95.6% for brood 2, 99.6% for brood 3, 98.3% for brood 4, and 99.6% for brood 5. However, importance should not be attached to the accuracy of these figures, nor should the numerical values for brood size be taken as indicative of actual field numbers. What is important is that the greatest decline in potential numbers comes between the laying of eggs and the detection of third-instar larvae. A high level of control is exerted by the environment and by natural enemies particularly in broods 3 to 5.

Logistics, let alone environmental considerations, mitigate against use of insecticides after the onset of flooding. Therefore, our preseason thinking was that the use of insecticides against brood 2 would be the only feasible time, and such use might depress the size of subsequent broods. Figure 2, if correct, shows that brood 2 is the only brood in which the degree of natural control could realistically be

enhanced. The model shows also that those larvae that penetrate into the stem are protected from outside influences and, thus, mortality is low. It seems possible, therefore, that one or two strategically timed applications of a suitable insecticide at the time of laying of the brood 2 eggs on deepwater rice seedlings might prove highly effective. Further applications at the time of laying of the brood 3 eggs, if not precluded by the onset of the floods, might be useful but the effect this would have on natural enemies still needs to be established.

Infestation and crop loss

Before starting our studies, we hypothesized that if it was possible to reduce the preflood brood of yellow rice borer and, thus, depress the size of subsequent broods there could be a consequent reduction in stem infestation in what Catling described as the critical period, June to September (Catling 1981). Although there seems to be little doubt that stem infestation is the best indicator of the numbers of stem borer larvae during June to September, it has still to be established whether or not such stem infestation is of prime importance in terms of actual crop loss.

What if loss of the main and primary tillers is the major cause of yield reduction? Setabutara and Vergara (1979) found that, in one variety, 90% of the total yield came from the main and primary tillers combined; in a second variety, their contribution was 77%. Similarly, Datta and Banerji (1979) found that, regardless of water regimes, grain yield and yield-contributing factors of basal tillers in both the varieties they studied were always greater than those of aquatic tillers. About 70-80% of the total grain production came from basal tillers.

Pot experiments carried out by Catling (1981) showed a loss of 27-30% in panicle weight if basal tillers were lost and replaced by aquatic tillers.

Crop loss studies in 1978 and 1979 with the variety Chota Bawalia (Catling 1981) showed that, although season-long insecticide use significantly reduced the stem infestation by yellow rice borer (as recorded at harvest) in both years and from identical levels the yield improvement was much less in 1979. The 1979 spraying of variety Lakshmidigha also gave a reduction in infestation but did not give a significant improvement in yield (in fact, only 3%). Not forgetting that 1979 was a poor year for crop establishment because of prolonged early drought, the major difference between the yield results in 1978 and 1979 may well have been that in 1979 yellow rice borer outbreaks did not occur until August and September. Therefore, in 1979 there could have been a lower than usual loss of basal tillers in the preflood period. Re-examining the field records of the 1978 study showed that no dissections were made in the early season but the deadheart level on 12 May was 14 times lower in the treated area than in the nontreated area ($0.5/m^2$ cf. $7.0/m^2$). There are few records, from 1977 to 1980, relating to yellow rice borer infestation before late June, but in 1978, at Agrakhola, deadhearts reached a peak of $11.0/m^2$ on 19 May.

This year, at Bastia, the nonsprayed control plots gave the following results: (of 100 stems examined and dissected)

22 May, 18% deadhearts and 19% infested;

4 June, 4% deadhearts and 11% infested;

17 June, 2% deadhearts and 6% infested;

1 July, 3% deadhearts and 9% infested.

Frame counts of tillers enabled us to estimate that there were 1.2 deadhearts/m^2 on 13 May and about 10.8 deadhearts/m^2 on 4 June.

From the limited data available, it seems that at the beginning of the season deepwater rice can be regarded the same as dryland rice and deadheart incidence will give a reasonable indication of infestation and damage by yellow rice borer. In the young plant, where there is little lumen development, the yellow rice borer larva is likely to cause much more damage to conducting tissues and to the apical meristem than in older plants. The elongated deepwater rice plant, with its massive stem lumens, probably provides a safe stable environment for the larva of the yellow rice borer, which feeds on the parenchyma tissue without damaging vascular tissue (Catling 1981). Thus, at this stage the yellow rice borer may achieve the status of the near-perfect parasite-host relationship. If correct, this would help to explain why the number of whiteheads at harvest represents less than 20% of the stem infestations recorded in the late season (Catling and Islam 1979).

