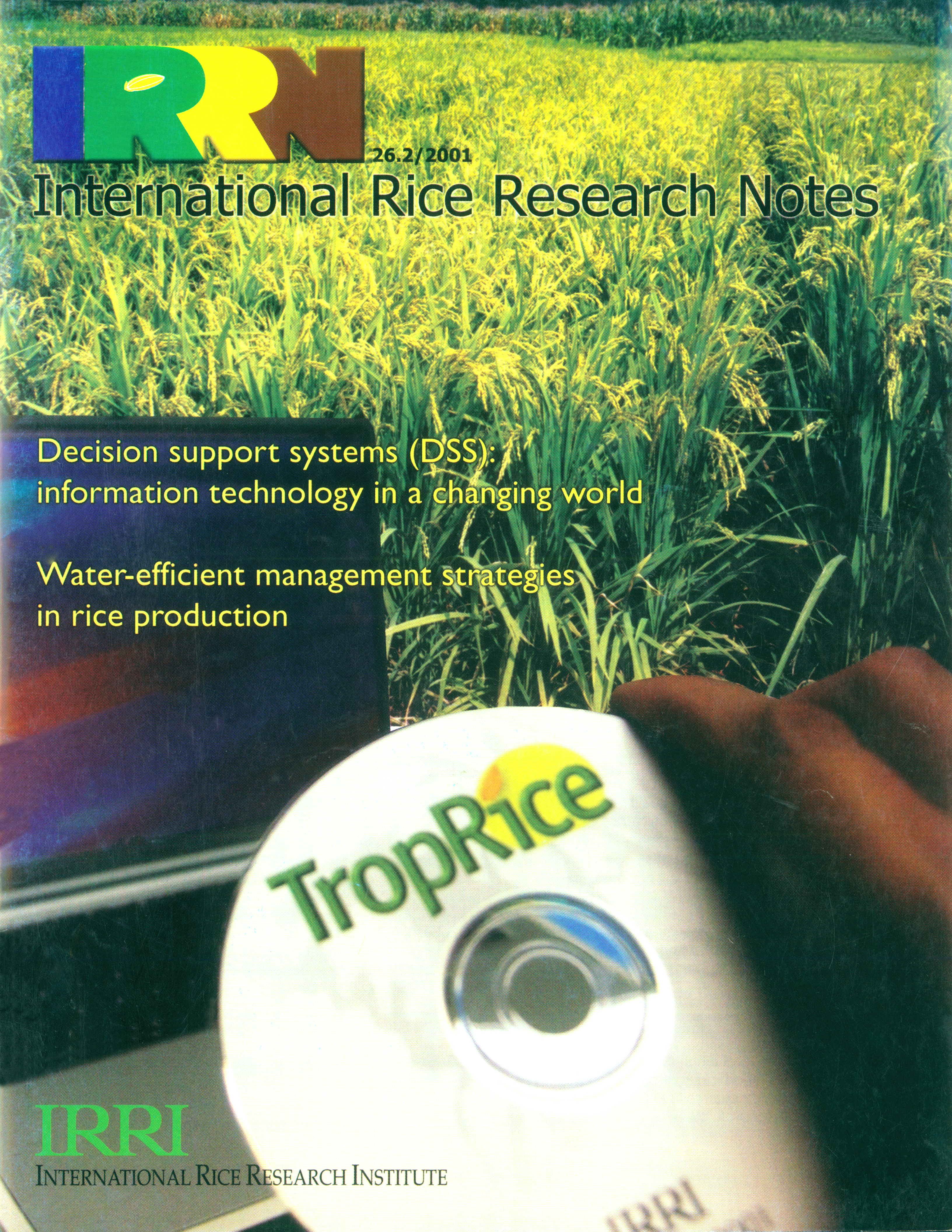
IRRN 26.2/2001

International Rice Research Notes

Decision support systems (DSS): information technology in a changing world

Water-efficient management strategies in rice production



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26.2/2001

December 2001

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The *International Rice Research Notes* (IRRN) expedites communication among scientists concerned with the development of improved technology for rice and rice-based systems. The IRRN is a mechanism to help scientists keep each other informed of current rice research findings. The concise scientific notes are meant to encourage rice scientists to communicate with one another to obtain details on the research reported. The IRRN is published twice a year in June and December by the International Rice Research Institute.

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Editors' Note

The year 2001 has been one of change at IRRN, unfortunately not all of it positive. Most significant is the reduction in the number of issues per year from three to two. IRRN will now appear in June and December. This change has been made necessary by declines in the budget of IRRI. IRRN has almost 4,000 names on its mailing list with 60 paid personal and institutional subscribers, but the great majority of our funding comes from IRRI's core budget. Reducing the number of issues per year will result in substantial savings in postage and production costs, without a reduction in the number of papers published per year. However, we regret the additional delay in publication that will result for some papers.

There was a substantial decline in the number of manuscripts submitted to IRRN in 2001. This continues a trend of declining submissions over the past 15 years, which may be related to the decline in the number of unpaid subscriptions to IRRN that IRRI provides. We encourage our readers to consider publishing their research papers in IRRN.

We believe that the free availability of IRRN online (www.cgiar.org/irri/irrn/htm) has enabled many to continue to read IRRN despite the reduction in the number of printed copies distributed. Many thousands of downloads have been made from the IRRN online version since it was established in 1998. The site has been—and continues to be—the most popular on the IRRI Web site.

Finally, we are pleased to announce that Dr. J.K. Ladha of IRRI's Crop, Soil, and Water Sciences Division will take over as editor-in-chief in 2002. He will succeed Dr. Michael Cohen, who has served since the establishment of the editorial board in 1998.

The Editorial Board

MINI REVIEW

Decision support systems (DSS): information technology in a changing world

R. Bakker-Dhaliwal, M.A. Bell, P. Marcotte, and S. Morin, IRRI, Los Baños, Laguna, Philippines
E-mail: r.dhaliwal@cgiar.org

Traditionally, geographical distances between potential centers and users of information, such as IRRI and universities, have made the acquisition and delivery of information intermittent and inconsistent. The significance of this physical distance has dramatically decreased with the advent of the computer, and more recently, the Internet, which have become effective and efficient tools for delivering information both locally and globally. In the agricultural sector, which is in the midst of powerful changes influenced by industrialization and modernization, farm consolidations, reduced or eliminated subsidies, environmental limitations, land use conflicts, biotechnology, and increased overall risk, the availability, accessibility, and application of contemporary expert agricultural information is of high priority for farmers, technicians, and researchers. In response to these changes and demands for the most current information, numerous scientific and academic institutions have turned to computerized decision support systems (DSS) as a means of packaging biological, agricultural, and technical information to make the information more easily accessible and useful for various beneficiaries in a rapidly transforming and competitive world.

Our objective in writing this review is to (1) articulate a coherent definition of DSS including the features they generally contain, (2) provide examples in agricultural and related sectors, (3) establish reasons or factors for their slow or lack of uptake, and (4) finally suggest strategies for increasing user acceptance. This paper is the first in a series related to DSS. The next three articles, immediately following this review, highlight specific DSSs.

What is a DSS?

There are many definitions of DSS but they usually fall into one of two categories: narrow or broad. The narrow definition takes the view that a DSS is an interactive computer program that uses analytical methods and models to help decisionmakers formulate alternatives for large unstructured problems, analyze their impacts, and then select appropriate solutions for implementation (Watkins and McKinney 1995). The DSS will essentially solve or give options for solving a given problem. The decision process is structured in a hierarchical manner, the user inputs various parameters, and the DSS essentially evaluates the relative impact of doing x instead of y. The broader definition incorporates the above narrow definition but also includes other technologies that support decisionmaking such as knowledge or information discovery systems, database systems, and geographic information systems (GIS) (Power 1997).

This review favors the broader perspective and defines a DSS as comprising the following: (a) it is computer-based, (b) it is an information and/or technology transfer agent, (c) it contributes to option selection, and (d) it aids decisionmaking irrespective of whether the solution is generated by the system itself or independently deduced by the user from the information provided.

Within this broad definition, it is further useful to think of DSS in terms of their primary driving source of information. Bhargava and Power (2001) have suggested the following five broad categories:

1. Communications-driven DSS emphasizes communications, collaboration, and shared decisionmaking support. Examples are simple bulletin boards, threaded e-mails, audio conferencing, web conferencing, document sharing, electronic mail, computer-supported face-to-face-meeting software, and interactive video. It enables two or more people to communicate with each other, share information, and coordinate their activities. Communications-driven DSS is often categorized according to a time/location matrix, using the distinction between same time (synchronous) and different times (asynchronous), and that between same place (face-to-face) and different places (distributed).
2. Data-driven DSS emphasizes access to and manipulation of time-series data from an internal or external database source. Users can access relevant data by simple query and retrieval tools for further synthesis and analysis: an example is weather-related databases.
3. Document-driven DSS integrates a variety of storage and processing technologies to provide users document retrieval and analysis: this may sometimes be found in libraries.
4. Knowledge-driven DSS is an expert or rule-based system where facts, rules, information, and procedures are organized into schemes that allow for more informed and effective decisionmaking. This is also sometimes referred to as the "expert" type of DSS.
5. Model-driven DSS emphasizes access to and manipulation of a model, for example, statistical, financial, optimization, simulation, and deterministic, stochastic, or logic modeling. Model-driven DSS generally requires input data from the end-user to aid in analyzing a situation. (See also Power 1999 and Watkins and McKinney 1995.)

Developers envision the ultimate DSS to be a compendium of several types of DSS (Fig. 1) to generate user-friendly, helpful, and resourceful recommendations.

However, developing a DSS as represented in Figure 1 is complex, requiring multicriteria analysis by a diverse group of knowledge experts and facilitated by the latest computer and/or web-based technologies. In addition, the software architecture involved in developing this type of DSS requires a long-term commitment of financial resources; a resource often limited in the nonprofit agricultural research sector. Currently, the most innovative DSS of this type originates in the industrial, financial,

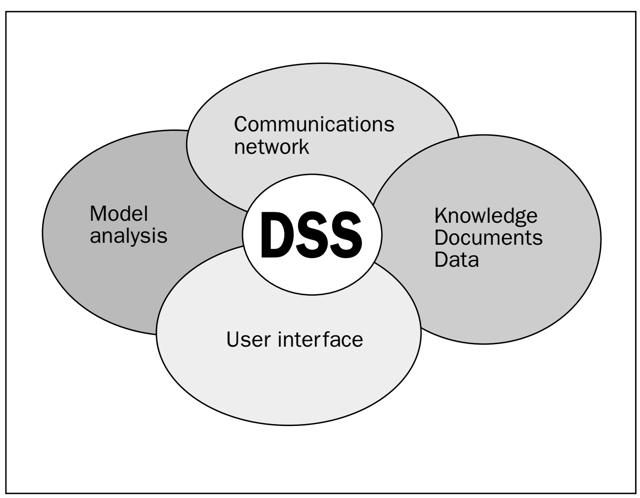

Fig. 1. The ideal DSS development model.
Source: Power (2000).

and commercial business sectors or within large government agencies.

This mini review and subsequent articles highlight knowledge- and model-driven DSS, the most frequently encountered types in the agriculture sector.

Who uses DSS?

DSS exist for a wide range of applications including business and organizational management, health, water resources, environment, agriculture, and transport systems. Within these sectors, the DSS can be targeted for a wide range of categories of people, environments, or jobs. For example, in the agricultural field, DSS can be designed for use by agronomists, soil scientists, agricultural engineers, or entomologists specifically, or by agricultural scientists, researchers, extension agents, students, and/or farmers in general. DSS can be further targeted for a variety of environments or agricultural commodities—for temperate or tropical conditions, rainfed or irrigated environments, upland or lowland areas, watershed or field levels, fruits or grains, rice or wheat, and others. In addition, DSS are developed by both the commercial and nonprofit sectors.

Most agricultural DSS aim to help companies/organizations/people realize their strategic aim of securing a competitive advantage through timely decisionmaking. In Europe, numerous DSS exist to predict appropriate pesticide application times for various crops including potato. Of these, the most common are Negfry (Denmark),[1] Prophy (Netherlands),[2] Plant Plus (Netherlands),[3] and Simphyt (Germany),[4] which focus on reducing fungicide inputs (Dowley and Leonard 2000). These four late-blight advice systems have the advantage of being in direct competition with each other and, as a result, may truly be useful for farmers. Each developer competes with the others to deliver the most accurate, reliable, and useful blight prediction system. In fact, the four systems were compared during a field test, where one outperformed the others. The "winning" developer can and does use the results to gain market share (see http://dacom.nl/pavtest.html).

Most nonprofit agricultural DSS also aim to help users realize their competitive advantage or profitability through timely decisionmaking, with the general goal of increasing field production yields. DSS originating from nonprofit institutions, in most cases, tend to be free of charge or have minimal fees.

Tables 1 and 2 show some agriculture-related DSS and their particulars. Table 1 is presented to highlight the availability of numerous DSS for a wide range of agricultural and/or environmental applications and Table 2 to highlight DSS specific for rice production. In addition, they are listed because of their ease of accessibility via the Internet. If a particular DSS in Table 1 or 2 is not viewable or downloadable through the Internet, a contact person's email address is referenced within the table. These tables are by no means comprehensive.

The most notable aspect of the DSS listed in Tables 1 and 2 is that a majority of the developers of the DSS system are nonprofit and publicly funded institutions. The exception is the CABI Compendium. In addition, they all require a fairly high level of computer literacy and competency in the use of the English language and scientific terminology. Lastly, most of the DSS have advanced state-of-the-art hardware/software or Internet connection (i.e., bandwidth) requirements for operation.

The target audience and/or environment for the DSS in Table 1 tend to be quite broad and sometimes very loosely defined. And although the information accessible via these DSS is useful, especially for policymakers and researchers interested in forecasting/simulating/testing hypotheses, its applicability and accuracy for a specific geographical area may be unreliable and risky in real terms for agriculture's ultimate end-users, the extension worker and the farmer.

The rice DSS in Table 2 differ from those in Table 1 in that their focus is on a narrower geographical area. With a narrower focus, the information is perhaps more applicable for the area targeted and less risky for farmers; however, the information is of little use if the environment within a geographical area remains highly variable. For example, the rice DSS for California (CALEX/Rice), south and midwest (DD50), and Riverine areas of Australia (MaNage) cover a fairly large and homogeneous growing environment. In comparison, the DSS for the tropics and Asia have a more difficult and challenging task as they must try and cover a highly heterogeneous agricultural environment. Due to Asia's complex environment and a developer's financial, time, and human resource constraints, in the short term, many of these DSS focus on a single rice-growing environment, i.e., irrigated systems.

[1]Danish Institute of Agricultural Sciences. [2]Opticorp. [3]Dacom Automatisering BV & Systems, Inc. [4]German Authority for Agriculture and Food.

Table 1. Some types of agricultural DSS currently in use or under development.

DSS	Target audience and environment	Developer and access information	DSS category	Description
CABI Compendium	Scientists, researchers, and extension staff; worldwide	Cabi International, UK; http://pest.cabweb.org/cpc/cpchp.htm	Database- and knowledge driven	Pest management for various crops
CROPWAT	Scientists and irrigation engineers; worldwide	Land and water development division of FAO; http://www.fao.org/ag/AGL/AGLW/cropwat.htm	Model- and database-driven	Irrigation management
DSSAT (Decision Support System for Agrotechnology Transfer)	Scientists and researchers; worldwide	International Consortium for Agricultural Systems Applications (ICASA) and Department of Biology and Agricultural Engineering, University of Georgia; http://www.icasanet.org/dssat/	Database-driven, model-driven (CERES, CROPGRO, and CROPSIM systems)	For various crops, analyzes and displays outcomes of simulated agronomic experiments
HOWWET	Researchers, extension agents, and growers; Australia	Queensland Department of Primary Industries and Queensland Department of Natural Resources; http://www.dnr.qld.gov.au/longpdk/ausrain/how.htm	Database-driven	Plant-water interactions
MAS (Multi-Agent System for Natural Resource Management)	Scientists, researchers, and extension workers; worldwide	Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), France; http://cormas.cirad.fr/	Model-driven	Uses CORMAS programming software for simulations of various natural resource management outcomes
NuMass (Nutrient Management Support System)	Scientists and researchers; worldwide	Cornell University, North Carolina University, University of Hawaii, and Texas A&M University deanna_osmond@ncsu.edu	Model- and database-driven	Soil nutrient management for various crops including rice, maize, cassava, etc.
WEPP (Water Erosion Prediction Project)	Scientists, researchers, and extension workers; worldwide	National Soil Erosion Research Laboratory – USDA-ARS; http://topsoil.nserl.purdue.edu/nserlweb/weppmain/wepp.html	Model-driven	WEPP is a process-based, distributed parameter, continuous simulation, water erosion prediction model for use on a PC

For a DSS developer, deducing the target audience and environment is admittedly a critical and challenging task. Nevertheless, outstanding DSS tend to have a clear idea of the audience to whom the information is targeted. For a DSS user, being aware of the target audience and the environment for which the DSS is developed is also vital, as well as discerning information and/or recommendations that are reliable and applicable to one's particular environment.

Issues for agricultural DSS

There is some debate on the use or value of DSS as a vehicle to communicate research results to farmers, agricultural technicians, extension agents, field advisors, and researchers (Parker and Campion 1997, Smith and Webster 1986). The debate is applicable whether the DSS is for use in developed countries or in the still developing part of the world. In some sectors, "the DSS technology is considered to have passed through the hype phase, where performance expectations outstripped the potential for delivery, and now might be considered to be maturing" (Parker and Campion 1997, Wong 1995). Nevertheless, a literature review of agriculture-related DSS innovations indicates a general realization that although there are many useful, scientifically valid models or knowledge-based tools currently available, a majority of these are underused. This may be partly due to the DSS's narrow target audience or environment. But the problem is most likely compounded by insufficient initial attention directed at delivery, including graphic user interface design, and development of an integrated knowledge system. Delivery, within the Asian context, incorporates the idea of getting the information to the user in the most practical, user-friendly, universally accepted, easily adaptable, reliable, and consistent format.

Table 2. Rice-based decision support systems currently in use or under development.

System	Target audience and environment	Developer and access information	DSS category	Description
CALEX/RICE	Researchers, extension workers, and growers; northern California	University of California, Davis http://www.ipm.ucdavis.edu/IPMPROJECT/soft&db.html-CALEX/RICE 1.1	Knowledge-driven	Irrigated rice, whole crop management
DD50 (Degree Day 50)	Researchers, extension workers, and growers; southern and midwestern USA	University of Arkansas, Missouri, and Mississippi, Louisiana State University via the university extension systems; http://www.deltaweather.msstate.edu/	Model- and database-driven	Irrigated rice, crop growth, and management prediction
MaNage Rice	Consultants, extension workers, and growers; Riverina, Murray Valley, Australia	NSW Agriculture and CSIRO Division of Plant Industry; http://www.pi.csiro.au/Brochures/FactSheets/Decision/Support/manage_rice.htm	Model- and database-driven	Nitrogen management for the Amaroo rice variety
NuDSS (Nutrient Decision Support System)	Scientists, researchers, and extension workers; irrigated rice, Asia	Soil and Water Sciences Division, IRRI; C.Witt@cgiar.org	Model- and database-driven	Integrated nutrient management
PRICE (Pesticide Residues in Irrigated Cereal Ecosystems)	Policymakers and extension workers; irrigated rice, tropics	University of Newcastle Upon Tyne, UK; Natural Resources International, Ltd., UK Richard.Wilkins@newcastle.ac.uk	Model- and database-driven	Risk simulation for herbicide use in tropical irrigated rice
RiceIPM	Researchers, extension workers, and students; tropics, Asia	IRRI and Center for Pest Information and Technology Transfer, University of Queensland; http://www.irri.org/	Knowledge-driven	Integrated pest management
ThaiRice	Researchers and extension workers; northern Thailand	University of Changmai; http://mccweb.agri.cmu.ac.th/research/DSSARM/ThaiRice/framework.html	Thai graphic user interface, CERES model and spatial database-driven	Integrated rice management system
TropRice	Researchers, extension workers and some farmers; irrigated rice areas, Asia	International Programs Management Office (IPMO), IRRI; http://www.irri.org/	Knowledge-driven	Integrated rice management system

Most agricultural DSS are developed by research scientists and engineers working within highly specialized technical domains. These domain experts have little or no experience in cognitive and user interface delivery concepts. Although the scientist's areas of specialization lead to high levels of efficiency in concept and content development, the DSS developed tend to be (1) highly complex; (2) directed at only other scientists or researchers with similar mind-sets and not necessarily the agricultural end-user (i.e., field- level agricultural technicians, extension field agents, or farmers); (3) directed at problems isolated from other production factors (e.g., they may only focus on fertilization, pest management, crop production management, weed control, or land use management, etc.); and (4) lacking in cost-benefit analysis (Ostergard and Goodell 2000, Parker and Campion 1997, Carrascal et al 1995). The idea of "delivery" is typically limited to technical and computer science aspects, neglecting aesthetics, use of appropriate terminology, ease of use, cost-benefit analyses, and integrated thought processes.