FUTURE STRATEGY

By the end of this season, our experiments should give us a reasonable indication as to which insecticides are most likely to be suitable for further testing. We hope that the 1981 yield data from Bastia will add weight to the view that there is a distinct place for preflood use of insecticides.

The overall program of the Deepwater Rice Pest Management Project for 1982 is likely to be one of concentrating efforts on a few representative areas and laying down trials of agronomic practices in farmers' fields. These trials will be overlaid with trials of crop protection methods, including insecticide use.

In suitable areas, a practice that may prove ideal from the point of view of insecticide use is transplanting the deepwater rice. The protection of the young plants in a discrete area, such as a seedbed, would have obvious advantages.

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MONITORING TOUR TO BIHAR, WEST BENGAL, BANGLADESH, AND THAILAND

An International Rice Testing Program (IRTP) group monitoring 26 October-4 November 1981 visited Bangladesh, India, and Thailand. Tour participants included D. HilleRisLambers and D. V. Seshu, IRRI; D. G. Kanter, IRRI-Bangladesh Rice Research Institute (BRRI) Collaborative Program; D. W. Puckridge, IRRI-Thailand Cooperative Project; Aung Kha, Agricultural Research Institute, Burma; P. Charoentham and C. Setabutara, Rice Division, Department of Agriculture, Thailand; M. Nasiruddin and A. Wahab, BRRI; S. Saran, Bihar Agricultural Research Institute, and R. Thakur, Bihar Agricultural College, India; and S. Sulaiman, Banjarmasin Research Institute for Food Crops, Indonesia.

Objectives of the tour were to:

- observe IRTP trials in rainfed and deepwater areas;
- evaluate the effectiveness of the stratification of IRDWON into three screening trials —flood tolerance, medium deepwater, and floating; and
- observe deepwater rice research in preparation for discussion at the 1981 International Deepwater Rice Workshop in Thailand.

Institutes visited included:

- India
  Bihar — Rajendra Agricultural University, Pusa
  West Bengal — Rice Research Station, Chinsurah
- Bangladesh
  Deepwater Station, Habiganj
  BRRI, Joydebpur and Rajbari
- Thailand
  Huntra and Prajinburi Rice Experiment Station

General observations were:

- Bihar — Rainfall from June to September was good, with drought prevailing later. The crop was submerged for 7-12 days 3 times. In Bihar, excess water occurs north of the Ganges River, associated with rains, and runoff from the Terai. Accumulating water in ill-drained *chaurs* and *jheels* calls for late-maturing floating rices, but excess rainfall is important in many shallower areas and is the reason for the need for tall rices with submergence tolerance.
- West Bengal — Rainfall started in February and continued without letup. The floating rice crop was not planted. The 100- to 150-cm-depth areas were affected by three flash floods between June and October. In West Bengal, rice scientists

breed for 4 water depths — 50 cm or less, 50-100 cm, 100-150 cm, and more than 150 cm. The 50- to 100-cm and 100- to 150-cm areas are most widespread and submergence tolerance in the seedling stage is an important requirement.

- Bangladesh — Rains started early and affected planting of some floating rice. Maximum water levels were often a meter lower than in 1980. Bangladesh deepwater areas are characterized by gradual or rapid increases in water depths that stay for a month or more. Floating rices are more consistently required than in the Indian states visited. Some submergence tolerance is required in northeastern Bangladesh.
- Thailand — Rains started early and the floating rice crop was planted in April, earlier than usual. Maximum water levels were often a meter lower than 1980 levels. Thailand deepwater areas in the Central Plain are characterized by gradual increases in water levels. The areas are suitable for floating rices that elongate at rates of 5 cm/day or sometimes more. Flash-flood-prone areas have not been precisely pinpointed, but are believed to be important.

OTHER PRESSURES ON DEEPWATER RICE

Stem borers were a problem throughout the regions visited. Good solutions to the problem are not available. Rice hispa was observed in late plantings at Chinsurah and was reported as important in Bangladesh as well. No resistance is known.