In addition, many agricultural scientists contend that crop management decisions are intrinsically "unstructured decisions," and thus application considerations ought to be ignored. Power (2001) defines unstructured decisions as a type of decision situation that is complex and no standard solutions exist for resolving the situation per se. Some or all of the structural elements of the decision situation are undefined, ill-defined, or unknown. For example, goals may be poorly defined, alternatives may be incomplete or noncomparable, and choice criteria may be hard to measure or difficult to link to goals (Power 2001). Trying to configure this unstructured decision state of affairs for crop management is a demanding, challenging, time-consuming, and possibly impossible task, especially without the use of high-powered hardware and artificial-intelligent-type software systems. However, there are general guidelines, based on years of experimentation, which are specifically appropriate and must be supplied whenever feasible.

In addition to the issues discussed earlier, Bell and Chung (2000) have identified multidimensional factors that limit communication and DSS adoption within Asia, including disproportionately large numbers of farmers relative to land ownership; farmer education and beliefs; language and cultural diversity; access to resources and credit; limited communication channels including mass media: radio, television, telephone, cell phones, and infrastructure; limited access to extension systems, consultants, and universities; underfunded and undertrained extension systems; and limited private sector development.

Therefore, although DSS continue to change rapidly and enormous innovation is occurring, several factors have to be built into DSS development from the start to ensure widespread usage. These factors include

1. A clear perception of "who" the end-user or target audience is
2. An awareness of the costs and benefits associated in developing the DSS for the long term
3. Simplicity for long-term sustainability (especially in the current Asian agricultural environment)
4. Formative evaluation and testing at every stage of development involving all stakeholders
5. A formal program to train users
6. A long-term support and consultation for users if feasible
7. Information that is accurate, clear, constructive, and cost effective for decisionmaking.

Strategies for increased use

The DSS developer perspective

Figure 2 is a simple representation and proposal for DSS development that may alleviate some of the problems inherent in their construction. Many of these strategies are not new and have been touched upon by scientists as lessons learned in developing decision support tools (Bell and Chung 2000). The comments specified in Table 3 in conjunction with Figure 2 may be useful for developers of rice-related DSS in Asia.

The majority of the lessons suggested by scientists are in reference to the content of the DSS. For example, if the DSS is model-based, then limit the amount of input data from the user or provide sufficient default values, indicate cost-benefit, show relative advantage, indicate risk, and answer the right questions. This is practical and constructive advice. However, the delivery aspect must also be more strongly emphasized and be continuously at the forefront of the development process. User-centered design is essential; it can be simple to complex, but the developer must be cognizant of its target audience, use formative evaluation, and design iteratively.

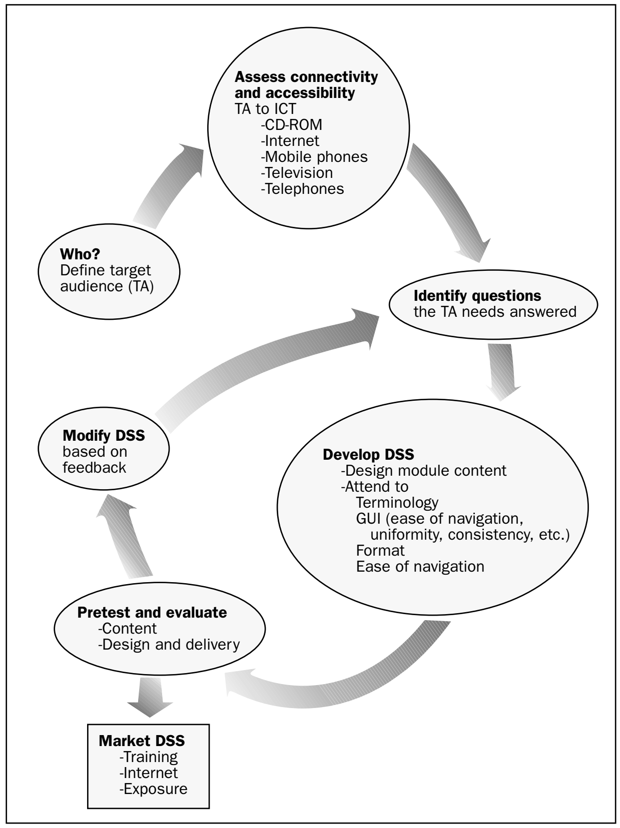

Fig. 2. Proposed DSS development cycle. GUI = graphical user interface, ICT = information and communication technology.

The DSS user perspective

Although Figure 2 and Table 3 are directed at DSS developers, they contain terminology and concepts that DSS users may also find helpful in evaluation and assessment during the iterative DSS development process. For example, users generally must evaluate and review the following:

1. Content is reviewed for accuracy, breadth (i.e., range of knowledge or skills covered), depth (i.e., degree of complexity and detail), clarity (i.e., how well text is written), and appropriateness (i.e., content is appropriate to the level

Table 3. Lessons learned by IRRI scientists in developing decision support tools.

Researcher	Comments
Achim Dobermann and Christian Witt in reference to a model-driven DSS	1. Keep the amount of input data required as small as possible. 2. Keep the system itself as flexible as possible, i.e., cater to missing data. 3. Give users reasonable default values (for their conditions) — users seem to be afraid to enter a "wrong" value. 4. Design a generic system that can give site-specific recommendations. The users do not appreciate a very general system–IRRI is interested in all of Asia, but the users are only interested in their specific regions. The more specific a system is for their conditions, the better. 5. For a generic system, quick indicators are needed to narrow the system to the one of interest to the user.
Reimund Roetter	1. Revise and refine — iterations, present the DSS to users, and continue to refine based on their new ideas for improvement. 2. Involve users of the DSS as soon as possible, that is, from the beginning. 3. Satisfy the need for clearly defined, sound underlying concepts. 4. Practice good documentation. 5. Present prototype models to other experts from the early stages.
Mark Bell in reference to a knowledge-driven DSS	1. Focus — do not try to solve all problems at once; choose your target very well (recommendation from Richard Plant). 2. Simplify, simplify, simplify — users will decide if a system is worth the bother of using based on the balance between ease of use, time required, and expected benefit. 3. At times, you will have to give generalized specific recommendations — do this, even though it is typically frowned upon.

Source: Bell and Chung (2000).

of knowledge, skills, and experience of the target audience);

2. Usability is reviewed for technical operation (e.g., the DSS CD-ROM is easy to install or easy to access online, other software or "plug-ins" are easy to access and install, the DSS runs smoothly without hanging up or crashing, speed is adequate, and printability of key information is easy) and hardware/software requirements.
3. Design and delivery is reviewed for clarity of directions and instructions, interface design consistency (e.g., icon locations, menu terms, screen layout), on-screen text readability (e.g., font size and styles), and ease of navigation (e.g., users can easily predict where a link will take them).

Clear and consistent terminology in assessment of DSS by users can be extremely useful for developers.

A strategic process for developing a DSS then includes the following types of individuals working as a team: (1) Domain expert—a person who has expertise in the domain or areas of interest in which a specific expert system is being developed; (2) Knowledge engineer—an information technology (IT) or artificial intelligence specialist responsible for the technical side of developing an expert system. (The domain expert, usually a scientist, works closely with a developer (i.e., the knowledge engineer) to capture the expert's knowledge (especially rule and relationship information) in a computer-readable representation often called a knowledge base [Power 2001]); (3) Graphics designer—an individual who can develop the graphical user interface (GUI)—a program interface that uses a computer's graphics capabilities to make the program more pleasant and easier to use. Graphical interfaces use a pointing device to select objects, including icons, menus, text boxes, and other devices. A GUI includes standard formats for representing text and graphics (Power 2001); and (4) Monitoring and evaluation specialist—a neutral assessor to monitor, test, capture information, and summarize evaluation results during a DSS iterative development process.

Once a DSS is ready for release, the process is not concluded, especially within the socially, culturally, and economically complex Asian agricultural framework. In this context, a strategic aspect that receives scant attention is that of training and marketing of the DSS products to end-users. Within Asia's culturally and educationally diverse agricultural sector, it cannot be assumed that end-users, whether they are scientists, managers, technicians, extension agents, NGOs, or farmers can access and manipulate the DSS. Many of the end-users must overcome their anxiety of new technology itself; however, once conquered, the access to information can be relatively painless and highly useful. Take for example, the head of a Municipal Agricultural Office, who participated in an information technology assessment workshop in the northern provinces of the Philippines. Although the agricultural officer was initially extremely hesitant and skeptical about approaching the computer, upon some brief instruction on TropRice, he was enthralled and eager to move around in the DSS using the mouse (without using the keypad). Thirty other extension agents attending this demonstration and evaluation activity, over a 2-day period, eventually conquered their anxiety, tried out TropRice, and gave feedback. An interesting note is that 90% of the extension agents had never worked on a personal computer, habitually delegating such work to their computer clerks.

The marketing of DSS does not have to be a cost-prohibitive activity. Many scientists and researchers travel regionally within Asia numerous times annually, conducting workshops, attending meetings and conferences, doing needs assessments, and other related activities. Many NARES, NGOs, universities, and individuals do have access to computers, if not yet the Internet. Showcasing the DSS to various counterparts regionally, and using CD-ROM or the Internet if feasible, would not be too difficult or demanding a task, especially when the information is practical and useful.

Conclusions

The Internet has indeed reduced the geographical distances between the target audiences and information sources—making information more easily accessible. At the same time, new developments in hardware and software technologies have encouraged the development of more user-friendly DSS that target a different level of the agricultural sector hierarchy. In the past, the problem has not been a lack of or existence of knowledge, but rather moving the knowledge from the research 'knowledge' centers to extension agents and farmers (Bell and Chung 2000). Although the extension systems charged with delivering information have all too often failed to meet their objectives in the past (Adhikarya 1994, Garforth and Lawrence 1999, Bell and Chung 2000), this failure may also be reflective of inconsistent delivery of information from the knowledge centers to the extension systems.

For research centers to have their findings reach farmers, new and more consistent forms of disseminating knowledge are essential for the future. DSS are a useful and legitimate means to deliver information as long as their development and production are done systematically, with adequate consideration given to target audience, target environment, target objective (i.e., what types of questions need to be answered), content complexity or simplicity, ease of navigation, and the graphical user interface, terminology, testing and evaluation, and an iterative plan. In addition, the DSS must be developed with sustainability and longevity as underpinning goals.

Within the complex environmental, cultural, and social context of Asia, the most useful agricultural DSS will most likely be those that simply present expert information and allow the user to use his/her experiences in conjunction with information presented to garner solutions.

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TropRice: a decision support system for irrigated rice

M. Bell, R. Bakker-Dhaliwal, and A. Atkinson, IRRI, Los Baños, Philippines
E-mail: m.bell@cgiar.org

TropRice is a knowledge-driven support system that delivers expert information to help technology transfer agents make more informed practical decisions related to rice production in the tropics. TropRice was developed in response to the recognition that many researchers, field extension agents, and farmers do not have access to the most up-to-date information on how to improve their rice-growing practices. Computers, the Internet, and information technologies offer innovative ways to package and present practical information.

Target audience and environment

TropRice is primarily aimed at intermediary technology transfer agents—the people who work with farmers in the field and need practical information on production and postproduction practices. They can be in government, nongovernment extension organizations, or the private sector. In addition, researchers will find TropRice useful as both a training and field practice resource.

Although TropRice is aimed at irrigated tropical rice, it is *not* a single system for all irrigated tropical rice systems. Although some information is generic, other information is site- or region-specific. TropRice is in fact a template (i.e., prototype) that is intended for modification by IRRI's collaborators to suit their particular rice-growing environments. The present system is aimed at irrigated rice in a lowland production environment. However, as additional information on improved practices for various environments and/or modules within TropRice becomes available, it will enter or be linked to the system.

Content

TropRice aims to provide practical information on all aspects of production and postproduction management of rice and answers questions related to

- Management timetable
- Land preparation and leveling
- Rice varieties
- Crop establishment
- Water management
- Nutrient management
- Pest management
  - -weed management
  - -insect management
  - -disease management
  - -snails, rats, and birds
  - -safe applications
- Postproduction
- Economics

In addition, TropRice contains two slide shows—one titled "Technology changes in Asia: The changing face of Asian rice production" and the other one on "Seed quality."

TropRice is now being used in China, India, Indonesia, the Philippines, Thailand, and Vietnam and is being translated or localized by national collaborators for local conditions in these same countries. Some of these collaborators also evaluate TropRice content for accuracy, reliability, depth, and breadth and recommend changes.

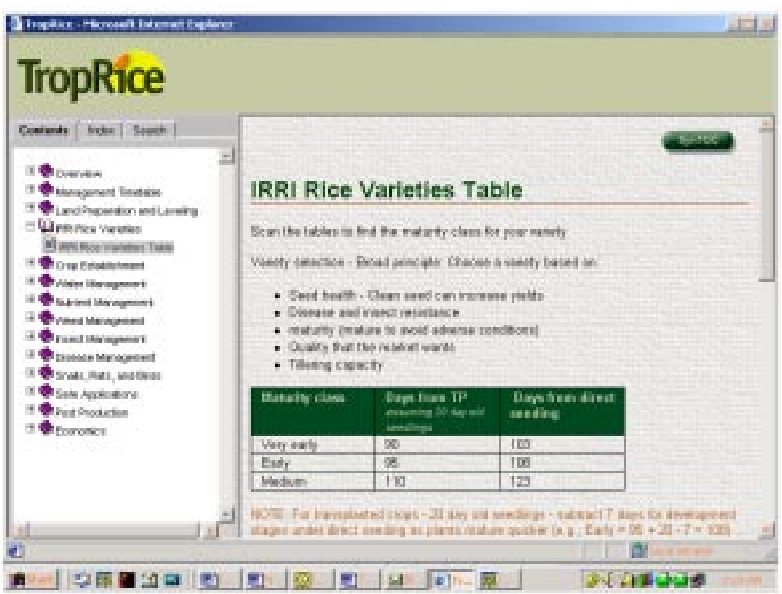
Graphical user interface and technology requirements

TropRice screens are designed to facilitate navigation. The user interface for TropRice is set up to maximize usability through a navigation scheme built upon the standard Microsoft Windows Help function, an index, a search feature, and a glossary.

The content is structured as information rather than education, as the intent of TropRice is to provide reference rather than on-line instruction. When appropriate, information is complemented by graphics, diagrams, and Java-enabled calculators.

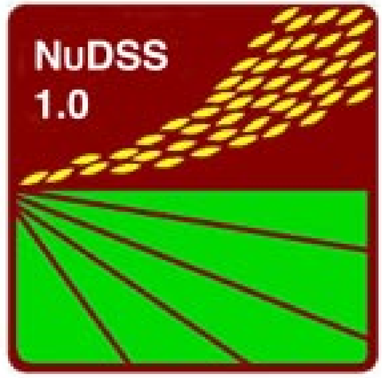
TropRice is written with open-source development software that will output to print, compiled help, or html. The primary delivery method will be on-line and, for those without on-line access, CD-ROM. An Internet browser such as Microsoft Internet Explorer (version 4.0, or later) is required for access. Hardware requirements are based on the ability to run the required software. At the minimum, your computer needs to be

- Windows 95/98/NT-based
- Multimedia capable with a minimum of 16-Mb RAM, 66-mHz processor, and 100-Mb hard disk.



Nutrient Decision Support System (NuDSS) for irrigated rice

C. Witt, IRRI, Los Baños, Philippines;
A. Dobermann, University of Nebraska, Lincoln, USA; J. Arah, AAT Consultants, Edinburgh, UK; and
R. Pamplona, IRRI
E-mail: c.witt@cgiar.org



The Nutrient Decision Support System (NuDSS) for irrigated rice is part of IRRI's initiative to provide decision support for site-specific nutrient management (SSNM) in the irrigated lowlands. The content of the software is consistent with printed information on SSNM provided by a field handbook (Dobermann and Fairhurst 2000) and a pocket guide (Fairhurst et al 2002). The NuDSS adds value to these materials by combining various models into one user-friendly software package to help users develop improved fertilizer strategies that aim at efficient fertilizer use and increased farmers' profit. The software was developed recognizing the need for decision aids providing assistance in complex mathematical calculations (e.g., through optimization routines) that would be difficult to perform otherwise.

Target audience and environment

The primary target audience of the NuDSS is intermediary technology transfer agents. The NuDSS can assist extension campaign planners from government or nongovernment organizations in the participatory development and validation of fertilizer strategies that are tailored to local conditions and farmers' needs. The software can also be used at the field scale, for example, assisting researchers in planning and evaluating experimental trials. Integrating agronomic and economic aspects of nutrient management makes NuDSS a powerful tool in teaching students.

The NuDSS is a generic decision support system for irrigated rice, capturing the most important cropping conditions in tropical and subtropical Asia. Guidelines for local adaptation are provided when conditions divert from standard situations. The underlying principles of plant nutrition are valid for all modern, high-yielding rice varieties with a harvest index of about 0.50 kg kg^{-1}. The model is currently also calibrated for wheat.

Content

The SSNM strategy in the NuDSS aims at achieving sustainable, large, and economic yields through proper nutrient management by

- Considering the differences in soil nutrient supply among sites (site-specific)
- Selecting reasonable yield goals (site- and season-specific)
- Making efficient use of all available nutrient sources including organic manures, crop residues, and inorganic fertilizers according to availability and costs
- Providing the crop with a balanced supply of nutrients (N, P, K, and micronutrients)
- Following plant-based N management using a leaf color chart (season-specific)
- Replacing nutrients, particularly P and K, removed with grain and straw to avoid depleting soil nutrient reserves
- Performing a gross margin analysis to obtain a profit estimate
- Performing cross-checks to reconsider developed strategies

The NuDSS is a Windows-based software that guides users step by step through the development of a fertilizer strategy. Figure 1 shows a flow chart of the various steps involved. The NuDSS requires a few input parameters that can be easily obtained at the farm level:

- Climate-adjusted yield potential of the variety used (season-specific)
- Current yield level in farmers' fields (season-specific)
- Current average fertilizer use in farmers' fields (season-specific)
- Plant-based estimates of indigenous soil N, P, and K supplies
- Available fertilizer sources including prices
- Costs of all inputs at the farm level for a gross margin analysis (optional)

Guidelines are provided to assist in the selection of default values where input parameters are not available. The NuDSS also provides suggestions for experimental layouts of on-farm validation trials to be used in farmer participatory evaluation of SSNM strategies. The NuDSS is complemented by IRRI's FarmMonitor, a database software for on-farm monitoring of agronomic and economic parameters measured at the field and farm levels.

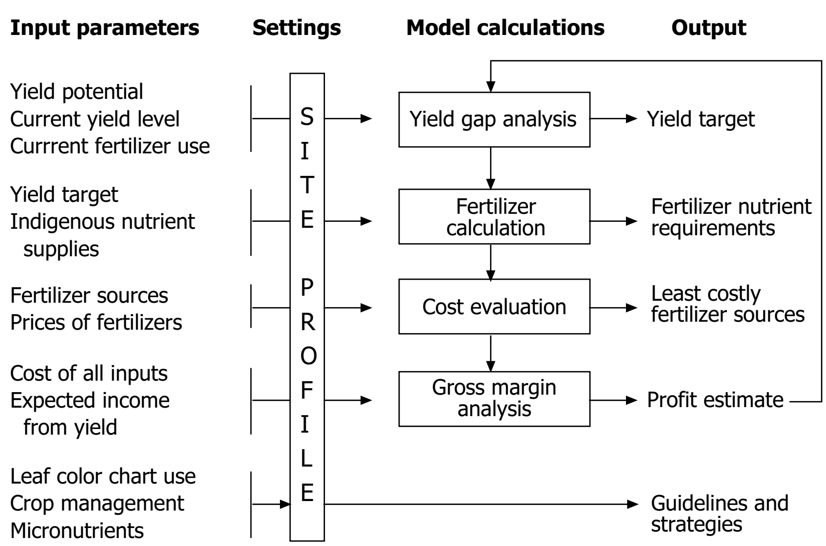


Fig. 1. Flow chart of the nutrient decision support system for irrigated rice.

Graphical user interface and technology requirements

Operating screens with a minimum of text provide users with options for data entry or selection of default values before they are prompted to run optimization routines. A tutorial and background information on the principles of SSNM are provided in the Help function. The software has a built-in database for storing information such as default values (e.g., fertilizer sources, nutrient concentrations, prices, etc.) and developed fertilizer strategies. The NuDSS also provides the option for printing user-customized reports.

NuDSS 1.0 was programmed using Visual Basic 6.0 and MS Access. The accompanying database software FarmMonitor 1.0 was developed using Delphi 5.0 and MS Access. Both applications run under MS Windows 95/98/NT or Windows 2000 on a personal computer with at least 16-Mb RAM, a 66-mHz processor, a 100-Mb hard disk, and a CD-ROM. The NuDSS and FarmMonitor will be officially released by the end of 2001.

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PRICE: a decision support tool for the control of weeds in tropical irrigated rice

R.M. Wilkins, J.A. Garratt, and A.J. Laister, Department of Agricultural and Environmental Science, University of Newcastle Upon Tyne, UK
E-mail: richard.wilkins@ncl.ac.uk

Herbicide use is increasing in Asian rice production and is likely to continue in the near future. Direct seeding is also increasingly replacing transplanting as the dominant cropping system. There is a direct interaction between the availability of rice herbicides and the increase in use of direct-seeding technology. Direct seeding is viable in high-productivity irrigated systems if cost-effective herbicides are included in the control of weeds (Naylor 1996).

The past decade has seen a slow migration of labor from rural communities to the industrializing urban areas in Bangladesh, following a general trend across Asia. This has led to increasing labor costs, which have made direct seeding with the use of herbicides much more viable. Herbicide use is also favorable in transplanted rice. Research has shown a benefit-cost ratio of 16:1 (up to 25:1 with complete control) for the use of herbicides versus 3.3:1 for hand weeding (Naylor 1996). In Bangladesh, labor costs are as much as 44% of the variable costs of production (IRRI 1995). Herbicide use reduces costs in both direct-seeded and transplanted rice by reducing the cost of labor for hand weeding. The use of direct seeding reduces labor costs further by eliminating the need for labor to maintain nurseries and transplant.

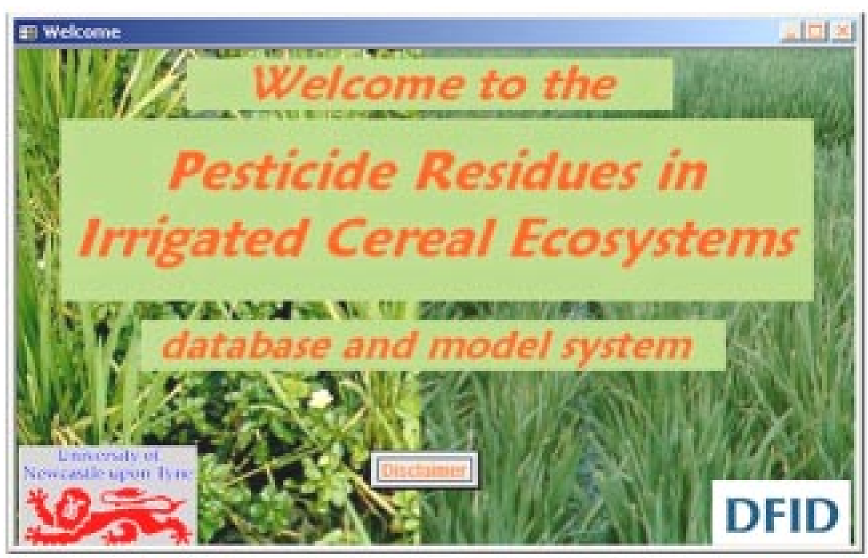
The major concern is how best to govern and regulate the use of rice herbicides as their use becomes more widespread. To do this, it is necessary to understand the effects of use on the population of the area, the effects of use on the environment, and the economic implications of usage or nonusage of herbicides.

Decision support systems and risk associated with increased herbicide use

The increased use of herbicides carries with it new risks. Herbicides may cause acute poisoning of workers or nontarget organisms. Residues may persist in soil and water, causing chronic health effects on both the ecosystem and humans. Rice plant vigor may be damaged if soil residues persist at phytotoxic levels until the next crop is established.

Decision support systems (DSS) provide a framework within which the severity of these risks can be evaluated along with the postulated yield and income benefits from herbicide use.

PRICE (Pesticide Residues in Irrigated Cereal Ecosystems) is a DSS that is partly data-driven and partly model-driven. It was developed to help determine environmentally acceptable and relevant herbicides for use in irrigated rice in the high-potential Indo-Gangetic plains of northern India and Bangladesh, but it is also useful in other tropical regions where irrigated rice is grown



(Laister et al 2000). Data on rice herbicides relevant to the buildup of residues in the environment and their effect on nontarget organisms, particularly fish, which are often grown in conjunction with rice, were collated and reviewed.

Target audience and environment

PRICE should prove useful to policymakers and extension workers, including those in NGOs, to help give advice to farmers, and to farmers themselves. Registration authorities may also use it to quickly identify problem compounds. PRICE may help research institutes and entities (governmental, university, and commercial) to define research priorities for study in terms of aspects of pesticide fate in the field environment.

The PRICE database contains information necessary to run a model of the environmental fate of herbicide residues. The model predicts the fate of the applied herbicide in the field environment. It takes into account the soil type, weather conditions, and crop (direct-seeded or transplanted) calendar. Also available are scenarios based on geographic information systems and environmental conditions of rice-growing locations in Bangladesh.

Content

A full list of all rice herbicides available is contained within the database, which gives limited information, such as manufacturer, product name, and use. Chemicals that are registered for use in the Indo-Gangetic floodplain contain more detailed information. This part of the database contains information on physicochemical properties, structure, mammalian toxicology, ecotoxicology, environmental fate, metabolic pathways, and species controlled. The information is accessed by clicking through a series of screens for a particular compound or by browsing through the complete list of compounds for a particular attribute.

The information within the database has been compiled from several sources: Tomlin (1994), Roberts (1998), Aizawa (1982), Johnson (1987), and Herner (1989).

Graphical user interface and technology requirements

Data entry has been designed to be simple (in general, options must be chosen from pull-down selection boxes). The predicted environmental concentrations are compared with known data on acute and chronic effects of the compound on target species. A risk level (low, medium, or high) is given for the soil, surface water, and groundwater using a system of easily identifiable icons. Separately, economic costs and benefits are calculated based on the cost of applying the compound, the expected level of control, and the expected yield increase.

The database part of PRICE was developed using Microsoft Access 97™. The model part was developed in Microsoft Excel 97™. Access is not required to run the DSS, but Excel is required. The DSS is available on a CD-ROM from the Crop Protection Programme, Natural Resources International Ltd., Pembroke, Chatham Maritime, Kent ME4 4NN, UK (tel: + 44 1634 883630, fax: + 44 1634 883937, e-mail Andy Ward at a.ward@gre.ac.uk). Further information is available from the author (richard.wilkins@ncl.ac.uk). A simple installation procedure loads the DSS onto the hard disk (occupying about 20 Mb). A Pentium or more powerful processor running Windows 95 or a later operating system is required.

The development of PRICE is still under way and the current version is not "bug-free." In particular, the look and feel of the interface need evaluation by potential users and the model part requires verification (requiring analysis of soil and water concentrations of pesticides under experimental conditions). PRICE was developed for herbicides on the Indo-Gangetic Plain, but there is no reason why the model could not be used in other rice-growing areas and expanded for use with all pesticides. Such development requires access to appropriate data on soils and climate and on additional pesticides. Development depends on further funding being obtained.

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Meetings, conferences, and symposia

International Conference on Impacts of Agricultural Research and Development: Why Has Impact Assessment Research Not Made More of a Difference?
4–7 February 2002, Meliá Confort Hotel, San José, Costa Rica
www.cimmyt.org/research/economics/impacts, E-mail: impacts@cgiar.org

ISCO 2002
12th Conference of the International Soil Conservation Organization, Beijing, China, 26–31 May 2002.

International Rice Congress
Beijing, China, 16–20 September 2002
www.cgiar.org/irri/irc2002/index.htm, E-mail: t.mew@cgiar.org

MINI REVIEW

Water-efficient management strategies in rice production

B.A.M. Bouman, IRRI, Los Baños, Laguna, Philippines E-mail: b.bouman@cgiar.org

Food security in Asia is challenged by increasing food demand and threatened by declining water availability. Rice is the most important staple in Asia, where it provides 35–80% of total calorie intake (IRRI 1997). More than 75% of the rice supply comes from 79 million ha of irrigated land. Thus, Asia's present and future food security depends largely on the irrigated rice production system. However, the water-use efficiency of rice is low, and growing rice requires large amounts of water. In Asia, irrigated agriculture accounts for 90% of total diverted freshwater, and more than 50% of this is used to irrigate rice. Until recently, this amount of water has been taken for granted, but now the global "water crisis" threatens the sustainability of irrigated rice production. The available amount of water for irrigation is becoming scarce (Gleick 1993, Postel 1997). The reasons for this are diverse and location-specific, but include decreasing quality (chemical pollution, salinization), decreasing resources (e.g., falling groundwater tables, silting of reservoirs), and increased competition from other sectors such as urban and industrial users. Because of the increasing scarcity of water, the costs of its use and resource development are increasing as well. Therefore, farmers and researchers alike are looking for ways to decrease water use in rice production and increase its use efficiency. A fundamental approach is to start at the field level, where water and rice interact. For farmers with no control over the availability or distribution of water beyond their farm gates, the crucial question to be addressed is "What are the options to cope with decreasing water supply (or the increasing costs of it) at the farm or field inlets?" To answer this question, we have to look at the flow of water in rice fields and understand where reductions in water use can be achieved without impairing yield (Fig. 1).

Rice and water input

Irrigated lowland rice in Asia is transplanted or direct (wet) seeded into puddled lowland fields. Land preparation consists of soaking, plowing, and puddling. Puddling is done not only to control weed, but also to increase water retention, reduce soil permeability, and ease field leveling and transplanting (De Datta 1981). Soaking, a one-time operation, requires water to bring the topsoil to saturation and to create a ponded water layer. After land preparation, there is an "idle period" until transplanting or direct seeding takes place. The growth period runs from crop establishment to harvest. During the idle period and crop growth, fields are typically flooded with 5–10 cm of water. Under flooded conditions, water is required to match several outflow processes. Because of the standing water, hydrostatic pressure continuously "pushes" water downward through the puddled layer. When this water flows vertically downward below the root zone, it is called percolation (P), and, when it flows laterally underneath bunds, it is called seepage (S). Because they are difficult to separate in the field, S and P are often taken together as one term: SP. Water is released into the air by evaporation (E) from the ponded water layer and transpiration (T) by the crop. Again, E and T are difficult to separate in the field and they are mostly considered together as evapotranspiration (ET). However, during land preparation and the idle period, only E takes place, whereas, during crop growth, both E and T occur. Finally, over-bund flow (or surface runoff) is the spillover when water depths rise above the field bunds.

Table 1 gives typical values of water outflows from a rice field. For a crop growth duration of 100 d (typical of modern high-yielding varieties), total water requirements vary from 675 to 4,450 mm, depending on the season and soil characteristics, with 1,500–2,000 mm as a typical value in many lowland areas. Of all outflows of water from a rice field, only

Table 1. Typical daily and seasonal rates of water use in rice production in the tropics.

Item	Daily (mm d^{-1})	Seasonal (mm)
Land preparation	–	175–750
Evapotranspiration		
Wet season	4–5	400–500
Dry season	6–7	600–700
Seepage and percolation		
Heavy clays	1–5	100–500
Loamy/sandy soils	25–30	2,500–3,000

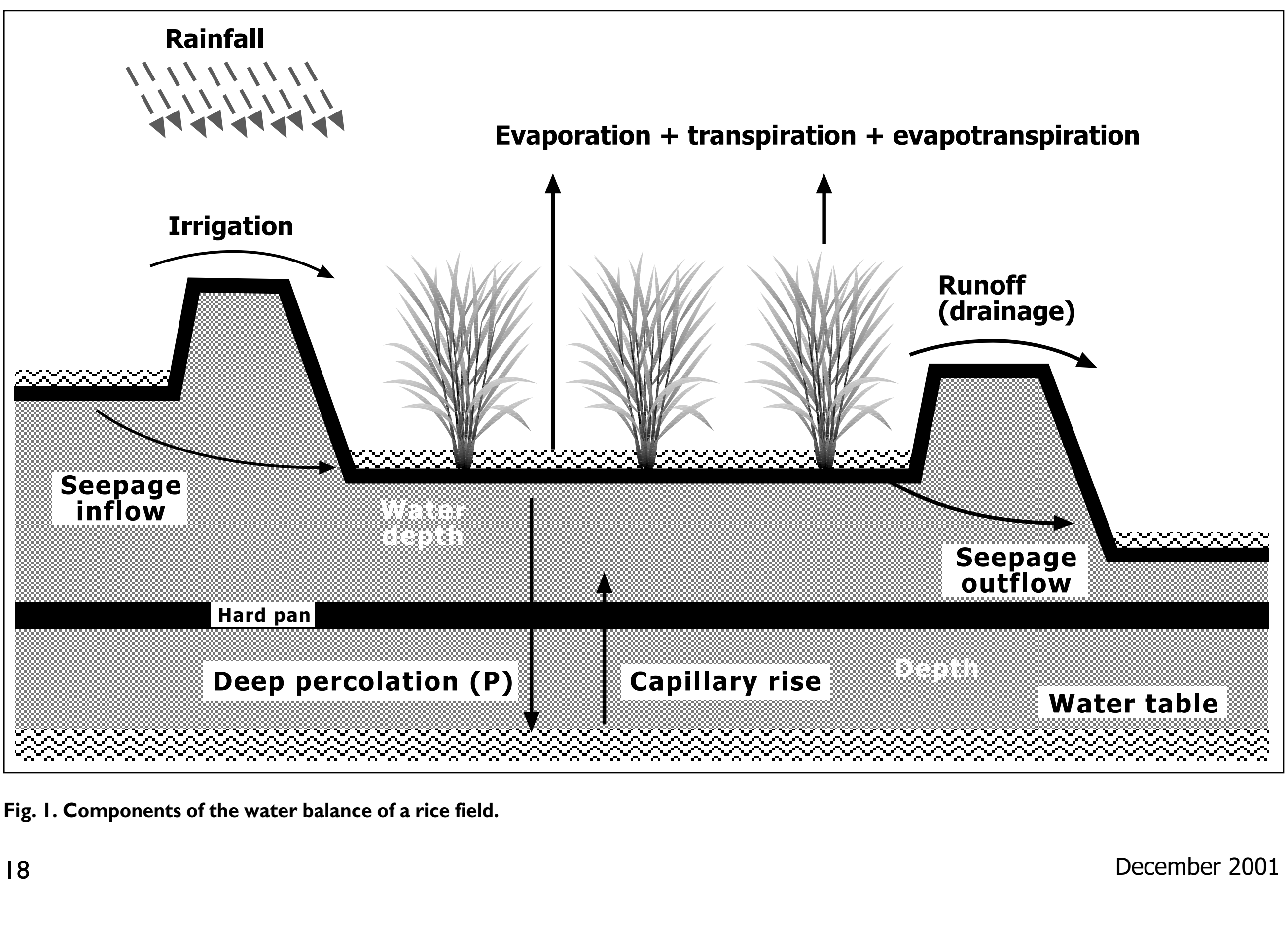

Fig. 1. Components of the water balance of a rice field.

T is "productive" water use as it leads directly to crop growth and yield formation. Transpiration is essential to crop growth because it provides cooling and is the driving process for water flow in plants that carries nutrients from the roots to the shoot. Most of the water use in rice, however, is caused by large losses of seepage and percolation. These flows are unproductive as they do not contribute to crop growth and yield formation.

Water management strategies to reduce water input

Large reductions in water input can potentially be realized by reducing the unproductive SP flows during crop growth and idle periods (Bouman and Tuong 2001). There are basically two ways to do so: (1) increasing the resistance to water flow in the soil and (2) decreasing the hydrostatic pressure (i.e., depth) of the ponded water. The resistance to water flow can be increased by changing the soil physical properties. Cabangon and Tuong (2000) have shown the beneficial effects of an additional shallow soil tillage before land preparation to close cracks that cause rapid bypass flow at land soaking. Thorough puddling results in a good compacted plow soil that impedes vertical water flow (De Datta 1981). Soil compaction using heavy machinery can decrease soil permeability in certain coarse-textured soil types (Harnpichitvitaya et al 2001). Finally, researchers have even experimented with introducing physical barriers underneath rice soils such as bitumen layers and plastic sheets (Garrity et al 1992). However, effective, though, most of these soil improvements are expensive and beyond the financial means of farmers.

Reducing SP flows through reduced hydrostatic pressure can be achieved by water management. Instead of keeping the rice field continuously flooded with 5–10 cm of water, the floodwater depth can be decreased, the soil can be kept around saturation (saturated soil culture [SSC]), or alternate wetting and drying (AWD) regimes can be imposed. Under these management practices, the hydrology of the soil changes from anaerobic under flooded and SSC regimes to alternately anaerobic and aerobic under AWD. Ultimately, rice could be grown under completely aerobic conditions and continuous SP eliminated (Table 2). These water management technologies are reviewed in more detail below.

Saturated soil culture and alternate wetting and drying

Bouman and Tuong (2001) compiled a database on SSC and AWD from IRRI experiments and those reported in the literature. The database contains information from 31 pot and field experiments undertaken in north and central India, the Philippines, and Japan. In SSC, the soil is kept as close to saturation as possible. This mostly means that shallow irrigation is given to obtain about 1-cm floodwater depth a day or so after the disappearance of standing water. In AWD, irrigation water is applied to obtain 2–5-cm floodwater depth after a certain number of days after the disappearance of ponded wa-

Table 2. Classification of rice production systems by water management strategies.

Flooded lowland → Dryland

Characteristic	Lowland (anaerobic)				Aerobic	
	Conventional flooded	Saturated soil culture	Alternate wetting and drying		Aerobic rice	Upland rice
			Irrigated	Rainfed		
Hydrology	Flooded	Saturation	Flooded ↔ aerobic	Flooded ↔ aerobic	Aerobic	Aerobic
Irrigation	Irrigated	Irrigated	Irrigated	Rainfed	Irrigated, rainfed	Rainfed
Tillage	Puddled, nonpuddled	Puddled, nonpuddled	Puddled, nonpuddled	Puddled, nonpuddled	Nonpuddled	Nonpuddled
	Bunded	Bunded	Bunded	Bunded	Bunded	Nonbunded?
Environment	Favorable lowland	Favorable lowland	Favorable lowland	Unfavorable lowland	Favorable upland, unfavorable lowland	Unfavorable upland
Germplasm	Lowland	Lowland	Lowland	Lowland	Improved upland × lowland	Upland
Yield level	High	High	High-medium	Medium-low	High-medium	Low

ter. In 92% of the cases investigated by Bouman and Tuong (2001), SSC and AWD resulted in decreased water input, but at the expense of decreased yield. The SSC practice was most efficient in decreasing water use: input reductions ranged from 5% to 50% and averaged 23%. However, reducing floodwater depth to just-saturated levels already reduced yields by 0–12%, with an average of 6%. Implementing SSC requires good water control at the field level and frequent shallow irrigations that are labor-intensive. Borell et al (1997) experimented with raised bed systems in Australia to ease SSC practices. Their beds were 120 cm wide, separated by furrows of 30-cm width and 15-cm depth. Near-continuous irrigation through the furrows kept beds saturated. Compared with flooded rice, water savings were 34% and yield losses 16–34%.

AWD practices resulted in both water savings and yield losses of 0–70% compared with flooded treatments, depending on the number of days between irrigations and existing soil conditions. Mostly, however, yield losses were smaller than reductions in water input, and water productivities therefore increased. There is a trade-off between land productivity (i.e., yield) and water productivity. Figure 2 shows the so-called water production functions for two examples of AWD field experiments in India and closed pot experiments in growth chambers in Japan. The lowest curve line is from Indian experiments in soils with SP rates of 21 mm d^{-1}, low N inputs (80 kg ha^{-1}), and zero P and K (Jha et al 1981). On the right-hand side of the curve are data on continuously flooded treatments. Going to the left are the first AWD treatments that reduced SP with no effect on yield levels. The crop was probably able to satisfy its transpiration requirements or the low nutrient level was more yield-limiting than water. Further to the left are data on more severe AWD treatments, where yields dropped when crop water consumption decreased. The second higher curve is also from Indian experiments, but with lower SP rates (9–14 mm d^{-1}) and higher nutrient inputs (120 kg N ha^{-1}, 26.4 kg P ha^{-1}, and 33.2 kg K ha^{-1}) (Tripathi et al 1986). From right to left on this curve, yields dropped faster than in the other experiment in India since water quickly became yield-limiting. Both Indian production curves illustrate the law of diminishing returns to water input. Water productivities were highest on the left side of the curves, where water was the most limiting growth factor, but where yield levels were low. Data on the straight line are from closed pot experiments in Japan (Anbumozhi et al 1998). Since closed pots have no SP losses, reductions in water input immediately affected ET; consequently, yields declined steeply. These data represent the absolute minimum water use by rice and the highest water productivities that can be realized. The challenge in developing water-efficient rice production systems is to reduce water inputs while maintaining yields at the same high level as that under flooded conditions. In Figure 2, that means going on a straight line along the top of the production curves of the field experiments from the right to the left until the straight line of the pot experiments is reached (as indicated by arrows).