Rice tungro virus showed as a major problem in Bihar, West Bengal, and Bangladesh, but not as much in Thailand. Ragged stunt virus was not seen in Bihar, West Bengal, or Bangladesh, but was a serious problem in Thailand and constitutes a major selection objective there. Bacterial leaf blight is considered the most important disease in Bihar. Its importance was also evident in West Bengal, on susceptible varieties. The problem seemed slightly less important in Thailand.

Cold temperatures affect the floating rice crops in the *jheels* of Bihar. A group of varieties known as Dessarja or Jessaria (from Jessore, Bangladesh) is presumed tolerant. Tolerance should be verified.

Crabs, in combination with flash floods, drastically damaged crops at the Chinsurah Rice Research Station. Apparently crabs are less important in farmer fields where there are fewer bunds per area. A suggestion of varietal resistance, escape, or nonpreference was seen at Chinsurah.

Drought in West Bengal in 1981 seemed mainly of the postseason type. In other areas there was no severe drought.

In Bihar, zinc deficiency is severe on the calcareous soils. Iron deficiency also occurs. In Thailand, acid sulfate soils occur east and northeast of Bangkok.

Harvest periods vary among and within regions. In Bihar, harvest is in November-December; in West Bengal and Bangladesh, it is between October-November, whereas on Thailand's Central Plain floating rice is harvested in December. Near Prajinburi, harvest is November to December.

OTHER FACTORS RELATING TO VARIETAL CHOICE

Grain shattering was a problem in varieties of Bihar and West Bengal. Grain dormancy is also a concern in both states, likely in relation to harvest. Harvest of floating rice in Bihar and West Bengal is by boat in standing water; in Bangladesh and Thailand harvest is on dry soil.

There is a stated preference for white slender grains in Bihar and West Bengal. This is less articulated in Bangladesh, but is of prime importance in Thailand; and grains should be 7.2 mm or longer. Clear grains are important in Thailand. In Bihar, West Bengal, and Bangladesh, where parboiling is practiced, some chalkiness is tolerated.

Chinsurah is actively searching for tall, nonlodging, good tillering, and stiff-strawed types. The new variety CN540 fits this requirements except for low tillering.

GERMPLASM OBSERVED

Observations on germplasm were made at each place toured.

Bihar

- The floating rice group called Dessaria deserves attention for the likelihood of their resistance to diseases and their tolerance for late-season cold temperatures.
- Chenab 64-117 has been released as Janaki. The variety does well in 150 cm water but needs improvement in disease and insect resistance, in grain quality, and in its shattering habit.
- IRDWON. IRDWON seeds were received too late for the normal February planting time. None of the floating entries survived. The medium-deep set, direct-seeded and transplanted on 23 June and 20 July, respectively, had Leb Mue Nahng 111, BKN76014-1-9-2, and BKNFR76014-1-9-3 as survivors.
- IRLRON drowned completely in the 10 July flooding.

West Bengal

- Tilokkachary survived a flash flooding remarkably well; so did Chenab 64-117.
- Chenab 540 is gaining acceptance by farmers for its good plant type, survival in early-season flash floods, and good eating quality.
- Mahsuri suffers from tungro, and farmers are said to be abandoning it.
- Several good floating rice lines were seen in the field. Many of the lines were selected from a deepwater composite obtained in 1974.
- IRDWON. The medium-deep IRDWON set showed good survival for BKNFR76001-36-4-2-2, GEU77057-1-1, HTA7403-110-1-5, and IR11185-9-0-416-1.

- Good tungro resistance was observed for IR5853-196-1-P_1.
- Of the flood-tolerant set, BR118-3B-17, IR13437-20-4E-P_1, and RP975-109-2 IET5656 looked best.

Bangladesh

- Many BR floating rice lines performed well in the Rajbari field trials.
- Many lines from Thailand had tungro. Among those that did not, several seemed worth evaluating in transplant aman and flash-flood-prone areas.
- At Habiganj, Habiganj Aman I and Habiganj Aman IV looked good in early receding floodwaters.
- Several DWCB lines did well as floating rices.
- IRDWON. In the medium-deepwater IRDWON set at Habiganj, best survivors were DWCT 156-0-0-0, DWCT 156-1-B-B, GEU77057-1-1, HTA7403-110-1-103, HTA7403-110-1-5, and Habiganj Aman I.