Aerobic rice

A fundamental approach to reduce water inputs in rice is to grow the crop like an irrigated upland crop such as wheat or maize. Instead of trying to reduce water input in lowland fields, the concept of having the field flooded or saturated is abandoned altogether. Upland crops are grown in nonpuddled aerobic soil without standing water. Irrigation is applied to bring the soil water content in the root zone up to field capacity after it has reached a certain lower threshold (e.g., halfway between field capacity and wilting point). The amount of irrigation water should match evaporation from the soil and transpiration by the crop. Since it is not possible to apply irrigation water to the root zone only, some of it is lost by deep percolation and is unavailable for uptake by the crop. Typical field application efficiencies vary from 60–70% using surface irrigation (e.g., flash or furrow irrigation) to more than 90% using sprinkler or drip irrigation. The

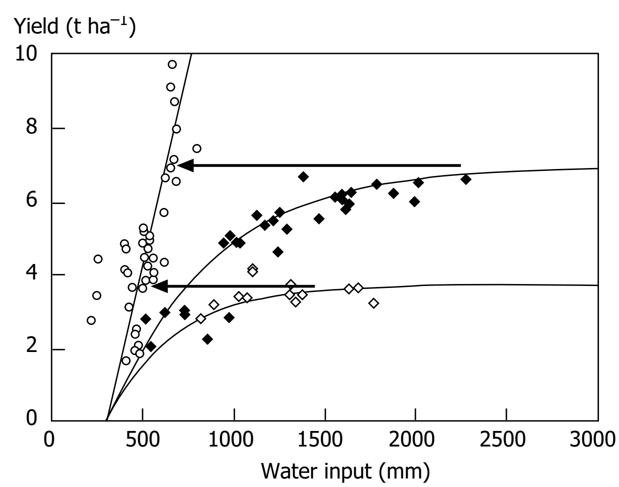

Fig. 2. Yield vs water input. Data from field experiments in India by Jha et al (1981) (◇) and Tripathi et al (1986) (◆), and in Japan by Anbumozhi et al (1998) (○). The arrows indicate the ideal line for water savings while maintaining high yields. Source: Bouman and Tuong (2001).

potential water savings when rice can be grown as an irrigated upland crop are large, especially on soils with high SP rates. Besides cutting down on SP losses, evaporation can also be reduced with this technique since there is no continuous standing water layer.

De Datta et al (1973) tried growing rice like an upland crop using furrow irrigation in the 1971 dry season at IRRI. Using the high-yielding lowland variety IR20, total water (irrigation plus rainfall) savings were 56% and irrigation water savings 78% compared with growing the crop under flooded conditions. However, yield decreased from 7.9 to 3.4 t ha^{-1}. Upland cultivars that performed equally well under flooded and dryland irrigation were used, but their yields of around 5 t ha^{-1} were much lower than those of lowland cultivars.

Studies on nonflooded irrigated rice using sprinkler irrigation were conducted in the United States in Texas and Louisiana (McCauley 1990, Westcott and Vines 1986). Experiments used commercial rice cultivars under lowland cultivation. Irrigation water requirements were 20–50% less than in flooded rice, depending on soil type, rainfall, and water management. The highest yielding cultivars (producing 7–8 t ha^{-1} under flooded conditions), however, had yield reductions of 20–30% compared with flooded rice. The most drought-resistant cultivars produced the same under both conditions, but their yields were much lower (5–6 t ha^{-1}). Under economic conditions prevalent in the US, the adoption of irrigated dryland rice (using existing cultivars) was not economically attractive.

New varieties must be developed if growing rice like an irrigated upland crop is to be successful. Lowland cultivars have been selected to give high yields under continuously flooded lowland conditions. They generally suffer a yield loss when the soil water content drops below saturation (see above). Upland varieties have been developed to give stable though low yields in adverse environments where rainfall is low, irrigation is absent, soils are poor or toxic, weed pressure is high, and farmers are too poor to supply high inputs. Therefore, IRRI recently coined the term "aerobic rice" to refer to high-yielding rice grown in nonpuddled aerobic soil. This aerobic rice, which can be rainfed or irrigated, should be responsive to high inputs and should tolerate flooding. It has to combine characteristics of both upland and high-yielding lowland varieties. Evidence for the feasibility of aerobic rice comes from Brazil and north China. In Brazil, aerobic rice cultivars have come out of a 20-year breeding program to improve upland rice with yields of 5–7 t ha^{-1} under sprinkler irrigation in farmers' fields (Silveira Pinheiro and Maia de Castro, pers. commun.). These varieties are grown commercially on 250,000 ha in the state of Mato Grosso. In north China, aerobic rice cultivars yield up to 6–7.5 t ha^{-1} in farmers' fields using flash irrigation in bunded fields (Wang and Tang 2000). It is estimated that these cultivars are now being grown on some 120,000 ha in the north China plains. Field visits in 2000–01 revealed that farmers have pioneered this system in different environments:

- Where rainfall is insufficient to sustain lowland rice production (estimated to require 1,200–1,500 mm) but thought to be sufficient for aerobic rice (estimated to require some 800 mm). Here, maize is the dominant crop and rice is an attractive alternative through the benefits of crop diversification. Moreover, the price of rice is supported by the government, and farmers perceive this as advantageous.
- In pump-irrigated areas where water has become so expensive that lowland rice production was abandoned.
- Where water is scarce during the first part of the growing season (necessitating irrigation), but floods occur in the second part. Upland crops such as maize and soybean cannot withstand flooding, but aerobic rice can.

In both Brazil and China, however, it has been reported that high initial yields are difficult to sustain and that yields may decline severely after 3–4 years of continuous cropping. Brazil has adopted a rotation system in which aerobic rice is only cropped once every 3–4 years. The causes for the yield decline are not yet understood, but likely candidates are the buildup of soil-borne diseases (such as nematodes) or toxic substances.

Discussion and conclusions

Water in irrigated rice production has been taken for granted for centuries, but the "looming water crisis" may change the way rice is produced in the future. Water-saving irrigation technologies that were investigated in the early 1970s, such as saturated soil culture and alternate wetting and drying, are receiving renewed attention from researchers. These technologies reduce water input, though mostly at the expense of some yield loss. Farmers in Asia who confront scarcity or high costs of water have already started to adopt these technologies. In China, various forms of AWD and reduced floodwater depths have been developed and massively adopted by farmers (Li 2001). Surveys in north-central India (A.K. Singh, pers. commun.) and in Central Luzon, Philippines (unpublished IRRI data), show that farmers who operate pumps to irrigate their fields consciously apply some form of AWD to save on energy costs.

Aerobic rice is a new concept to further decrease water requirements in rice production. It is commercially grown in Brazil and is being pioneered by farmers in northern China. In the heart of the rice-wheat belt in India (Haryana, the Punjab, and Uttar Pradesh), innovative farmers have begun to grow rice aerobically under furrow irrigation in raised-bed systems (personal field observations). Changes in the hydrology of rice production will have major consequences for its sustainability and appropriate management practices. Over the centuries, lowland rice has proven to be a remarkably sustainable system, mostly because of its particular anaerobic character. Water-saving irrigation practices shift away from continuous anaerobic conditions to alternate anaerobic-aerobic and continuous aerobic conditions. Table 2 lists water management strategies in rice production and summarizes some key characteristics. The shift from anaerobic to aerobic systems will have major consequences for weed, disease, and insect pest management, nutrient and soil organic matter dynamics, and greenhouse gas emission and sequestration. Weed control is an especially crucial issue in most water-saving irrigation technologies. Water has long been the cheapest herbicide, but this may not be so any more in the near future. Breeders have to respond to the challenge of breeding varieties that perform well under nonpermanently flooded conditions. The development of aerobic rice varieties is probably the most ambitious challenge of all.

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Polymorphism of DNA markers linked to bacterial blight resistance genes in useful rice germplasm

J. Ramalingam, H.S. Basharat, and G. Zhang, Plant Molecular Breeding Research Center, South China Agricultural University, Guangzhou 510642, China E-mail: jrjagadish@yahoo.com

Bacterial blight (BB) caused by *Xanthomonas oryzae* pv. *oryzae* is found worldwide and wreaks substantial damage on rice yield. Host-plant resistance has proven to be an effective and economical way of controlling this disease. About 23 resistance genes have been identified (Zhang et al 1998). The genes *xa5*, *xa13*, and *Xa21* together have shown resistance to all known races of the pathogen (Huang et al 1997). Pyramiding of these three genes could be impossible using conventional methods because of their masking effects. The use of polymerase chain reaction (PCR) markers can significantly increase the efficiency of marker-assisted selection (MAS). A germplasm survey for polymorphism will facilitate PCR-based marker-aided transfer of BB resistance genes to elite breeding lines in the future.

Fifty-six lines representing indica, japonica, intermediate, wide compatibility, and specific compatibility germplasm were surveyed for PCR polymorphism to facilitate the marker-assisted transfer of the three BB resistance genes (*xa5*, *xa13*, and *Xa21*) to elite varieties. Table 1 shows the details of DNA markers linked to the BB resistance genes used in the experiment. Table 2 lists the distribution of alleles of the four marker loci linked to the resistance genes among 56 germplasm samples.

For *xa5*, three alleles were identified among germplasm surveyed with RG 556 primers and PCR products digested with *Dra*I and RM 122 microsatellite markers. The allele in IRBB5 was designated as allele 1; 29 lines carry this allele. MAS cannot be used in this group because it possesses an allele similar to that of IRBB5. The marker allele in the susceptible line IRBB4 was designated as allele 2. An additional allele was found in six lines and designated as allele 3. PCR products were not detected in the four rice lines after many attempts, suggesting that these lines carry a null allele. Similarly, using RM 122, three alleles were detected. Allele 1 was detected in 11 lines, allele 2 in 26, and allele 3 in 15 lines; four lines had no allele.

The majority of the genotypes carry either allele 2 or 3. A PCR polymorphism can be generated between these accessions and IRBB5, thus allowing MAS between these lines. Only two lines, IRBB13 and IRBB60, carry allele 1; others have allele 2. This provided a good opportunity to employ MAS. Most of the crosses between IRBB13 and other lines will develop polymorphism. Chungwongse et al (1993) found two alleles of locus pTA 248: allele 1 in IRBB21 and IRBB60 and allele 2 in susceptible lines IRBB4 and HJ74. A third allele was reported by Huang et al (1997) in a survey of 187 germplasm samples. Among 56 lines tested,

Table 1. Details of PCR markers used and their linkage to BB resistance genes.

Marker	Primer sequence (5'——3')	Enzyme	Linked gene	Distance (cM)	Chromosome no.	Reference
RG 556STS	**F** TAG CTG CTG CCG TGC TGT GC **R** AAT ATT TCA GTG TGC ATC TC	*Dra*I	*xa5*	1.7	5	Yoshimura et al (1995)
RM 122	F GAG TCG ATG TAA TGT CAT CAG TGC **R** GAA GGA GGT ATC GCT TTG TTG GAC	_	*xa5*	0.4	5	Blair and McCouch (1997)
RG 136STS	**F** TCC CAG AAA GCT ACT ACA GC **R** GCA GAC TCC AGT TTG ACT TC	*Hind*III	*xa13*	5.5	8	Zhang et al (1996)
pTA 248[a]	**F** AGC CGC GGA AGG GTG GTT CCC GA **R** AGA CGC GGT AAT CGA AAG ATG AAA	–	*Xa21*	0-1	11	Ronald et al (1992)

[a]Primer sequences are from Chungwongse et al (1993).

Table 2. Polymorphism of DNA markers linked to the BB resistance genes in 56 rice germplasm samples.

Variety	Source[a]	Group[b]	Allele assignment			
			xa5 (RG 556)	*xa5* (RM 122)	*xa13* (RG 136)	*Xa21* (pTA 248)
Dee-geo-woo-gen	SCAU	Indica	3	2	2	3
Guang luai 4	SCAU	Indica	3	2	2	3
Aijiao nante	SCAU	Indica	–	–	–	–
Zhai ye queing 8	SCAU	Indica	3	2	2	2
IRBB21	IRRI	Indica	2	2	2	1
Sheng you 2 hao	SCAU	Indica	3	2	2	3
Shen nong 265	SCAU	Japonica	1	2	2	2
IR5598-1	IRRI	Japonica	1	2	2	3
Taichung 65	SCAU	Japonica	1	3	2	3
Dai bai mang	SCAU	Japonica	1	3	2	3
Zi pe han dao	SCAU	Japonica	1	3	2	3
Nong ken 58	SCAU	Japonica	1	3	2	3
G11353	SCAU	Indica, W & SCV	1	2	2	2
Hua jing xian 74	SCAU	Indica, W & SCV	1	1	2	2
G02428	SCAU	Indica, W & SCV	1	3	2	3
CPSL 017	SCAU	Indica, W & SCV	1	2	2	3
Dular	SCAU	Indica, W & SCV	–	–	2	2
Hao gelao	SCAU	Indica, W & SCV	1	2	2	2
G1165	SCAU	Indica, W & SCV	1	3	2	3
G2123	SCAU	Indica, W & SCV	1	3	2	3
G2410	SCAU	Indica, W & SCV	3	3	2	2
G2417	SCAU	Indica, W & SCV	1	2	2	2
G2615	SCAU	Indica, W & SCV	1	1	2	3
G3004	SCAU	Indica, W & SCV	1	1	2	2
Guang lu ai	SCAU	Indica	1	1	2	3
Cong lu	SCAU	Indica	1	1	2	2
Aijiao nante	SCAU	Indica	1	1	2	2
Zhai ye quing	SCAU	Indica	–	–	2	2
Calotoc	SCAU	Indica, W & SCV	1	1	2	2
Ketan Nangka	SCAU	Indica, W & SCV	1	1	2	2
N29	SCAU	Inter	1	1	2	2
Ji dao	SCAU	Indica	2	2	2	2
Nulsuriwai	SCAU	Inter	–	–	2	3
Karang serang 55	SCAU	Inter	2	3	2	3
Mahao 12	SCAU	Inter	2	3	2	3
Haogeo lao 1	SCAU	Indica	2	3	2	3
2595-1	SCAU	Indica	2	3	2	2
2595-2	SCAU	Indica	2	3	2	2
Huan jing xian 55	SCAU	Indica, W & SCV	3	3	2	3
Zhen shan 97	SCAU	Indica	2	3	2	2
Mangu	SCAU	Indica	2	2	2	2
Zai yen qin	SCAU	Indica	2	2	2	2
Zei bu tou	SCAU	Indica	2	2	2	2
Mai xi tou	SCAU	Indica	2	2	2	2
Wan li xian	SCAU	Indica	2	2	2	2
Shen li xian	SCAU	Indica	1	2	2	2
Yun nan bai	SCAU	Indica	1	2	2	2
Hei du 4	SCAU	Indica	1	2	2	2
Aizi pu	SCAU	Indica	2	2	2	3
Hauke zi	SCAU	Indica	1	2	2	2
H16	SCAU	Indica	1	2	2	3
IRBB4	IRRI	Indica	2	2	2	2
IRBB5	IRRI	Indica	1	1	2	3
IRBB13	IRRI	Indica	2	2	1	3
IRBB60	IRRI	Indica	1	1	1	1
IR24	IRRI	Indica	2	2	2	2

[a]SCAU = Rice Germplasm Centre, South China Agricultural University, Guangzhou. [b]W & SCV = wide and specific compatibility variety, Inter = intermediate.

23 were reported to carry allele 3, 30 had allele 2, and no allele was reported in one genotype. Allele 1 does not exist among other cultivated lines; this confirmed the hypothesis that the segment carrying *Xa21* was introgressed from the wild species *Oryza longistaminata*. Lines carrying allele 3 can be used in marker-aided breeding programs as they can generate polymorphism between IRBB21 and IRBB60 and these germplasm lines.

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Preliminary studies of a lysine-rich protein gene transferred into rice

Yuefeng Gao and Yuxiang Jing, Institute of Botany, Chinese Academy of Sciences (CAS), Beijing 100093, China
E-mail: yxjing@ns.ibcas.ac.cn

The nutritional quality of proteins in cereals such as rice, maize, wheat, and other crops is comparatively low because of a deficiency in some essential amino acids. Lysine is the first restrictive amino acid in these cereals. Lysine-rich proteins were isolated and purified from seeds of the winged bean *(Psophocarpus tetragonolobus)*, a legume. According to N- and C-amino acid sequences of the protein, a pair of primers was synthesized from the deduced nucleotide sequences of both end amino acids. The lysine-rich protein cDNA was cloned by using the primers to run polymerase chain reaction (PCR) according to a cDNA template from a reverse transcription of mRNA of the plant. The purpose of this study was to transform lysine and the lysine-rich protein cDNA cloned from this legume into a japonica rice variety, ZH8, and study the possibility of improving the nutritional quality of rice by genetic engineering (Liu et al 1993, Sun et al 1998).

The plant expression plasmid pBRLys, which contains the lysine-rich protein gene (*Lys*), *gus* reporter gene, and plant selectable marker *hygromycin phosphotransferase* gene, was constructed (Fig. 1). The plasmid pBRLys carrying the *Lys* gene under the control of maize ubiquitin 1 promoter was introduced into immature rice embryos and embryogenic calli via a particle delivery system (PDS-1000/He). Transformants were selected using hygromycin and transgenic plants were confirmed by PCR, PCR-Southern blot, Southern hybridization (Fig. 2), RNA dot blotting, and gus histochemical assay.

Data analyses showed that lysine content in most of the 11 transgenic rice plants improved differentially. Three displayed notable qualitative improvement, increasing to 12.45%, 16.04%, and 9.10% (Fig. 3), respectively, compared with the lysine content of nontransformed rice plants.

Further genetic analyses of transgenic rice plants No. 2, No. 6, and No. 9 are still in progress. Simultaneously, the transformation of maize and wild barley is under way. Further research on the *Lys* gene would have great potential value for improvement of the protein quality of these cereals.

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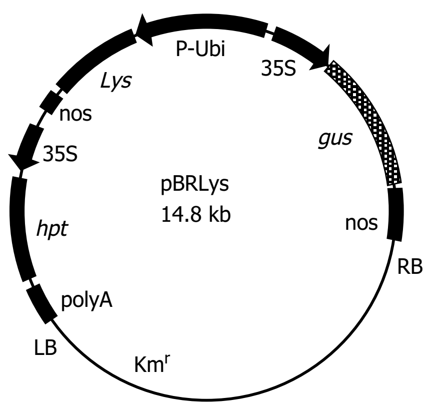

Fig. 1. Plant expression plasmid pBRLys. LB = left border, RB = right border.

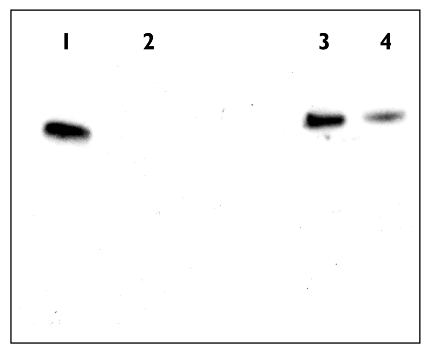

Fig. 2. Southern blot analysis of transgenic rice plants. Lane 1 = pBRLys/*Hin*dIII + K*pn*I as positive control, 2 = nontransformed rice plant PND/*Hin*dIII + K*pn*I as negative control, 3 and 4 = transgenic rice plant DNA/*Hin*dIII + K*pn*I.

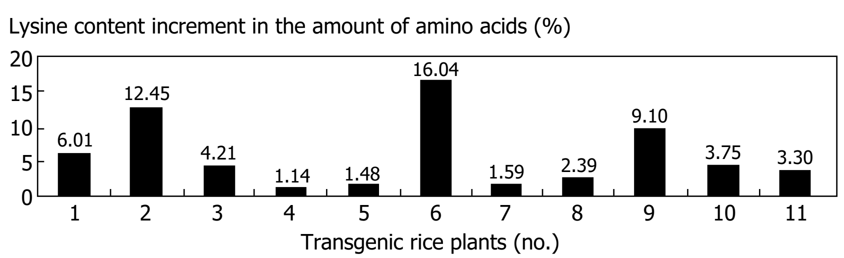

Fig. 3. Lysine content analysis of transgenic rice plants. Notes: 1. Of amino acids in lysine-rich proteins, 15 were determined: aspartic acid, threonine, serine, glutamic acid, glycine, alanine, valine, methionine, isoleucine, leucine, tyrosine, phenylalanine, histidine, lysine, and arginine. 2. Each column represents the amount of lysine content in transgenic rice plants minus the amount from nontransgenic rice as a control.

Comparison of nutrient quality between new and stored grains in japonica rice

Yan Wenchao, Jin Qingsheng, and Yu Faming, Zhejiang Academy of Agricultural Sciences (ZAAS), Hangzhou 310021, China; K. Tomita and H. Hisamitsu, Fukui Agricultural Experiment Station (FAES), Fukui 9188215, Japan

The current emphasis of breeding programs in the major rice-producing countries has shifted from increasing yield to improving quality to increase market value. It is well known that the eating quality of rice undergoes a remarkable change during storage. The eating quality of stored rice deteriorates with changes in various chemical characteristics. It was reported that the appearance, aroma, taste, cohesiveness, and hardness of stored rice deteriorate during storage and this deterioration could be predicted by evaluating changes in some chemical characteristics. Introducing indica-type or early maturing traits to japonica cultivars would lower the linoleic acid content and prevent storage deterioration.

Up to now, only a few reports have focused on differences in deterioration of the eating quality of stored rice among ordinary cultivars. No reports exist on changes in nutrient quality for recently developed superior cultivars with good eating quality. This study was conducted to determine the differences in nutrient quality characteristics among cultivars stored for about 8 mo at room temperature. Seven cultivars of japonica rice were used in this experiment: Koshihikari, Nihonbare, and Akihikari (with excellent or good eating quality), Hanaecheizen and Etsunan 162 (recently developed in Japan, with good to excellent palatability), and Xiushui 11 and Xiushui 27 (with ordinary eating quality in China). These cultivars were grown in 1996 at the experimental field of the Rice Breeding Department of FAES. All cultivars were transplanted in mid-May and harvested in late September. The moisture content of fresh brown rice and stored rice for the sensory test was about 13.5%. For storage, rice was hulled and kept in iron boxes at room temperature for about 8 mo.

All analyses were conducted in November 1996 for new rice and from May to June 1997 for stored rice. Amylose and protein content were measured by near-infrared reflectance spectroscopy (NIRS). Free fatty acid content was measured following the method of Matsue (1990).

The mean amylose content of new and stored rice was 19.7% and 19.4%, respectively (Table 1). The mean protein content of new and stored rice was 6.4% and 6.2%. There seemed to be no difference in amylose and protein content during postharvest storage. This consistency in both protein and amylose content between stored and new rice showed that deterioration of the eating quality could not be attributed to protein and amylose content.

Table 1 shows free fatty acid content of new and stored rice. Free fatty acid content of milled rice (mg %) varied from 14.6 to 25.0 for a new crop and from 19.8 to 39.7 for stored rice. Free fatty acid content of all cultivars increased and variation among cultivars widened during storage. Free fatty acid content in stored rice seed of Xiushui 27 and Xiushui 11, which had ordinary eating quality, was high, but that of Koshihikari, Hanaecheizen, and Etsunan 162, which had better eating quality, was low. The coefficient of correlation between overall eating quality and free fatty acid content of stored rice was –0.890** (Table 2). Therefore, palatability of stored rice could be partly evaluated by measuring its free fatty acid content.

Table 1. Amylose, protein, and free fatty acid content of new and stored rice.[a]

Cultivar	Amylose (%)		Protein (%)		Free fatty acid (mg %)	
	New rice	Stored rice	New rice	Stored rice	New rice	Stored rice
Koshihikari	18.0	17.5	5.6	5.5	17.6	19.8
Akihikari	17.2	17.3	6.6	6.5	21.7	26.0
Nihonbare	20.7	19.8	6.2	6.3	25.0	30.9
Xiushui 27	23.9	23.6	6.8	6.6	14.6	39.7
Xiushui 11	19.4	20.4	7.3	7.0	20.8	34.7
Hanaecheizen	19.5	18.9	6.4	6.4	21.9	24.9
Etsunan 162	19.2	18.6	5.9	5.6	23.5	26.2
Mean	19.7	19.4	6.4	6.2	20.7	28.9

[a]Values of amylose and protein were % weight basis for milled rice.

Table 2. Coefficient of correlation among eating quality factors and free fatty acid content of stored rice.

Trait	Ara	T	S	H	OEQ
Free fatty acid (FFA)	–0.379	–0.196	0.201	0.183	–0.890**
Aroma (Ara)		0.716*	0.297	–0.215	0.182
Taste (T)			0.694*	–0.463	0.948**
Stickiness (S)				–0.735*	0.906**
Hardness (H)					–0.137

[a]$P<0.05$, **$P<0.01$. OEQ = overall eating quality.

Interrelationship between protein content and degree of polish of milled rice

A. Singh, D.K. Gupta, and J.P. Pandey, Department of Process and Food Engineering, College of Technology, Pantnagar, U.S. Nagar 263145, India

Rice continues to be the most important food source in the world, with about 20% of the global population depending on it as a major staple food (Singh 1992). Degree of polish is one of the most important parameters considered during milling for trading. It affects the proximate composition of milled rice, milling yield, and whiteness value, which influence the overall economics of the production system.

Rice protein is unique among cereal proteins, being the richest in glutelin and lowest in prolamin. Ellis et al (1986) noted that regular milling removes all the pericarp, seed coat, nucellus, a major portion of the aleurone layer, embryo, and an insignificant amount of the nonaleurone endosperm except from the lateral ridges. Similar work has been reported by Juliano et al (1973), Pandey and Sah (1990), and Pal Veena et al (1999). Although some researchers have attempted to correlate the extent of degree of polish on removal of bran and protein content, no systematic work has been reported on the mathematical modeling of these parameters. This study was undertaken to explain the interrelationship between degree of polish and protein content of milled rice.

Four common rice varieties (Manhar, Govind, Pant Dhan 4, and Type 3) were collected from the Department of Plant Breeding, Pantnagar, to ensure genetic purity. Experiments were designed to vary the degree of polish by changing the milling time from 0 to 110 s at 10-s intervals. Degree of polish was computed as the ratio of cumulative bran removed and brown rice. A sample of 150 g of unconditioned rice was taken and later conditioned to 13 ± 1% (db) for the entire experiment. Dehusking and polishing were done using a Satake dehusker and polisher. Weighed brown rice was fed into the polisher for 10 s. After polishing, milled rice and bran were collected separately. Milled rice (milled for 10 s) was again polished for another 10 s. A similar procedure was followed for the different sets of samples until the milling time of 110 s was completed. Milled rice samples of different varieties with varying milling times were analyzed for protein content (Kjeldahl method, AACC [1962]). Crude protein content was calculated for different samples of milled rice.

The degree of polish of milled rice ranged from 0% to 11.43%, whereas protein content varied from 4.69% to 8.95%. Data revealed that protein content decreased as the degree of polish increased for all varieties (Table 1). This may be due to a nonuniform distribution of protein, since, within the endosperm, the outer layer has been shown to have a much higher concentration of protein than the whole kernel. The rate of decrease did not appear to be constant (Table 1) for the test varieties. The loss of protein content during 110 s of polishing was minimum (4.43%) for

Table 1. Degree of polish and protein content of milled rice.

Time (s)	Manhar		Govind		Pant Dhan 4		Type 3	
	Degree of polish (%)	Protein content (%)	Degree of polish (%)	Protein content (%)	Degree of polish (%)	Protein content (%)	Degree of polish (%)	Protein content (%)
0	Nil	8.95	Nil	8.69	Nil	8.00	Nil	7.17
10	1.37	7.16	2.37	7.77	1.50	7.52	1.43	6.96
20	2.73	7.13	4.11	7.48	2.88	7.40	2.86	6.94
30	3.73	6.95	5.72	7.23	4.19	7.24	3.90	6.90
40	4.55	6.79	6.99	7.00	5.12	6.96	4.77	5.81
50	5.26	6.50	7.93	6.68	5.97	6.81	5.51	5.80
60	5.95	6.27	8.66	6.42	6.67	6.45	6.24	5.59
70	6.59	6.01	9.31	6.25	7.32	6.17	6.92	5.43
80	7.11	5.80	9.86	6.19	7.89	5.90	7.47	5.37
90	7.57	5.46	10.41	6.10	8.45	5.59	7.96	5.30
100	7.99	5.14	10.93	5.85	8.99	5.40	8.41	5.16
110	8.39	4.78	11.43	5.40	9.50	5.21	8.84	4.69

Type 3. The protein content of milled rice after 110 s ranged from 4.3% to 5.4%, which indicates a loss of 30–50%. Hence, excessive polishing is detrimental not only in terms of not breakage but also nutrient loss.

Attempts were made to develop prediction models between protein content of milled rice and degree of polish. The modeling of protein vs degree of polishing relationship was considered in linear, semilogarithmic, and polynomial models of second- and third-order forms. Table 2 gives the resulting models along with the associated statistical parameters.

The regression coefficient (*r*) for linear and semilogarithmic models ranged from 0.87 to 0.97, whereas, for second- and third-order polynomial models, the *r* value indicated a high correlation coefficient (0.99). The standard error of the estimate (SEE) was considerably lower for semilogarithmic models than for linear models. It was consistently lower for second- and third-order polynomial models. On the basis of regression coefficients and the SEE, polynomial models can perform better than other tested models.

It may be concluded that milling time strongly influenced protein content in milled rice. Excessive polishing can result in a considerable loss of protein in milled rice (2.48–4.43%), depending on variety, at 8–11% degree of polish. The protein content of milled rice can be estimated within 7.14% prediction error using a third-order polynomial.

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Table 2. Accepted models for protein content vs degree of polish.[a]

Variety	Models (Pr/Dp)	r	SEE	E_M	E_{90}
Manhar	Ln (Pr) = 2.124861 – 0.5577 Dp	0.93	0.0534	2.27	5.14
Manhar	Pr = 8.076650 – 0.33928 Dp	0.94	0.0279	3.62	6.28
Manhar	Pr = 6.926385 + 0.227489 Dp – 0.05619 Dp^2	0.99	0.074	0.78	1.03
Manhar	Pr = 7.260756 – 0.06362 Dp + 0.011486 Dp^2 – 0.00459 Dp^3	0.99	0.064	0.63	1.15
Govind	Ln (Pr) = 2.171384 – 0.03674 Dp	0.97	0.0292	1.08	1.66
Govind	Pr = 8.527198 – 0.24428 Dp	0.98	0.155	1.62	2.58
Govind	Pr = 7.896996 – 0.02878 Dp – 0.01526 Dp^2	0.91	0.102	1.15	2.56
Govind	Pr = 8.229708 – 0.21886 Dp + 0.015045 Dp^2 – 0.00144 Dp^3	0.99	0.104	1.11	2.34
Pant Dhan 4	Ln (Pr) = 2.1546 – 0.04855 Dp	0.96	0.0395	1.70	2.81
Pant Dhan 4	Pr = 8.355399 – 0.31024 Dp	0.97	0.218	2.64	4.53
Pant Dhan 4	Pr = 7.507885 + 0.066535 Dp – 0.03344 Dp^2	0.99	0.0636	0.69	0.56
Pant Dhan 4	Pr = 7.266054 + 0.254605 Dp – 0.07213 Dp^2 + 0.00232 Dp^3	0.99	0.0584	0.55	0.75
Type 3	Ln (Pr) = 2.059753 – 0.05257 Dp	0.96	0.146	1.63	3.94
Type 3	Pr = 7.635754 – 0.31147 Dp	0.95	0.246	3.12	5.85
Type 3	Pr = 7.520631 – 0.25749 Dp – 0.00508 Dp^2	0.95	0.259	3.17	6.31
Type 3	Pr = 6.894650 + 0.261082 Dp – 0.11971 Dp^2 + 0.00739 Dp^3	0.96	0.263	3.01	5.56

[a]E_M = mean error, %; E_{90} = error based on 90% data, SEE = standard error of the estimate. Pr = protein content, Dp = degree of polish, Ln = natural log.

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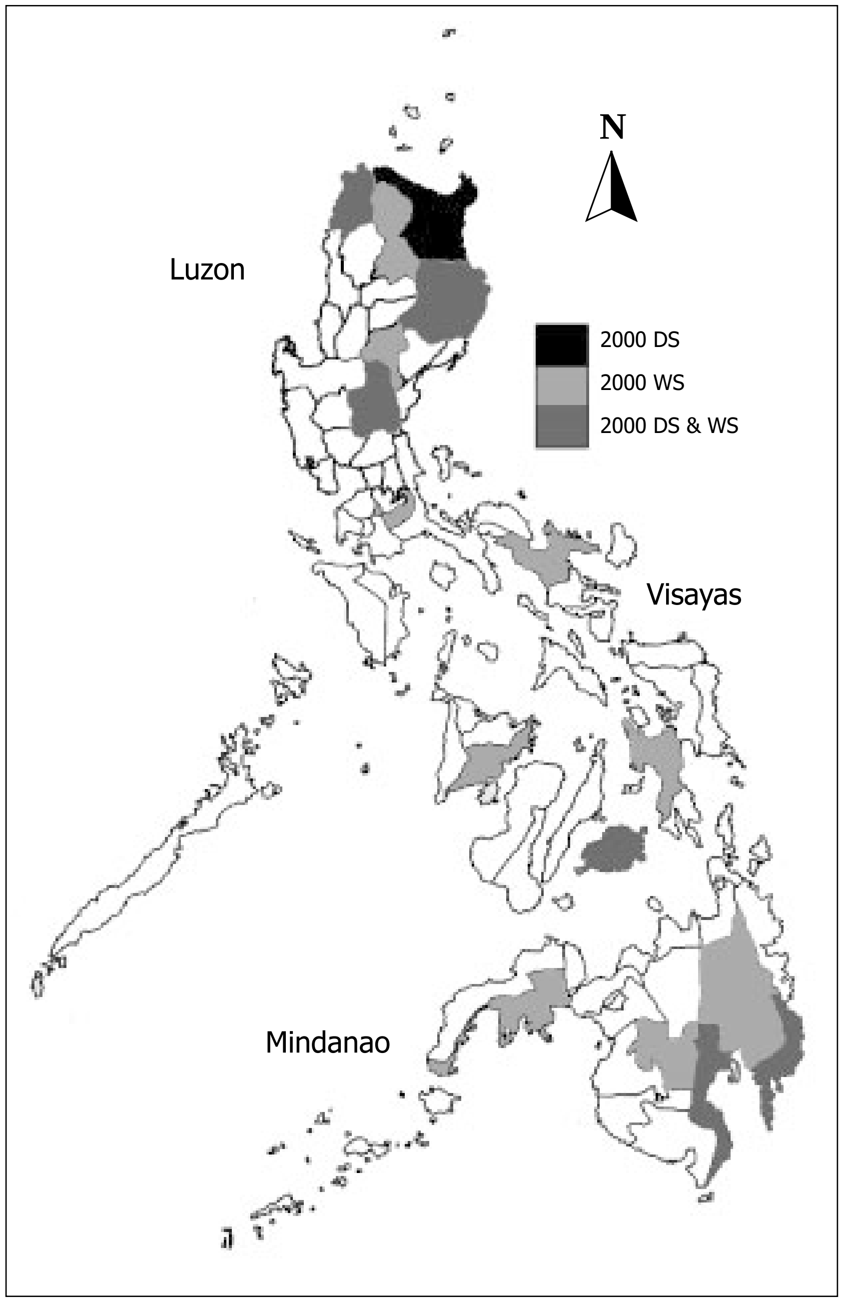
Performance of Chinese hybrid rice in the Philippines

A.T. Rigor, R.C. San Gabriel, S.A. Ordoñez, R.E. Irang, A.J. Pajarito, M.R. Ramos, L.C. Javier, F.M. Malabanan, and E.D. Redoña, Philippine Rice Research Institute (PhilRice), Maligaya, Muñoz, Nueva Ecija 3119, Philippines E-mail: atrigor@philrice.gov.ph

In the Philippines, hybrid rice (HR) technology is now used as a key approach for increasing rice production. In recent years, the Philippine Department of Agriculture (DA)-PhilRice strengthened its HR program through collaboration with rice research and development institutes of other countries such as China. A demonstration of Chinese HR technology in the country was implemented under a Technical Cooperation Agreement between the DA and the Ministry of Agriculture of the People's Republic of China. The objectives were to test the yield and general adaptation of elite Chinese rice hybrids in different parts of the country and to identify hybrids for possible commercial seed production and large-scale cultivation.

Thirteen Chinese hybrids were tested at eight locations during the 2000 dry season (DS), while six hybrids were tested at 19 locations (8 in Luzon, 4 in the Visayas, and 7 in Mindanao) during the 2000 wet season (WS). These were planted together with local hybrid PSBRc72H or Mestizo and the best and most popular variety in the area. The testing sites (see figure) represented major rice-growing areas in the Philippines and have favorable growing environments and good irrigation and drainage systems. The total area for each site ranged from 0.4 to 1.5 ha. Yield data were taken by using cut samples of 30 m^2 $hybrid^{-1}$ $variety^{-1}$.

In the DS, Mestizo yielded the highest across locations and under favorable locations (no pest and disease incidence and yields of >4 t ha^{-1}), with an average of 7.2 and 8.9 t ha^{-1}, respectively (see table). Among the Chinese hybrids, Jin You 63 yielded the highest, with a mean of 5.7 t ha^{-1} across locations and 7.7 t ha^{-1} under favorable environments. During the WS, Shan You Duoxi I yielded the highest across locations and under favorable conditions (13 out of 19 locations), with a mean of 5.6 and 7.4 t ha^{-1}, respectively.



Testing sites for technology demonstration of Chinese rice hybrids, 2000, Philippines.

Under favorable environments, this hybrid outyielded Mestizo and the local check by 19% and 30%, respectively.

Overall, local hybrid Mestizo was superior to and had better adaptability than the Chinese hybrids, both under favorable environments and across environments during the DS. Some Chinese hybrids such as Jin You 63 had yields comparable with those of local inbred varieties. Although Mestizo outyielded this hybrid by more than 1 t ha^{-1} under favorable environments, Jin You 63 matured 15 d earlier (see table). Shan You Duoxi I, another early maturing hybrid, exhibited superiority under favorable conditions and across locations during the WS; hence, these two hybrids may be preferred over Mestizo in some areas of the country with short rice-growing periods (e.g., northeastern Luzon). Seed production of these hybrids in these areas may, thus, be explored. Some Chinese hybrids such as Jin You 198, which yielded more than 11 t ha^{-1} at one location during the DS and WS, may also be suited for specific regions of the country. Furthermore, under circumstances in which no diseases were noted, most Chinese hybrids had a notable performance.

Results, however, indicated that the potential yields of Chinese hybrids were not realized under Philippine conditions. One major reason could be the shortening of the growth duration from 122–153 d in China to only 100–114 d in the Philippines (see table). Consequently, the period between the vegetative and reproductive stages was reduced, leading to fewer tillers, fewer panicles, and consequently lower yields. Another reason was the susceptibility of Chinese hybrids to local rice diseases, such as rice tungro virus disease, that caused considerable yield losses. Hence, further improvement in resistance breeding may be required before these hybrids can be widely adapted locally. Chinese hybrids may be grown in locations where diseases are absent or minimal.

Results indicated that the direct introduction of hybrids from other countries without prior testing may not be a sound strategy in commercializing hybrid rice technology.

Grain yield (t ha^{-1}) and average maturity (d) of Chinese rice hybrids under Philippine conditions, 2000.

Entry	Mean yield (t ha^{-1})				Maturity (d)		
	DS		WS		China	Philippines	
	Across locations	Favorable[a]	Across	Favorable[a] locations		DS	WS
Shan You Duoxi I	5.0	7.0	5.6	7.4	148	105	107
Shan You 46	4.8	6.6	–	–	125	103	–
Wei You 46	4.5	6.2	–	–	122	100	–
II You 58	4.9	6.9	–	–	142	108	–
Jin You 63	5.7	7.7	4.8	6.1	139	103	106
Shi You 63	5.0	6.3	5.0	6.2	122	114	112
Yi You 96	5.3	7.1	–	–	126–130	106	–
Shan You Gui 99	4.2	6.4	–	–	125	105	–
Jin You Gui 99	4.9	7.3	–	–	122	102	–
Wei You 198	4.9	6.7	–	–	123–135	103	–
Jin You 198	5.2	7.2	5.0	6.6	123	104	104
Shan You 198	5.2	7.2	4.3	5.5	na	102	108
II You 501	5.4	6.8	–	–	154	112	–
Pei Liang You Te Qing	–	–	4.5	5.8	na	–	108
PSBRc72H (local hybrid)	7.2	8.9	5.5	6.2	–	118	120
Local check	6.5	7.5	5.0	5.7	–	111	115

[a]Av of sites unaffected by rice tungro virus; yields >4 t ha^{-1}; na = not available.