The floating rice screening set was planted in shallow water at BRRI, Joydebpur. Resistance to tungro was seen in BKNFR76029-100-1-5-1, BR224-2B-2-5, BR232-2B-3-4/4, IR11288-B-B-118-1 (outstanding), SPRBR7411-7-2-2, IR42, SPR7239-1-14-1-2, and SPR7410-0-147.

At Joydebpur, the best surviving entries from an 80-cm flood were BKNFR76014-1-9-3, BKNFR76026-3-2-2-3, BKNFR76035-112-1, DWCT156-0-0-0 (tungro susceptible), DWCT 156-1-2-0-1, GEU77001-3-4, HTA7403-110-1-5, and IR11185-B-B-850-1.

Thailand

- In the regional yield trial at Prajinburi HTA7205-11 and HTA7421-8-1 were best.
- In an observation trial at Prajinburi, HTA7406-110-1-2 and HTA7403-110-1-1-3 were maturing and looked good. Many lines in the observation trials were maturing in early November and should have appropriate maturities for India or Bangladesh.
- IRDWON. In the IRDWON flood-tolerant screening set BH2, BKNFR76109-1-2-1, IR13260-135-IE-P_1, IR196061-57-4E-P_1, IR191061-57-4E-P_2, FR13A, IR9288-B-B-B5-2, and IR9288-B-B-B252-1 looked best in a test at Huntra.

AGRONOMY WORK

Agronomy experiments observed or discussed were concerned with stand establishment, response to fertilizer type or rate, herbicides and weed removal, and cropping time and cropping systems.

Stand establishment

At Pusa an experiment comparing drill, dibble, and broadcast seeding was observed. No yield differences were obvious but weed control was facilitated by drilling and dibbling.

At BRRI, a spacing trial suggested best results from the 1 plant/hill (10 × 5 cm^2).

Fertilizers

In a floating rice experiment in Bihar no response to complete (NPK) fertilizer was observed in two experiments, but in a flood-affected experiment, fertilizer helped the crop establish quicker and gave better subsequent survival.

At Chinsurah nitrogen source and nitrogen efficiency experiments were observed on transplanted crops of CN540, a medium-deepwater variety.

In Bangladesh, a fertilizer experiment on many lines in a farmer field were observed. At Habiganj an INSFFER trial on Habiganj Aman IV had an initial response in vegetative growth before flooding, but this response was no longer visible after the flood.

In Thailand, nitrogen-response experiments on the stations and in farmer fields compared traditional floating rices with the modern deepwater variety RD19. It showed positive response to nitrogen. At Prajinburi, all but the floating rice variety Leb Mue Nahng 111 were destroyed by the combined action of acid sulfate soil and (minor) flooding.

Weeds

In Thailand, oxadiazon or ioxanyl in combination with 2,4-D appeared to give best results.

Cropping timing and cropping systems

In Bihar, a double-transplanting experiment in receding water identified Chenab 64-117, BR8, and 62-28 as the best for transplanting older seedlings in September. Direct seeding in May or June in medium-deep water instead of transplanting in July gave improved yield and survival.

In Bangladesh, the transplanting of (normally broadcast) floating rice was evaluated in connection with fertilizer application. An experiment using the variety Gilamite was observed at Rajbari. Under these conditions, urea increased number of tillers.

DISCUSSION AND RECOMMENDATIONS

A diversity of situations and breeding objectives was noted between the areas visited. Some varieties that can serve as recurrent parent for further improvement have now been identified:

- RD19 is a Thai modern variety with photoperiod sensitivity and elongation ability, thereby increasing its range of survival in water depths as deep as 170 cm, provided water depth increases slowly. Defect to be corrected is its lack of resistance to tungro, ragged stunt virus, and bacterial blight. Its flowering date would be too late for most deepwater areas in India.
- CN540 is a West Bengal medium-statured variety with stiff straw. CN540 is good for water depths to 1 m and tolerant of early flash floods. Good grain quality makes it highly acceptable to farmers. More tillering ability would be desirable.
- Janaki (Chenab 64-117) is a tall variety adapted to 150-cm water depths in Bihar. It is tolerant of flash floods and resistant to tungro. Its major defects are lack of resistance to bacterial blight, shattering habit, and grain type and red pericarp.