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A study of pollen viability and longevity in *Oryza rufipogon*, *O. sativa,* and their hybrids

Z.P. Song, School of Life Sciences, Wuhan University, Wuhan 430072; B.R. Lu and J.K. Chen, Ministry of Education Key Laboratory for Biodiversity Science and Ecological Engineering, Institute of Biodiversity Science, Fudan University, Shanghai 200433, China E-mail: jkchen@fudan.edu.cn

The length of pollen viability after anther dehiscence is crucial to successful pollination (Stone et al 1995), particularly for outbreeders. It determines the possibility of outcrossing between species, provided that limited specific reproductive barriers exist. With the rapid development of biotechnology, more transgenic crops, including transgenic rice, are becoming available, resulting in biosafety concerns about possible ecological risks. Evaluation of transgenes introgressing to wild rice species becomes an important issue for rice breeders, environmentalists, and policymakers. Studying pollen viability and longevity of wild and cultivated rice species as well as their hybrids is important in evaluating outcrossing frequencies.

Identifying a suitable method is the key to a more accurate estimation of pollen viability (Rodriguez-Riano and Dafni 2000). In rice, the common approach to estimating pollen fertility is to examine mature pollen stained with iodine-potassium iodide solution (I_2-KI). In vitro germination for pollen fertility has also been used but difficulties in obtaining an optimal culture medium were reported (Khatun and Flowers 1995). We conducted experiments on screening various culture media to estimate pollen viability and longevity after dehiscence of *Oryza rufipogon*, *O. sativa*, and their hybrids over time. We also compared pollen viability immediately after anther dehiscence with pollen fertility obtained using I_2-KI staining to understand the relationships of the two data sets.

Oryza rufipogon was collected from a natural population in Chaling, Hunan Province, China. Seeds of rice cultivar Minghui 63 were donated by Prof. S.M. Mu from the Hubei Academy of Agricultural Science and hybrids were obtained from crosses between *O. rufipogon* (female) and Minghui 63 (male) in 1999. The three taxa were grown in the experimental field of the Genetics Institute of Wuhan University in 2000. For pollen fertility estimation, fresh and mature pollen grains were examined under the microscope 10 min after staining with 1% I_2-KI solution. Culture media with different components were screened (Table 1) for optimal pollen germination. Pollen grains with different time intervals after anther dehiscence—i.e., 0, 1, 2, 3, 4, 5, 8, 10, 13, 15, 18, 20, 25, 30, 35, and 40 min—were germinated in a petri dish with about 1.5 mm of ply glutin medium. The number of germinated pollen grains was scored under the microscope 1 h after incubation at 34 °C.

P4, P5, and P6 culture media gave the highest percentage germination (Table 1). P5 was selected for subsequent pollen germination. We also found that a higher percentage of rice pollen germinated at temperatures ranging from 25 to 40 °C, with the highest germination rate at 34 °C.

Table 1. Components of different culture media used in the experiment and their effect on pollen germination of *O. rufipogon*, Minghui 63, and their hybrids.

Code of culture medium	Component				Pollen germination (%)[a]		
	Borax (g)	Sucrose (g)	Glutin (g)	Water (mL)	*O. rufipogon*	Minghui 63	Hybrid
P1	0.1	8	20	100	29.4 f	58.4 f	24.2 e
P2	0.1	8	25	100	35.4 e	67.5 e	25.4 de
P3	0.1	8	30	100	48.7 bc	81.7 abc	30.1 bcd
P4	0.1	12	20	100	55.9 ab	85.2 a	32.3 abc
P5	0.1	12	25	100	58.4 a	84.9 a	33.9 a
P6	0.1	12	30	100	54.3 ab	83.2 ab	32.4 ab
P7	0.1	15	20	100	49.1 b	79.6 bc	30.5 bcd
P8	0.1	15	25	100	40.5 c	77.1 cd	29.1 bcd
P9	0.1	15	30	100	36.3 d	72.3 de	27.2 cde

[a]Means of pollen germination followed by different letters are significantly different ($P<0.05$) according to Duncan's multiple range test.

The number of viable pollen at 0 min after dehiscence was much lower than the I_2-KI stainable pollen in the three taxa (Table 2). About 40% of the stainable pollen grains in *O. rufipogon*, 13.5% in Minghui 63, and 50% in the hybrids did not germinate. This indicated that pollen stainability using the I_2-KI staining method did not correctly reflect pollen fertility, and that the method can be used only as a relative measure of fertility.

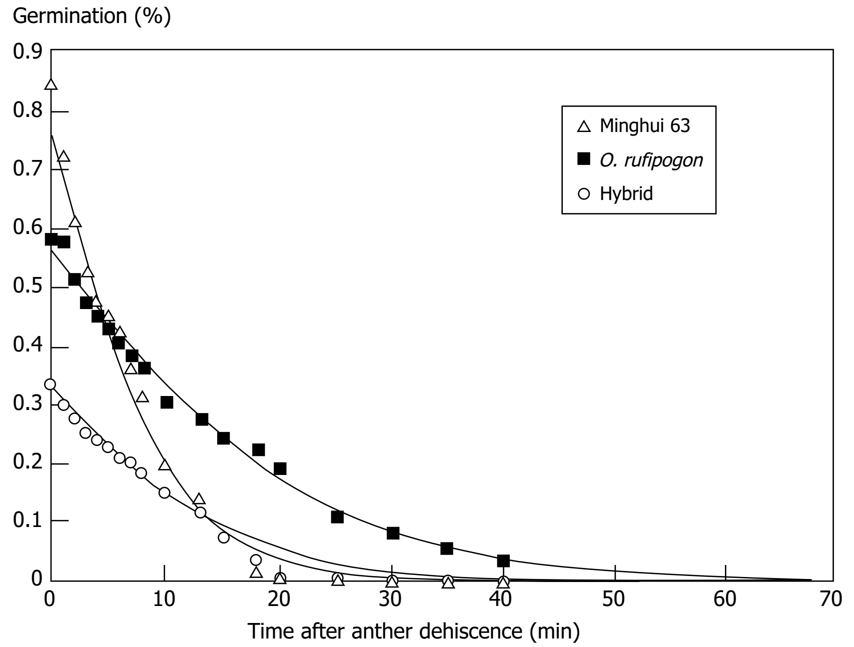
In the pollen germination experiment, the three taxa showed variable pollen viability at different time intervals and had different half-life (50% loss of pollen viability) rates after anther dehiscence (see figure). Minghui 63 not only had the highest pollen germination rate (approximately 85%) at 0 min after anther dehiscence but also the fastest decline in pollen viability. It lost 50% of viable pollen within 6 min and nearly 100% about 30 min after anther dehiscence. Compared with Minghui 63, *O. rufipogon* had a lower pollen germination rate (approximately 60%), but its pollen viability was much longer, retaining 50% pollen viability after 12 min. Its pollen viability could last for 60–70 min based on regression analysis. The hybrids had the lowest pollen germination rate (approximately 34%) and medium pollen longevity. More than 50% of the pollen grains were viable after 10 min and a few were still viable after 40 min. These results indicated that pollen viability and pollen longevity varied among the three taxa studied. This supports the report by Khatun and Flowers (1995) that rice pollen remains viable for only a short time. Moreover, pollen longevity does not depend on initial pollen viability.

Pollen grains can remain viable for a certain time after anther dehiscence. This time varied among the three taxa studied. Some *O. rufipogon* pollen remains viable even after 60–70 min, indicating the potential for outcrossing with cultivated rice. Our unpublished data showed overlapping flowering time of cultivated rice and *O. rufipogon*, which allows outcrossing between *O. rufipogon* and *O. sativa* to occur if the physical distance between the two is relatively close. In addition, our study showed partially fertile pollen of hybrids (34%), indicating the possibility that any transgene in a partially fertile hybrid can be passed on to its selfed and backcrossed progenies. We believe that, once transgenic rice is available in the environment, transgenes will have good opportunities to be captured by close relatives of rice such as *O. rufipogon*.

Table 2. Relationship between I_2-KI stainable and viable pollen (± = standard deviation).

Material	Stainable pollen (%)	Viable pollen (%)[a]	Viable/stainable pollen
O. rufipogon	98.1 ± 1.72	58.4 ± 2.76	0.60
Minghui 63	94.0 ± 2.35	84.9 ± 2.05	0.87
Hybrid	66.2 ±14.5	33.9 ± 3.41	0.51

[a]Percentage of viable pollen was recorded by in vitro germination at 34 °C with pollen grains sampled at 0 min after anther dehiscence.



In vitro pollen germination after anther dehiscence. The nonlinear regression was $Y_{Minghui\ 63} = 1.92/(1 + 1.376\ exp^{(0.177x)})$, $R^2 = 0.99$; $Y_{O. rufipogon} = 0.88/(1 + 0.616\ exp^{(0.093x)})$, $R^2 = 0.98$; $Y_{hybrid} = 0.413/(1 + 0.309 exp^{(0.179x)})$, $R^2 = 0.99$, respectively.

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Acknowledgments

This research is supported by the National Nature Science Foundation of China (39893360). The authors thank Prof. Bo Li for his assistance in data analysis.

Sashi (CN842-15-5, IET14105), a high-yielding, long-slender grain variety for shallow water conditions in West Bengal, India

S.K. Sinha, B.K. Mandal, and S.D. Chatterjee, Rice Research Station (RRS), Chinsurah Hooghly, Pin 712102, West Bengal, India

Most varieties cultivated for shallow water conditions have bold grains, resulting in a low return from low market value. A breeding program began in 1984-85 to select for long-slender grain lines only from segregating generations along with other desired characters such as high grain yield and disease and pest resistance.

Sashi, derived from crossing IR50 and Patnai 23, was first nominated to the All-India testing under the Initial Variety Trial (shallow water) with IET14105 in 1993 after testing at the RRS under shallow water conditions. Based on overall performance, it was promoted to the Advanced Variety Trial (shallow water) in 1995 and subsequently recommended for cultivation in West Bengal and eastern Uttar Pradesh in 1997, released for West Bengal by the state Variety Release Committee in 1999 for shallow water areas, and finally approved for seed production by the Variety Identification Committee in 2000.

Before its release, IET14105 (CN842-15-5) was tested extensively under the Front Line Demonstration Program trial in different districts of West Bengal in the 1998 and 1999 kharif (wet) season in farmers' fields. Results (Table 1) unequivocally proved the superiority of the variety over other checks with improved grain type (Table 2). The variety has now gained popularity for its long- slender grains; higher yield; tolerance for submergence; better straw height suitable for animal feed and domestic use in urban areas; tolerance for diseases and pests, particularly sheath blight and sheath rot, which mainly prevail in shallow-water ecosystems; and tolerance for lodging. Based on this, IET14105 was released as Sashi in West Bengal in 1999 and subsequently elevated for breeder seed production in 2000.

Table 1. Performance of IET14105 (Sashi) under the Front Line Demonstration Program in different districts of West Bengal, 1998 kharif.

Variety	Farmers (no.)	Area (ha)	Grain yield (t ha^{-1})	Mean grain yield (t ha^{-1})	% increase
1998 kharif					
24-Parganas (South)					
IET14105	38	15	3.6–5.4	4.5	–
Salibahan	38	5	2.5–3.4	3.0	53 over Salibahan
Patnai 23	38	–	–	2.2	101 over Patnai
Hooghly					
IET14105	24	10	3.5–4.5	4.0	–
Bipasa	24	10	3.3–4.5	3.9	3 over Bipasa
Swarna	24	–	–	3.8	4 over Swarna
Midnapur (West)					
IET14105	31	10	3.0–5.0	4.0	–
Bipasa	31	10	2.5–5.5	4.0	7 over Bipasa
Swarna	31	–	–	3.7	8 over Swarna
1999 kharif					
24-Parganas (North)					
IET14105	47	12	5.0–5.2	5.0	–
IET5656	47	8	3.8–3.9	3.9	28
Burdwan					
IET14105	9	10	3.8–4.5	4.1	–
Swarna	9	10	3.0–3.7	3.5	17
Malda					
IET14105	4	5	–	4.2	–
Swarna	4	5	–	4.0	5
Hooghly					
IET14105	13	10	3.5–4.5	4.1	–
IET5656	13	10	3.0–4.1	3.9	5
24-Parganas (South)					
IET14105	30	10	3.2–3.8	3.5	–
Local varieties	30	10	1.9–2.4	2.0	75
Murshidabad					
IET14105	8	10	2.7–5.8	4.9	–
IET5656	8	10	2.6–4.5	4.3	12

Table 2. Comparative data on grain and quality characteristics of some lowland cultivars.

Characteristic	Sashi	Salibahan	Pronava	Swarna	Swarnadhan	Mahsuri	Pankaj
Milling recovery (%)	70.0	67.8	69.5	69.8	–	75.8	73.4
Head rice recovery (%)	65.0	64.9	67.0	66.0	–	59.2	58.8
Kernel length (mm)	6.47	5.27	5.81	5.32	5.6	5.42	6.04
Kernel breadth (mm)	1.96	2.22	2.27	2.14	2.4	2.63	2.42
Length/breadth	3.30	2.37	2.37	2.48	2.3	2.65	2.34
Grain type	Long slender	Short bold	Short bold	Short bold	Long bold	Medium slender	Long bold
Grain chalkiness	Very occasional	Occasional	Occasional	Occasional	–	–	–
Alkali value	6.6	5.7	5.8	–	–	–	–

Preliminary evaluation of potential pathogenic fungi as bioherbicides of barnyardgrass (*Echinochloa crus-galli*) in China

S.W. Huang, China National Rice Research Institute (CNRRI); A.K. Watson, IRRI; G.F. Duan, and L.Q. Yu, China Rice Research Institute, Hangzhou 310006, China E-mail: ylq@zgb.com.cn

This study evaluated the use of pathogenic fungi in the biological control of barnyardgrass (*Echinochloa crus-galli*), which has been rated as the most serious weed in rice (Holm et al 1977). From 1997 to 1999, more than 10 pathogenic fungi were isolated from naturally infected barnyardgrass leaves collected from different rice-growing areas in China. Preliminary bioassays show that *Exserohilum monoceras* (EM) and *Drechslera monoceras* (DM) are the most pathogenic to barnyardgrass. Further evaluation of these fungi as biocontrol agents was also conducted.

Fungi cultured for 7 d on potato dextrose agar were used as seed inoculum. Conidia were mass-produced on a barnyardgrass seed solid substrate (Huang et al 1999). Three pieces of agar plugs from the margins of young colonies were transferred to sterilized substrates and then incubated at 28 °C in the dark. Conidia were harvested 14 d after incubation by shaking the flask with 50 mL of 0.05% Tween 20 distilled water, suspensions of which were filtered through a layer of cheesecloth. Conidia concentrations were determined with a hemacytometer.

To quantify the virulence of these two isolates on barnyardgrass, germinated seeds (coleoptile and radicle just emerged) were direct-seeded (10 seeds pot^{-1}) in plastic pots filled with saturated soil. Pots were placed in the greenhouse at 35/25 ± 5 °C day/night temperatures with natural light. Seedlings at 1.5–2.0-, 3.0–3.5-, and 4.5–5.0-leaf stages were inoculated by spraying 50 mL m^{-2} of suspension of 10^6 conidia mL^{-1}. After spraying, pots were placed in a dark dew chamber with more than 95% relative humidity (RH) at 28 °C for 24 h. Subsequently, pots were returned to the greenhouse and the RH was kept at 85–90% by spraying water. Disease reactions of barnyardgrass seedlings to two fungal isolates were evaluated 14 d after inoculation. Observation and recording followed the methods and standards of Zhang et al (1996). The experimental design was a randomized complete block with three replications. The control treatment was sprayed with distilled water containing only Tween 20.

A similar experiment was conducted to determine the pathogenicity of these two fungi to plants other than barnyardgrass. All experimental methods in the host range test were the same as in the virulence test, except for plant growth stage at inoculation. The Fabaceae and Brassicaceae species were at the first true leaf stage and the Poaceae species were at the 1.5–2.0-leaf stage.

Disease incidence (DI, percentage of infected plants) of EM in barnyardgrass seedlings at the 1.5–5.0-leaf stage was more than 90% (Table 1). Seedlings at the 3.0–3.5-leaf stage were the most susceptible to EM, reaching 99.6% DI and more than 80% mortality. The DM isolate had 97.5–100% DI in barnyardgrass seedlings at all

Table 1. Virulence of potential biological control fungi on barnyardgrass seedlings at different growth stages.

Fungus	1.5–2.0 leaf					3.0–3.5 leaf					4.5–5.0 leaf				
	DI[a] (%)	MR (%)	LAD (%)	PH (cm)	FW[b] (%)	DI[a] (%)	MR (%)	LAD (%)	PH (cm)	FW[b] (%)	DI[a] (%)	MR (%)	LAD (%)	PH (cm)	FW[b] (%)
EM	91.8 b	85.4 a	46.7 a	14.3 b	48.4 a	99.6 a	81.5 a	63.8 a	15.6 b	65.1 a	95.4 b	77.2 a	53.3 a	15.9 b	57.1 a
DM	100.0 a	75.2 b	42.6 b	14.2 b	40.8 b	99.7 a	73.4 b	57.6 b	14.8 c	41.7 b	97.5 a	70.7 b	53.8 a	16.0 b	37.8 b
Control	4.3 c	0 c	3.3 c	17.5 a	3.3 c	5.9 b	0 c	1.8 c	19.1 a	4.8 c	5.8 c	0 c	1.7 b	19.8 a	5.2 c

[a]DI = disease incidence, MR = mortality rate, LAD = leaf area damage, PH = plant height, FW = fresh weight reduction. [b]Values in the control line of FW are av fresh weights of pots. Values in the same column followed by different letters are significantly different at $P<0.05$ according to ANOVA and the LSD test.

leaf stages tested. The 1.5–2.0-leaf stage was the growth stage most susceptible to DM (100% DI), with a mortality of 70.7–75.2%. The percentage leaf area damage (LAD, excluding dead plants) on seedlings caused by both fungi was not as high as expected. EM and DM significantly inhibited the height of barnyardgrass seedlings at different leaf stages. Other experiments have indicated that LAD and mortality rates were positively correlated with inoculum dose and duration of the dew period after inoculation.

Under greenhouse conditions and when applied at an inoculum dose of 5.0×10^7 conidia m^{-2}, EM and DM were not pathogenic to rice seedlings (including indica, japonica, and hybrid rice) and to most other crops tested (Table 2). However, sorghum (*Sorghum bicolor*) was susceptible to EM and slightly susceptible to DM, and maize (*Zea mays*) was also slightly susceptible to EM. Barnyardgrass was the only plant species highly susceptible to these fungi, with EM causing plant death.

Preliminary results indicated the potential of DM and EM pathogens in controlling barnyardgrass, but further research is required to assess the risks to nontarget plant species and to evaluate performance under field conditions.

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Table 2. Susceptibility of selected crop plants to potential biological control fungi of barnyardgrass.[a]

Crop	EM	DM	Control	Crop	EM	DM	Control
Zea mays	ls	ns	ns	*Hordeum vulgare*	ns	ns	ns
Glycine max	ns	ns	ns	*Brassica napus oleifera*	ns	ns	ns
Vigna sesquipedalis	ns	ns	ns	*Oryza sativa* Jiayu 293 (indica)	ns	ns	ns
Vicia faba	ns	ns	ns	*O. sativa* Xiushui II (japonica)	ns	ns	ns
Sorghum bicolor	s	ls	ns	*O. sativa* Xieyou 46 (hybrid rice)	ns	ns	ns
Triticum aestivum	ns	ns	ns	*Echinochloa crus-galli*	d	hs	ns

[a]ns = not susceptible; ls = lightly susceptible, with a few and small lesions on leaves; s = susceptible; hs = highly susceptible with many and expanded lesions on the leaves; d = dead plant. EM = *Exserohilum monoceras*, DM = *Drechslera monoceras*.

Response of two rice cultivars to competition from *Echinochloa crus-galli*

S. Pheng, School of Land and Food, University of Queensland, St. Lucia, Queensland 4072, Australia; G.C. Jahn, IRRI; and B. Khiev and C. Pol, Crop Protection Program, Cambodian Agricultural Research and Development Institute (CARDI), P.O. Box 01, Phnom Penh, Cambodia E-mail: s800661@student.uq.edu.au, g.jahn@cgiar.com, kbunnarith@bigpond.com.kh

Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] is an important weed of rice in irrigated and rainfed ecosystems in Cambodia. Rice yields decrease as barnyardgrass populations increase (Smith 1968). To minimize weed competition, Cambodian farmers transplant rice and practice hand-weeding (Jahn et al 1997). The success of this method depends on the amount of standing water after transplanting and the critical period of weeding. Unpredictable rainfall does not favor the use of water in weed management. In addition, labor for hand-weeding is becoming scarce because of competition from other industries. Although herbicides can be used as a labor-saving option, they are expensive and may cause health and environmental hazards if incorrectly applied. In low-input farming systems such as those in Cambodia, competitive rice cultivars may be an important part of weed management.