IRDWON

- IRDWON screening sets should be distributed earlier for timely arrival. Screening sets, when arriving on time, should be planted in farmer fields, under appropriate natural flooding.
- Breeding programs for excess water are urged to send 500 g of each breeding line they wish to nominate to IRTP as soon as possible. Seed should reach IRRI in December. Alternately they may send 50 g seed/entry for seed increase at IRRI and inclusion in the nursery in the following year. A description, including flowering date, plant height, and deepwater tolerance type should accompany the nomination.

Agronomy

- Fertilizer applications in direct-seeded floating rice did not seem to give significant responses in tests seen or discussed.
- Response to basal fertilizer applications in long-duration rice crops appeared mainly associated with survival of short-statured varieties in flooding, of short and tall varieties in poor soils, or of transplanted floating rices in the face of flooding soon after transplanting.
- In-line or broadcast seeding may have their greatest facility of weed removal. They should be assessed with that in mind.
- Previous breeding work on new deepwater rice types has concentrated on survival ability of deepwater rices in the winter season because this would remove complications arising from vastly different maturing periods.

Persons met during the 1981 IRTP Deepwater Rice Monitoring Tour

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J. Mandal, research officer (breeding)
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S. Mallik, research officer (breeding)
A. Ray, agronomist
Anima Pal, asst. plant pathologist
S. K. Datta, operational research project

Bangladesh Rice Research Institute

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Murshedur Rahman, scientific officer (Comilla Station)
Abu Bakar, station in charge (Habiganj Station)
A. Salam, scientific officer (Habiganj Station)
A. Jabbar, scientific officer (Habiganj Station)
Muklesur Rahman, scientific officer (Habiganj Station)
S. M. Zaman, director (BRRI headquarters)
M. A. Ahmed, associate director (BRRI)
B. A. Dewan, senior scientific officer (breeding), BRRI
Enamul Kabir, liaison officer, BRRI
Paul Francis, experimental scientist (ODA), BRRI
F. W. Sheppard, IRRI representative, Bangladesh

Thailand

B. R. Jackson, IRRI representative in Thailand
H. D. Catling, entomologist, IRRI
Sermsak Awakul, asst. chief, Rice Division
Soonthorn Naka, chief, Huntra Rice Experiment Station
Chai Prechachat, head, Deepwater Rice Section, Rice Division
Kalaya Kupkanchanakul, breeder, Huntra Rice Experiment Station
Prathes Sittiyos, agronomist, Rice Division, Deepwater Rice Section
Lalida Laisakul, breeder, Huntra Rice Experiment Station
Siriporn Karin, breeder, Rice Division, Deepwater Rice Section
Samlee Boonyaviwatana, breeder, Rice Division, Deepwater Rice Section
Amara Wiengweera, breeder, Rice Division, Deepwater Rice Section

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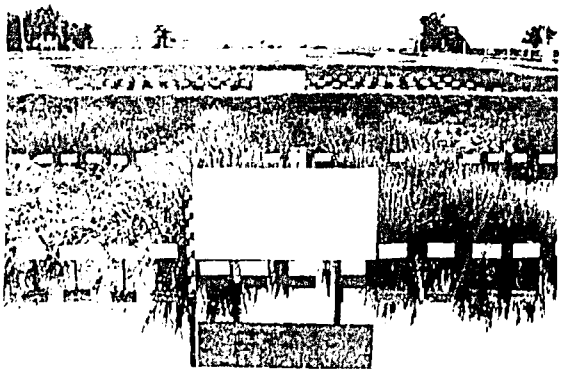
A. Participants in the monitoring tour observe deep-water yield trials at Rajbari, near Joydebpur, Bangladesh.

B. The variety Tilokkachary, one of the few varieties that survived the July flash flood at Chinsurah, West Bengal, India.

C. Dr. D. G. Kanter observes an F_2 population of IR33710 that has survived naturally flooded conditions at Joydebpur, Bangladesh.

D. The variety Tilokkachary, tolerant of flash floods at Chinsurah, West Bengal, India. Kneeing ability is evident.

E



F.

G

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E. Participants in the Deep-water Rice Workshop observe a deepwater rice yield trial at Huntra Rice Experiment Station, Ayuthaya, Thailand.

F & G. The IRTP floating rice screening set in one-meter-deep water at Huntra Rice Experiment Station, Ayuthaya, Thailand.