An experiment was conducted from September 1997 to January 1998 in Phnom Penh, Cambodia, to determine the competitive abilities of two rice cultivars, IR66 and CAR8 against different weed densities. The experiment consisted of six treatments resulting from the possible combination of varieties IR66 and CAR8, and three densities of barnyardgrass (0, 20, and 40 kg ha^{-1}). The experiment, conducted under rainfed conditions, used a randomized complete block design with five replications.

IR66, a modern rice cultivar, is early maturing. It has short stems and short, narrow leaves, whereas CAR8 has long stems and large leaf areas (Table 1). CAR8 is a Cambodian traditional rice cultivar selected for purity by the Cambodia-IRRI-Australia Project (CIAP). IR66 required only 66 d to complete the vegetative growth stage, while CAR8 required 112 d. The analysis of variance indicated that CAR8 had significantly higher yields than IR66. Partitioning of sum of squares (PSS) indicated that the rice yield of both cultivars decreased linearly when weed density increased (Table 2). However, IR66 was more susceptible to weed competition than CAR8. When the weed-seeding rate was increased to 20 kg ha^{-1}, the average yield of IR66 decreased by 71% compared with a yield reduction of 37% for CAR8. When the weed-seeding rate was increased to 40 kg ha^{-1}, a rare case of weed infestation, CAR8 still yielded an average of 1.3 t ha.

CAR8 could have outperformed IR66 against *E. crus-galli* because it possesses competitive traits such as late maturation, longer stems, and droopy leaves (Ampong-Nyarko and De Datta 1991, Smith 1983). In addition, laboratory tests indicated that CAR8 exhibits allelopathic activity, while IR66 does not (Peng et al 1999). CAR8 is recommended for rainfed lowland areas with high weed infestation. Weed management can be enhanced when competitive cultivars are integrated with other weed management options.

Table 1. Phenological and morphological characteristics of IR66 and CAR8 in monoculture under rainfed conditions without fertilizer, based on average measurements taken from five plants plot^{-1}.

Characteristic	IR66	CAR8
Phenology™		
Vegetative stage (d)	66	112
Duration (d)	96	142
Morphology		
Plant height (cm)	78.8	131.7
Leaf length (cm)	30.6	42.0
Leaf width (cm)	0.6	0.7

Table 2. Mean rice yields (t ha^{-1}) of two varieties (IR66 and CAR8) grown at three different densities of *E. crus-galli* seeds.[a]

Density (kg ha^{-1})	IR66	CAR8
D_1 (0)	1.1 a	3.5 a
D_2 (20)	0.3 b	2.2 b
D_3 (40)	0.3 b	1.3 c

[a]Means within columns followed by the same letter are not significantly different (P > 0.05, LSD test).

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Acknowledgments

We thank the Australian Agency for International Development (AusAID) for financing this research through CIAP. Special thanks go to Mr. K.H. Pith of CIAP for providing us with the germplasm.

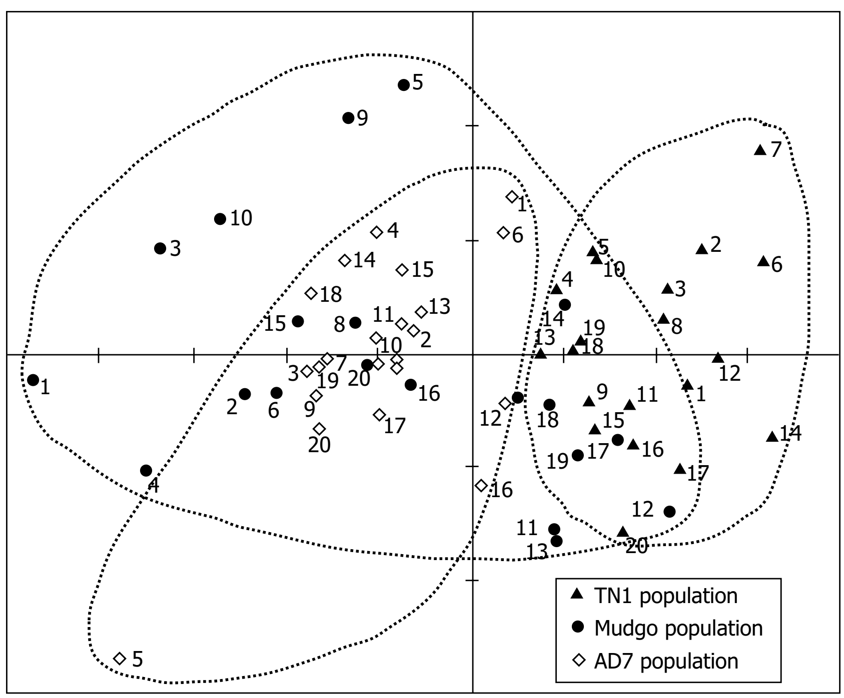
Comparing the performance of three host-related populations of *Nilaparvata lugens* (Stål) on holidic diets with various amino acid compositions

Qiang Fu, Zhitao Zhang, China National Rice Research Institute (CNRRI), Hangzhou 310006; Cui Hu, Zhejiang University, Hangzhou 310029; China and Fengxiang Lai, CNNRI E-mail: quiangfu@mail.hz.zj.cn; abpi@public.fy.hz.zj.cn

An evident virulence shift of the brown planthopper *Nilaparvata lugens* (Stål) to rice varieties with specific major resistance genes generally occurs upon rearing the insects for several generations on resistant varieties (Rombach and Gallagher 1994, Ketipearachchi et al 1998). Amino acids are the dominant nitrogen nutrients in rice phloem (Fukumorita and Chino 1982). However, little information exists about the effect of amino acids on the survival and development of different host-adapted populations (or biotypes) of *N. lugens*. In this study, we compared the performance of three host-related *N. lugens* populations on holidic (chemically defined) diets with various amino acid compositions.

The three populations used have been successively maintained for more than 30 generations on one of three rice varieties: TN1 (susceptible), Mudgo (*Bph1*), and ASD7 (*bph2*). They were reared on 20 holidic diets, varying in overall amino acid content (2.4%, 3.2%, 4.0%, 4.8%, W/V) and Eaa (essential amino acid)-nEaa (nonessential amino acid) ratio (58:42, 50:50, 42:58, 34:66, 26:74), based on the chemically defined diet D-97 (Fu et al 2001). One hundred 1-d-old nymphs from each population were fed on each diet using four feeding chambers (25 nymphs chamber^{-1}) at 27 °C, >85% relative humidity (RH), and a photoperiod of 12–14 h light (Fu et al 2001). The emergence rate, proportion of brachypterous adults, nymphal development period, and weight of newly molted adults were measured.

The three populations differed substantially in the effects of dietary amino acid composition (see table). Overall amino acid content had no significant effect on any of the performance indices of the ASD7 populations, but it affected the emergence rate of TN1 populations. It significantly affected all the indices of the Mudgo population, except for emergence rate. Eaa-nEaa ratio had smaller effects on the TN1 population than on both Mudgo and ASD7 populations. In addition, interactions between overall amino acids and Eaa-nEaa ratio also had the greatest influence on the Mudgo population. Principal component analysis based on all performance indices indicated that the variation in amino acid composition caused the Mudgo population to spread over the largest area and the TN1 population over the smallest area (see figure). Variation in amino acids in the three populations conformed to the sequence Mudgo > ASD7 > TN1. Populations of resistant rice varieties (Mudgo and ASD7) were more sensitive to variation in dietary amino acids than the TN1 population.



Principal component analysis based on all performance indices of the three *Nilaparvata lugens* populations on 20 holidic diets.The numbers 1–20 represent 20 holidic diets with varying overall amino acid Eaa-nEaa ratio. Dotted lines enclose the area of each population on various diets.

Results indicated that amino acid requirements of *N. lugens*, mainly total concentration, differed across the three populations (see table). The Mudgo population required the highest concentration (4.0–4.8%).

The three populations differed in adaptation to variation in amino acids. It is possible that amino acids are an important biochemical basis for resistance to *N. lugens* in rice and play an important role in the formation of new host-related populations or biotypes of the insect.

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Effects of amino acid composition of the diet on the performance of three host-related populations of *Nilaparvata lugens*.[a]

Factor	*N. lugens* population	Emergence rate	Proportion of brachypterous adults	Weight of newly molted adult		Nymphal duration	
				Female	Male	Female	Male
Overall amino acid content (%)	TN1	** (3.2–2.4)	ns	ns	[b]	ns	ns
	Mudgo	[b]	* (2.4)	** (4.0–4.8)	*** (4.0–4.8)	*** (4.0–4.8)	*** (4.0–4.8)
	ASD7	[b]	ns	ns	ns	ns	ns
Eaa-nEaa	TN1	ns	ns	ns	[b]	*** (50:50)	*** (50:50)
	Mudgo	[b]	ns	*** (50:50–42:58)	* (50:50)	*** (50:50)	*** (50:50)
	ASD7	[b]	* (34:66–50:50)	* (50:50)	ns	*** (50:50)	*** (58:42–50:50)
Interaction	TN1	ns	ns	ns	**	**	ns
	Mudgo	*	ns	***	ns	***	***
	ASD7	*	ns	ns	ns	ns	**

[a]ns = no significant effect ($P>0.05$); *, **, and *** = significant effect at 0.05, 0.01, and 0.001 level, respectively (F test). Numbers in parentheses are the optimum overall amino acid level (%) or Eaa-nEaa determined by Duncan's multiple range test. [b] Main effects are not examined when the interaction term made up a large proportion of the ANOVA total sum of squares.

Effects of genotypes and insecticide application on tungro disease incidence and grain yield of rice

P. Nagaraju, N. Dronavalli, and D.P. Biradar, University of Agricultural Sciences, Dharwad, Agricultural Research Station (ARS), Siruguppa 583121, Karnataka, India

Rice tungro disease (RTD) is a devastating viral disease of rice caused by rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV). It can be managed by controlling its insect vectors—green leafhoppers (*Nephotettix* spp.). However, there is still a debate on RTD management through insecticide application. Ganapathy et al (2001) and Batay-an and Mancao (2001) have found that RTD could be managed by applying insecticides to control leafhoppers. However, this has not been universally accepted among research workers. Villareal (2001) reported that leafhopper control by insecticides is not a solution to the tungro problem as application of insecticides to control leafhopper vectors of RTD cannot be justified in areas where inoculum sources are not present. In view of these findings, more studies are needed under different agroecological zones so that a more suitable approach to control RTD can be developed.

A field experiment was conducted at ARS in Siruguppa, Karnataka, India, during the 1998 and 1999 wet seasons. The experiment was carried out in a split-plot design with three replications. Treatments consisted of three genotypes in the main plots (6 × 4 m) and two disease management levels in the subplots (3 × 4 m)—disease management (DM), in which insecticide monocrotophos was sprayed, and no disease management (NM), in which no insecticide was sprayed.

Soil at the experimental site was deep black with pH 8.0 and available N, P, and K content of 318, 47, and 447 kg ha^{-1}, respectively. The crop was fertilized with 150, 75, and 75 kg of N, P, and K ha^{-1}, respectively, of which 50% N and full P and K doses were applied uniformly as basal dressing. The other 50% N was applied in two equal splits at tillering and panicle initiation. Seedlings (30 d old) were transplanted at 20 × 10-cm spacing with 2–3 seedlings hill^{-1}. Monocrotophos (360 g ai ha^{-1}) was applied at 40 and 55 d after transplanting. Disease incidence was recorded 15 d after the second spray by fixing a 1-m^2 area at random in each plot and disease severity was scored using the 0–9 scale of the *Standard evaluation system for rice* (IRRI 1980). After harvest, grain yield (t ha^{-1}) was recorded from a 2.8 × 3.6-m plot.

The analysis indicated that year significantly affected grain yield and disease incidence. Results for each year are reported separately in the table. Both grain yield and percent disease incidence differed significantly in relation to genotype and DM. The interaction between genotype and DM was significant for percent disease incidence (PDI). DM recorded a higher grain yield than NM in all three genotypes studied for both years. PDI in IR64 and IET10719 was significantly higher in NM than in DM for both years. Vikramarya had no disease incidence and had a higher grain yield than IET10719 and IR64 during both years. The high yield of Vikramarya may be attributed to its tungro virus resistance, while the lower yields of IR64 and IET10719 may be due to the higher disease incidence observed.

From these studies, it is evident that Vikramarya can be grown in RTD-endemic areas. When growing either IET10719 or IR64 in the Tungabhadra project command area of Karnataka, where RTD appears sporadically every year, insecticide spraying can be adopted.

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RTD incidence (%) and grain yield (t ha^{-1}) as influenced by genotype and disease management level at Siruguppa, Karnataka, India, 1998-99 wet seasons.

Year	Genotype	Disease incidence (%)		Grain yield (t ha^{-1})	
		With disease management	No disease management	With disease management	No disease management
1998	IR64	37.6 (6.2)[a]	60.7 (7.9)*	3.2	2.7*
	IET10719	26.7 (5.3)	48.1 (7.0)*	4.2	3.2*
	Vikramarya	0.0 (1.0)	00.0 (1.0) ns	6.8	6.6 ns
	CD (5%)		0.17		0.67
1999	IR64	17.0 (4.2)	34.1 (5.9)*	3.7	2.8*
	IET10719	19.3 (4.5)	30.4 (5.6)*	3.2	2.5*
	Vikramarya	00.0 (1.0)	00.0 (1.0) ns	5.7	5.2*
	CD (5%)		0.49		1.23

[a]Numbers in parentheses are square root-transformed values. The value in the no-disease management subplot is significantly different ($P<0.05$) from that in the disease management subplot (LSD test).

Bionomics of vectors and dynamics of rice yellow mottle virus in Tanzania

O.O. Banwo and R.H. Makundi, Sokoine University of Agriculture, P.O. Box 3005, Morogoro; R.S. Abdallah, Tropical Pesticides Research Institute, P.O. Box 3024, Arusha; J.C. Mbapila, Agricultural Research Institute, P.M.B. Ifakara, Tanzania
E-mail: banwo@hotmail.com

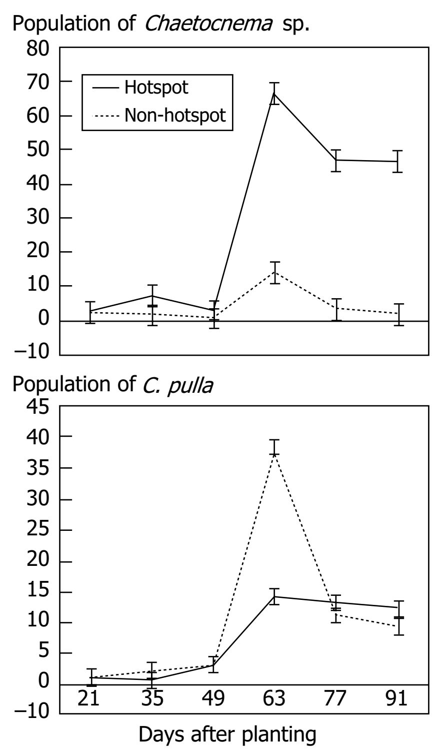
Rice yellow mottle virus (RYMV) is the only known viral disease of rice in Africa and it is endemic to the continent. It is now the most important disease of rice in Tanzania and is commonly found in lowland rice, which accounts for 80% of the country's rice production. The disease was first observed in Tanzania and Zanzibar in the early 1980s but has only lately drawn research attention. Ali (1999) and Luzi-Kihupi et al (2000) reported that RYMV has been observed in most of the major rice-growing regions in Tanzania and that the disease is spreading at an alarming rate between and within these regions. RYMV is transmitted efficiently by chrysomelid beetles (Bakker 1974). The important vectors in Tanzania are *Chaetocnema* sp. (a yet to be described species), *C. pulla* Chapuis, and *Dactylispa* sp. (not *Dactylispa bayoni* Gestro) (Banwo et al 2000). However, *Dactylispa* sp. is believed to be a potentially important vector since it is not found in all RYMV fields.

Nwilene (1999) reported that the dynamics of virus spread and the role of vectors are still poorly understood. To understand the dynamic nature of RYMV, studies on the bionomics of the vectors under two disease situations (hotspot and non-hotspot) were carried out. A good control measure depends on a thorough knowledge of virus epidemiology, vector bionomics, and ecology.

The experiment was conducted in the field in Ifakara in the Morogoro region. Four fields (replicates) were used for the two treatments (RYMV-infected/hotspot and no recorded history of RYMV infection/non-hotspot). Hotspot areas were chosen from places believed to be RYMV-infected, with a high rate of spread occurring consistently over the years. Non-hotspot areas were chosen from fields with no recorded history of RYMV. These fields (hotspot and non-hotspot) were within about a 1-km radius of one another. Each field (hotspot/non-hotspot) was in a different area. The selection was based on farmers' experience (of about 10 years) in relation to RYMV infection.

Traditional lowland rice variety Supa (susceptible to the disease), which requires 135–150 d of growth and is widely grown by farmers, was used. The broadcast system of planting is normally used for this variety. The crop was sown on 23 Jan 2000 under rainfed lowland conditions. Quadrats measuring 15 × 15 m were used in each selected field. The population of insect vectors (*Chaetocnema* sp. and *C. pulla*) was determined by taking 20 sweeps (with a sweep net) per quadrat biweekly from 21 to 91 d after planting (DAP). After this stage, there is less chance of RYMV infection to the crop. Populations of insect vectors of these two treatments were compared with each other over time.

The figure shows statistically significant differences ($P<0.05$) between the *Chaetocnema* sp. population in hotspot and non-hotspot areas at 35 and 49 DAP, with a higher vector population in hotspot areas. Also, highly statistically significant differences ($P<0.001$) were obtained at 63, 77, and 91 DAP. For *C. pulla*, the difference in vector population was highly statistically significant ($P<0.001$) only at 63 DAP, with a higher vector population in non-hotspot areas. Results of the regular sampling of vectors (*Chaetocnema* sp.



Population of *Chaetocnema* sp. and *C. pulla* in rice yellow mottle virus areas.

and *C. pulla*) in two RYMV areas (hotspot and non-hotspot) clearly showed that there was a higher population of *Chaetocnema* sp. in hotspots than in non-hotspot areas and that this difference increased with time. Thus, the population of the novel species *Chaetocnema* partly explains the difference in infection between the two RYMV areas. Other factors such as farmers' practices, elevation, and surrounding nonrice vegetation are the same for both the hotspot and non-hotspot areas selected.

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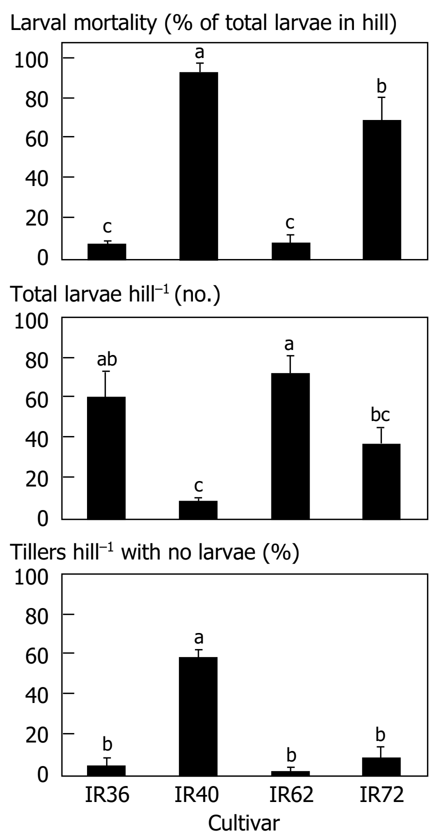
Mortality of first- and second-instar larvae of yellow stem borer in four indica cultivars at the vegetative stage

E. Rubia-Sanchez, J. Catindig, and K.L. Heong, IRRI E-mail: e.sanchez@cgiar.org

At the tillering stage, larvae of the yellow stem borer (YSB) *Scirpophaga incertulas* (Walker) cause deadhearts after about 1 wk of feeding inside the leaf sheath. At the preheading stage, larvae cause whiteheads after about 4 d of feeding inside the panicle stem. Cultivars that cause high early mortality of YSB larvae are good sources of resistance for breeding programs because many larvae will be killed before they have done sufficient feeding to cause deadheart or whitehead. In this study, we compared early larval mortality of YSB on four indica cultivars.