H. D. HilleRisLambers briefs participants in the Deep-water rice workshop on the IRTP flood tolerant rice screening set.

WORKSHOP RECOMMENDATIONS

For Varietal Improvement of Deepwater Rice

1. Deepwater situations in different countries need to be better characterized to help understand specific varietal requirements.
2. Collection and evaluation of local deepwater rices from different countries will help diversify the genetic base for varietal improvement. Scientists in national programs are urged to send seed of their local varieties to IRTP headquarters. IRTP should organize the exchange and testing of those varieties.
3. Segregating generations and rapid generation advance material for deepwater rice work should be distributed to different countries where there can be selections in local environments. The promising selections from different sites should further be exchanged among different scientists through entry in international nurseries.
4. The potential of elongating semidwarf rices should continue to be exploited. However, breeding approaches must be modified and diversified. For example, past attempts were toward incorporating elongation genes in the semidwarfs. Attempts should also be made to incorporate dwarfing genes in local varieties. The latter can be attempted, among other approaches, through mutation to shorten breeding time and to ensure retention of adaptive features of the local varieties.
5. Breeding objectives should include:
   - resistance to diseases and insects (ufra is one of the major stresses; severe incidence of tungro occurred in 1981 in deepwater areas of eastern India and Bangladesh);
   - tolerance for drought at early growth stage;
   - improved grain quality;
   - incorporation of submergence tolerance in new varieties for the flash-flood-prone rainfed areas; and
   - incorporation of submergence tolerance in some of the floating rices to provide additional insurance for growth and development where stem elongation does not keep pace with rapid increases in water depth.
6. Genetic and other basic studies on various traits relevant to deepwater culture need to be carried out to help in the planning of the breeding programs.
7. Training of junior scientists involved in deepwater varietal improvement is essential.
8. Increased facilities for screening for various traits relevant to deepwater varietal improvement at major experimental stations in different countries are needed.
9. All IRTP cooperating scientists should nominate their promising new material from deepwater breeding programs to the IRDWON. A 500-g seed sample is required for each entry. If 500 g is not available a 50-g seed sample is needed for seed increase.

For Plant Protection in Deepwater Rice

GENERAL

1. The group recognized yellow stem borer, ufra nematode, and rats as major pests of deepwater rice. Other pests that are sporadic or potential pests are tungro, ragged stunt, root knot nematode, hispa, green leafhopper, and mealybug. Thrips, root aphids, and crabs are minor pests. (The word pest includes mainly insects and diseases; weed recommendations are considered as cultural practices.)
2. There is a lack of basic information on the population dynamics and epidomiology of major deepwater rice pests in many of the deepwater areas. These data are essential to the development of control strategies.
3. Surveying and monitoring for the yellow rice borer and other pests should be encouraged, particularly in India, Burma, and Indonesia. The rice crop preceding deepwater rice should also be monitored. Preliminary data on the insect and disease situation in each country should be sought immediately. The pest status of yellow rice borer has been established in Bangladesh and Vietnam.
4. Because the use of pesticides is difficult in deepwater rice, it is important to concentrate on control methods such as varietal resistance, cultural methods, and trapping.
5. IRRI should collect information on methods for surveying and monitoring and screening techniques for major deepwater rice pests from different sources and circulate it to each country before November 1982.

SPECIFIC

1. *Yellow stem borer.* Screening deepwater rices using potted plant in small metal tanks should be started. Promising breeding lines and some entries from IRDWON must be included. Plants should be exposed at the same stage as under natural conditions. Raja Mondal should be used as a susceptible check and Shulpan as a resistant check. Yield loss assessments should continue to clarify actual yield losses.

   BRRI/ODA are investigating the feasibility of chemical control and are screening new insecticides. That group should also look into the feasibility of crop residue treatment to reduce overwintering populations.
2. *Ufra.* No feasible chemical control method is known at this stage. The new screening technique developed in Bangladesh can be used elsewhere, but care should be taken to prevent the spread of nematodes. The BRRI group has agreed to screen materials from other countries.
3. *Rats.* Control measures are available in each country, but joint action by the community is necessary for effective results.
4. *Tungro.* Tungro is sporadic, but was severe in eastern India and Bangladesh in 1981. More attention should be given to incorporate resistance in breeding programs and in monitoring for green leafhopper.
5. *Ragged stunt virus.* This disease was severe in deepwater rice in Thailand in

1981. Thailand will screen advanced breeding lines for ragged stunt resistance. Other countries should watch carefully for the appearance of this disease.

6. *Root knot nematode.* Root knot nematode has been found in several countries in Asia and has often been overlooked or confused with nutrient deficiency or toxicity. Screening techniques are available in Thailand and Bangladesh but need to be improved. Yield loss assessment studies are essential.
7. *Monitoring tours.* The IRTP deepwater monitoring program should include visits to deepwater rice areas in Africa.
8. *Regional pest management.* The regional pest management project in Thailand will cooperate with the FAO-IPC project, which is also based in Bangkok. The two projects should assist in coordinating and encouraging the surveying and monitoring of deepwater rice pests, and in the development of field survey methods and screening techniques.

For Basic Studies in Deepwater Rice Improvement

1. *Drought tolerance.* Because the effect of soil moisture stress at early vegetative stages on the yielding ability of deepwater rice is not well established there should be:
   - study of the effect of soil moisture stress at different stages of vegetative growth on the final yield and on growth duration; and
   - expansion of screening both for drought tolerance and for ability to recover following moisture stress.
2. *Submergence tolerance.* Screening for submergence tolerance of floating rice should be done differently from the system normally used for the intermittently flooded type. Submergence tolerance in floating rice must be associated with rapid elongation ability, which is not usually desirable for an intermittently flooded area. The screening method proposed is:
   - Grow the plants for 40-50 days for production of basal tillers.
   - Take notes on basal tillering.
   - Submerge plants in turbid water with depth increased at 50 cm/day for 3 days.
   - Keep the water depth constant for 4 weeks.
   - Reduce the water level to 70 cm and estimate the percentage of surviving basal tillers. Score plants on:

Surviving basal tillers	*Score*
0- 10%	9
20- 30%	7
40- 50%	5
60- 70%	3
80-100%	1

In screening for submergence tolerance in nonfloating rice, the vigor of the recovered plants should be noted in addition to percentage of dead plants. Vigor scoring is proposed at 10-15 days after drainage of water, according to the scoring system

Score	*Vigor* (visual)
1	Excellent (as FR13A)
3	Good
5	Fair
7	Poor
9	Very poor

3. *Blue-green algae.* Because blue-green algae are now assumed to be associated with deepwater rice nutrition there is need to:
   - Survey the abundance of epiphytic algae at different sites and growth stages of rice and relate the abundance to cultural practice and water chemistry.
   - Do ^{15}N dilution studies at various sites to demonstrate the role of floodwater and biological N_2 fixation in nitrogen nutrition of deepwater rice.

   Studies on the contribution of blue-green algae to deepwater rice nutrition should continue.
4. *Terminology.* Because all rice tillers arise from nodes and adventitious roots also arise from nodes, the terminology *nodal tiller* and *nodal roots* are botanically incorrect. New scientific terms should be found to replace nodal tiller and nodal root. Names discussed included aquatic tiller and aquatic root, deepwater rice tiller and deepwater rice root, and higher node tiller and higher node root.

For Cultural Practices for Deepwater Rice Improvement

1. *Tillage.* The possibilities of reducing number of tillage operations while maintaining efficiency should be studied. Possibilities include use of punch planter for direct seeding in stubble, or combining tillage, seeding, and fertilization in one operation. Attention should be given to timeliness of tillage operations in relation to weed control, plant populations, and stand establishment in both monocultures and mixed crops. The importance of soil mulches in water conservation should be considered. Tillage methods that require less energy are needed.
2. *Stand establishment.* Methods and equipment should be developed for even distribution of seeds at appropriate depth to ensure uniform plant stands. Line-sowing, dibbling, drilling, and transplanting should be compared. Seeding rates and spacing should be adjusted to give plant and tiller populations appropriate for the rice varieties used. Both basic and applied experiments to determine contribution of individual tillers to crop yield should be continued.
3. *Weeds.* A cooperative survey of predominant weeds and development of standard methods to ascertain crop losses are needed. Culture techniques should reduce the weed population and minimize labor inputs for weeding.

   A coordinated program for testing herbicides should be established (IRRI to provide chemicals for testing). Some combinations of chemicals are promising, but the effect of soil moisture should be evaluated. All weed control experiments should record the costs as well as the effectivenesss of treatments.

   Wild rice is a major weed problem in deepwater areas and research on its control and classification is needed.

4. *Fertilizers.* There is insufficient information on the nitrogen cycle in deepwater rice. Further studies should be made on the nitrogen effects at the onset of flooding when plants turn yellow and later green.

   Plant samples should be collected for analysis to examine utilization of fertilizers. More response to fertilizer is expected from improved plant types with upright leaves. The effect of fertilizers on harvest index should be noted, and fertilizer effects should be separated from factors such as insects, pests, and diseases.

   Further information on the function of aquatic roots and uptake of nutrients from floodwater is needed. Research emphasis should be placed on fertilizers other than nitrogen — phosphorus and trace elements.
5. *Cropping systems.* Cropping patterns in deepwater areas are dependent on soil type, early rainfall, and residual water. Further study of the reason farmers adopt particular cropping patterns, the effect of land preparation, component technology needs with early-maturing varieties, use of line-sowing for more efficient intercropping, and the use of earlier deepwater rice varieties to enable more favorable establishment of subsequent crop is needed. The interaction of factors in yield constraint studies should be studied cooperatively.

WORKSHOP CLOSING

Tanongchit Wongsiri
Director General of Agriculture

Now that this Deepwater Rice Workshop is ending it is my sincere hope that your participation has been worthwhile. On behalf of my government, I thank the International Rice Research Institute for its financial and logistical contributions to make this workshop possible. To my Thai colleagues in the Ministry of Agriculture I suggest that you assimilate the information gained over the past week and see what parts are applicable to Thailand's farms.

To the international participants and IRRI staff I convey the appreciation of my government for your willingness to come here and share your knowledge and experience with us. No doubt we have received more than we have given because the workshop was held here and enabled more Thai scientists to participate. Nevertheless, we believe cooperation is a two-way street and trust you have also learned something from us.

I wish all of you a safe return to your homes and look forward to significant progress in deepwater rice research in the coming years. I now declare this meeting closed.

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A. The 1981 International Deepwater Rice Workshop participants pose after their tour of the Huntra Deepwater Rice Research Station, Thailand, on 4 November 1981.

B. Mr. Phaderm Titatarn, director of agriculture, gives the welcome address to the workshop. From left: Dr. Marcos Vega, deputy director general, IRRI, Mr. Narong Wongwan, deputy minister of agriculture, Ministry of Agriculture and Cooperatives, Dr. Dioscoro Umali, FAO regional representative for Asia and the Pacific, Bangkok, Thailand, Mr. Amphon Senanarong, deputy director general, Department of Agriculture, Ministry of Agriculture and Cooperatives, and Dr. Titatarn.

INTERNATIONAL DEEPWATER RICE WORKSHOP

Bangkok, Thailand
Nov 2-6, 1981

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D

C. Ms. Siriporn Karin of the Rice Division, Thailand, explains the influence of seedling age on the submergence tolerance of three rice varieties.

D. Participants in the Deepwater Rice Workshop observe an elongation test at Huntra Rice Experiment Station, Ayuthaya, Thailand.

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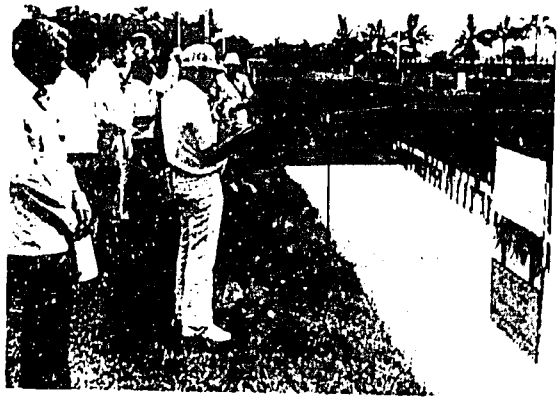

F

E. Successful survivors of a submergence test had been transplanted into this field, and are now ready for harvest.

F. Dr. D. G. Kanter, associate plant breeder, BRRI/IRRI Cooperative project, Bangladesh, compares the performance of Bangladesh and other entries in the floating IRTP rice screening set at Huntra Rice Experiment Station, Ayuthaya, Thailand.

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