IR36, IR40, IR62, and IR72 rice seedlings were transplanted in a screenhouse at the rate of two seedlings hill^{-1}. One month after transplanting, hills were transferred into 13-cm-diam pots (one hill pot^{-1}) and caged in a greenhouse. There were four replicates for each cultivar. One egg mass (130–135 eggs; approximately 5 × 4 mm) was placed on a hill in each cage. Three days after egg hatching, plants were uprooted from pots and stored at ambient temperature for 0–24 h before being dissected under a binocular microscope. Data were subjected to ANOVA and means were compared by LSD.

Larval mortality inside leaf sheaths was highest on IR40, followed by IR72 ($F = 4.68$, df = 15, $P<0.05$; see figure). The cause of larval death is unknown but may be due to chemicals produced by plants in response to feeding. Further work will be done to identify these chemicals. IR40 and IR72 also had the lowest numbers of larvae recovered hill^{-1} ($F = 21.32$, df =15, $P<0.01$). IR40 also had more tillers with no larvae ($F = 24.30$, df = 15, $P<0.01$) because there were only a few larvae in the hill. The most susceptible cultivar, IR62, had an average of 6.2 larvae tiller^{-1} with 92% live larvae hill^{-1}, whereas IR40 showed only 1.6 lar-



Larval mortality (%), total larvae (no.), and tillers (%) without larvae of four indica cultivars 3–4 d after egg hatching. Vertical lines indicate standard error.

vae tiller^{-1} with only 7% live larvae hill^{-1}. These results suggest that the larvae did not bore into or remain inside the sheaths of IR40 because it is a poor host.

Early larval mortality is a resistance mechanism that is complementary to the ability of rice plants to compensate for YSB injury at the vegetative stage (Rubia et al 1990, 1996). We found that the greater the number of tillers uninfected by YSB larvae, the faster the rice plants compensate for injury because there are enough assimilates to produce new tillers (unpubl. data).

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Effects of the ladybird beetle *Micraspis discolor* on yield components and grain yield of rice

N. Afsana and Z. Islam, Entomology Division, Bangladesh Rice Research Institute (BRRI), Gazipur 1701, Bangladesh
E-mail: islamz@bangla.net

Micraspis (= *Verania*) *discolor* Fab. (Coleoptera: Coccinellidae) preys on several rice pests (Samal and Misra 1985, Shepard and Rapusas 1989) and also feeds on rice pollen (Pathak and Khan 1994). *M. discolor* pollen feeding on rice panicles increases at flowering in all three rice seasons—boro (winter rice), aus (summer rice), and T. aman (monsoon rice)—in Bangladesh (Rahman et al 1991). A study was undertaken to determine the effects of pollen feeding by adult *M. discolor* at different population densities on yield components and grain yield of rice.

To test the effects of 0, 2, 5, 10, and 20 adult *M. discolor* rice hill^{-1} on yield components and grain yield, we conducted an experiment on the experimental farm of BRRI in Gazipur, Bangladesh, in the 1990 boro season. The experiment was using a completely randomized block design with 10 replications. A field where BRRI Dhan 29 was planted at a spacing of 20 × 20 cm was divided into fifty 2 × 2-m plots and a single hill was selected randomly in each plot. Adult *M. discolor* were confined on selected rice hills by white fine-mesh nylon net cages measuring 20 × 20 × 120 cm (length × breadth × height). Another set of 10 rice hills was marked but not covered by nylon mesh cages and kept free from *M. discolor* by hand-picking to determine whether shading at flowering and early grain filling affects grain filling and grain yield. Mesh cages and *M. discolor* beetles were removed 20 d after confinement, when panicles of all tillers either reached or passed the milky stage. We recorded the number of panicles hill^{-1}, the number of filled and unfilled grains panicle^{-1}, and grain weight (adjusted to 14% moisture content).

On average, there were 11.8–13.3 panicles hill^{-1} and panicle densities between treatments were similar (see table). An *M. discolor* density of 2–20 hill^{-1} did not affect filled grain number panicle^{-1}, average panicle weight, individual grain weight, grain sterility, and grain yield. Rice hills that were not covered by the mesh cage had a significantly lower sterility (P<0.01) and more filled

Effects of pollen feeding by *M. discolor* on yield components and grain yields of rice (var. BRRI Dhan 29), BRRI farm, Gazipur, Bangladesh, 1999.[a]

M. discolor density (no. hill^{-1})	Panicles (no. hill^{-1})	Filled grains (no. panicle^{-1})	Panicle weight (g)	Individual grain wt. (mg)	Sterility (%)	Yield (g hill^{-1})
0	12.3 a	72.8 b	1.5 b	20.48 a	46.6a	18.3 a
2	11.8 a	82.6 ab	1.7 ab	20.33 a	47.2 a	19.2 a
5	13.1 a	75.9 b	1.6 ab	20.85 a	51.1 a	19.8 a
10	13.3 a	75.6 b	1.6 ab	21.69 a	48.6 a	20.9 a
20	11.8 a	78.2 ab	1.7 ab	20.55 a	46.2 a	19.0 a
0 (not enclosed)	12.4 a	91.2 a	1.8 a	20.16 a	34.5 b	22.7 a
P<	ns	0.05	0.05	ns	0.01	ns
CV%	25.1	19.9	20.9	14.1	17.8	26.0

[a]Data are av of 10 replications. In a column, means followed by a common letter are not significantly different at the 5% level by Duncan's multiple range test. CV = coefficient of variation. ns = not significant.

grains panicle^{-1} ($P<0.05$) than plants covered by the mesh cage without *M. discolor* beetles. Grain yields, however, were similar, indicating that shading affects yield components. Our results showed that rice pollen feeding by *M. discolor* even at high population densities did not increase grain sterility or affect filled grain number, grain filling, and grain yield. Therefore, it can be concluded that, although *M. discolor* has a phytophagous habit, it is not a pest of rice.

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Effects of rice hispa damage on grain yield

S.S. Haque and Z. Islam, Entomology Division, Bangladesh Rice Research Institute (BRRI), Gazipur 1701, Bangladesh
E-mail: islamz@bangla.net

Rice hispa [*Dicladispa armigera* (Olivier) (Chrysomelidae: Coleoptera)] is a major rice pest in Bangladesh. Adults feed on the green tissue of the leaf blade externally and grubs are leaf miners. Rice hispa (RH) prefers young rice plants, but, in their absence, it also attacks maturing plants. Some reports estimate time- and space-specific damage ranging from 14% to 62% yield losses from RH (Alam 1977, Karim 1987, Islam 1989, Chatterjee and Bera 1990, Nath and Dutta 1997). However, the relationship between damage level and grain loss is not clear. Therefore, we carried out several experiments at BRRI under irrigated conditions in the 1999 aus (summer rice) and transplant aman (monsoon rice) seasons.

To simulate leaf damage in BR3 in the aus season and BRRI Dhan 32 in the T. aman season at different plant growth stages, adult RH beetles were confined at different densities—0, 0.2, 0.5, 1, 2, and 4 beetles tiller^{-1}. In total, seven experiments were conducted in a randomized complete block design with four replications. Rice plants were protected from other insect pests by applying granular insecticide (diazinon 5G) at recommended doses well before or after the treatment. In the aus season, experiments were conducted at 20, 40, and 60 d after transplanting (DAT) and at 20, 30, 50, and 70 DAT in the T. aman season. Unit plot size was 2 m × 2 m. Four rice hills (except border hills) were selected and marked in each plot. Tiller and leaf numbers were counted. Leaf damage was achieved by confining RH beetles on selected hills by a white nylon mesh cage. After 12–15 d of confinement, when the desired level of leaf damage was achieved, beetles and cages were removed. Leaf damage was estimated visually (0–100%). Grain yields were estimated by harvesting four marked hills plot^{-1}. Yields were adjusted to 14% moisture content.

In the aus season, different densities of RH caused about 9–89% leaf damage at 20 DAT, 5–69% at 40 DAT, and 3–36% at 60 DAT, suggesting increased resistance against RH feeding with plant age. Rice plants recovered from the damage by producing new leaves. The effect of RH density on grain yield was not significant (see table).

Effect of different densities of rice hispa beetles on grain yield of rice (BR3) in the summer rice season, BRRI farm, Gazipur, Bangladesh, 1999.[a]

Hispa density (no. tiller^{-1})	Grain yield (g 4 hills^{-1})			
	20 DAT	40 DAT	60 DAT	Mean
0	99.5	74.5	95.5	89.8
0.2	83.6	94.8	98.5	92.3
0.5	102.9	80.6	93.5	92.3
1	90.2	95.8	90.7	92.2
2	85.3	83.5	100.6	89.8
4	80.4	95.9	107.5	94.6
Mean	90.3	87.5	97.7	91.8
P	ns	ns	ns	ns

[a]DAT = days after transplanting. Rice hispa was allowed to incur damage for 12–15 d.

In the T. aman season, different densities of RH also caused a gradient of leaf damage: 5–75% at 20 DAT, 5–53% at 30 DAT, 5–65% at 50 DAT, and 14–55% at 70 DAT. Plants apparently recovered from leaf damage by producing new leaves. However, four beetles hill^{-1} significantly reduced grain yields regardless of the crop stage when the damage occurred. A significant negative correlation between leaf damage and grain yield was apparent (see figure). Plants suffered minor to moderate leaf damage of 0.2–2.0 RH tiller^{-1}, which did not result in significant yield losses (data not shown). Our results also suggest that photoperiod-sensitive rice grown in the monsoon season is more sensitive to yield loss from RH than photoperiod-insensitive rice grown in the summer.

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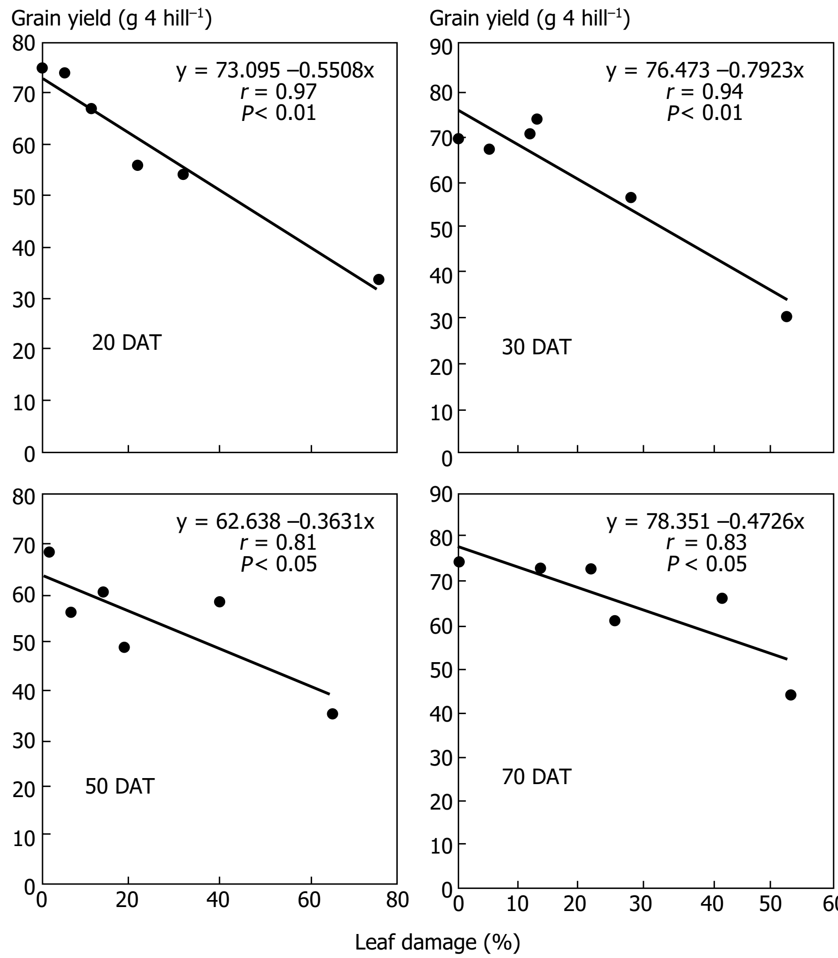

Relationship between leaf damage by hispa beetle and grain yield (var. BRRI Dhan 32) at 20, 30, 50, and 70 DAT in monsoon rice, BRRI, Gazipur, Bangladesh, 1999.

Diurnal distribution of the money spider *Atypena formosana* in the rice plant and its relation to tiller density

L. Sigsgaard and S. Villareal, IRRI, Los Baños, Philippines E-mail: les@kvl.dk

The diurnal vertical distribution of spiders is of interest to understand which prey types *Atypena formosana* (Araneae: Linyphiidae) may encounter over the course of 24 h. In this study, we visually assessed the diurnal distribution of *A. formosana* in rice plants and the effect of tiller number on spider number.

Field samplings were done at the IRRI experiment station on clear sunny days with little wind. Initially, we sampled (by using a sweep net) *A. formosana* at the panicle initiation stage of IR72 at 50 days after transplanting (DAT) on 23 Sep 1999. Temperatures ranged from 23.0 to 31.8 °C, with an average (±SD) of 28.5 ± 3.2 °C, and relative humidity (RH, ±SD) was 74 ± 13.8%. Sweep netting provides a fast and useful indirect measure of diurnal changes in the proportion of the spider population in the upper portion of the crop, but it is less efficient in sampling arthropods at the lower level. Ten sweep-net samples, each consisting of 10 sweeps, were taken four times over a 24-h period (0600 h, noon, 1800 h, and midnight). We sampled the field diagonally, avoiding sampling any location twice.

Atypena formosana goes through five immature instars, of which the first is completed in the egg sac. Second-instar spiderlings are around 0.8 mm long (Sigsgaard et al, in press; Sigsgaard et al, unpubl.), whereas adults are 1.5–3 mm long, with females being larger than males. A precise determination of a spiderling's instar is difficult, so spiderlings were recorded as small (2d–3d instar), medium (3d–4th instar), or large (4th–5th) instar, whereas adults were separated by sex.

In a second experiment, we counted the number of *A. formosana* in the lower, middle, and upper portions of 40 rice plants in each of two plots of IR72 at 30 DAT and one plot of IR72 at 60 DAT, both on 30 Mar 2000. Spiders were counted at 0600 h, noon, 1800 h, and midnight. To compare the observed with the near-actual number of spiders, 10 blower-vac samples were collected in plots. Each sample represented 0.0625 m^2, equivalent to one hill. Temperatures ranged from 24.0 to 31.0 °C, with an average of 28.1 ± 2.8 °C; RH was 80.5 ± 14.2%. Visual observations were limited to 2 min $plant^{-1}$ during daytime and 3 min $plant^{-1}$ at night, when head lamps had to be used. Rice at 30 DAT is approximately 30 cm tall, so we designated the first 0–10 cm as the lower portion, the next 10–20 cm as the middle portion, and the last 20–30-cm portion as the top. At 60 DAT, the lower portion was 0–20 cm, the middle was 20–40 cm, and the top was 40–60 cm above the ground. Since visual observations tend to underestimate smaller arthropods, we used the proportion of spiders observed in the middle and top canopies for our analysis.

Tiller number in a rice hill may affect the number of *A. formosana* spiders found, since more tillers may provide a better refuge as well as more prey. We tested this on 80 rice plants of IR72 at 35 DAT on 3 Apr 2000. Temperatures ranged from 24.6 to 31.0 °C, with an average of 27.3 ± 2.1 °C; RH was 82.7 ± 10.2%. Data were tested for normality and homogeneity of variance. When requirements for a parametric analysis were met, data were analyzed by ANOVA. For the analysis of visual observations of the vertical distribution of the spider, the proportions of a given class size (small, medium, large) and sex present in the medium and top portions of the canopy were used. Data were arcsine-transformed ($\sin^{-1}\sqrt{y}$) prior to analysis. Since data from the two 30-DAT plots were not significantly different, they were pooled.

The initial sweep netting showed a significant effect of both spider instar and time on number caught (both $P<0.0001$). Significantly, more spiderlings of all instars were caught at 1800 h than at any other time: 93% of small spiderlings (n = 258), 90% of medium spiderlings (n = 60), and 88% of large spiderlings (n = 16). The number of males and females peaked at midnight, when all males (n = 3) and 94% of females (n = 16) were caught. Densities of *A. formosana* at 30 and 60 DAT were not significantly different as determined by blower-vac sampling, except for *A. formosana* females (1.9 ± 0.3 females at 30 DAT and 4.0 ± 0.5 females at 60 DAT, $P<0.001$). At 30 DAT, spiders were observed on the top part of the canopy only at midnight. At 60 DAT, no spiders were observed on the top part (Fig. 1).

Time of day had a significant effect on the proportion of all *A. formosana* observed in the middle and top portions of the canopy at 30 and 60 DAT (both $P<0.001$). At 30 DAT, the highest proportion of all age classes in the middle and upper parts of the rice plant was observed at midnight. Time had a highly significant effect at 30 DAT on all sizes of spiderlings and for both sexes (all $P<0.0001$). Pairwise comparisons revealed that, in all cases, significantly more were observed in the middle and top portions of the canopy at midnight at 30 DAT than at the other three times. In addition, more small- and medium-sized spiderlings were observed at 1800 h than at 0600 h (t test, $P<0.05$). At 60 DAT, the only significant effect of time, when analyzed for age classes separately, was observed among medium- and large-sized spiderlings ($P<0.002$ and $P<0.004$, respectively). A higher proportion of these spiderlings was observed in the middle and upper portions of the canopy at 0600 h than at other times of the day (t test, $P<0.05$). However, actual numbers observed in this portion of the canopy were low.

A significant linear relation was found between tiller number per hill and spider density ($P<0.0001$) (Fig. 2). Visual counts showed that *A. formosana* had a higher probability of encounter-

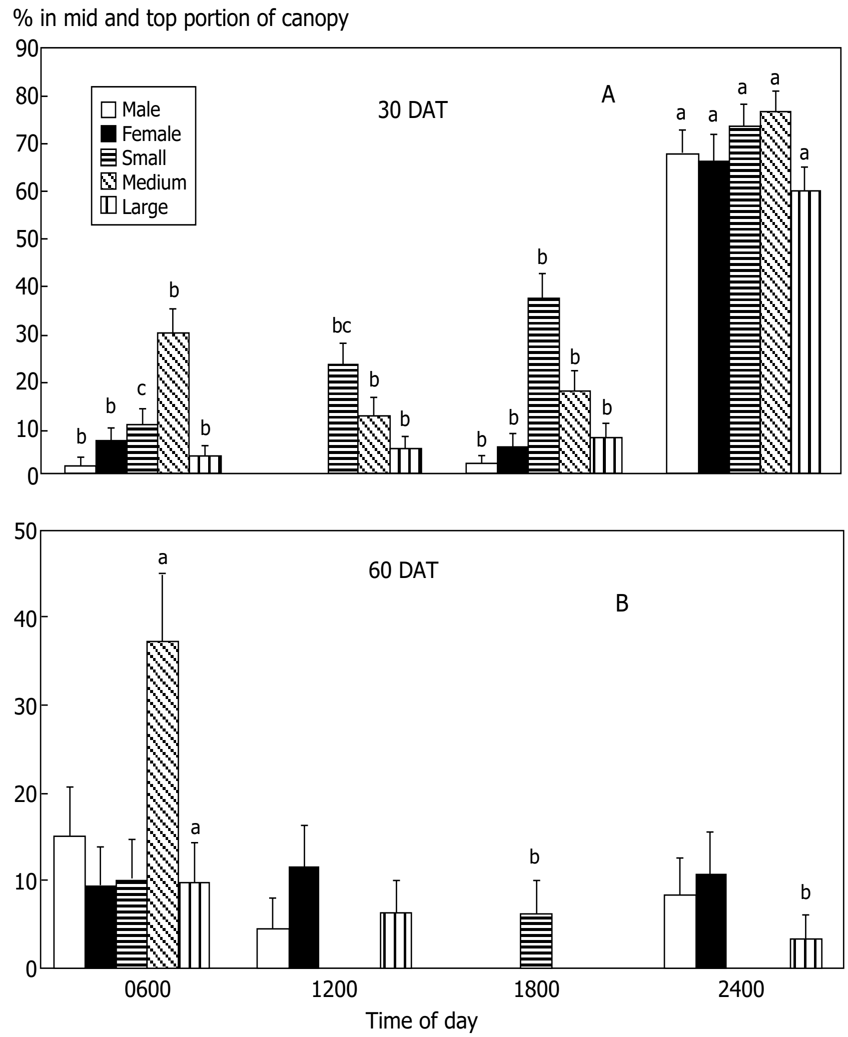

Fig. 1. The proportion of small, medium, and large spiderlings and male and female *A. formosana* in the middle and top portions of the rice canopy at (A) 30 d after transplanting (DAT) and (B) 60 DAT. Columns of an age class or sex with different letters are significantly different (t test, *P*<0.05).

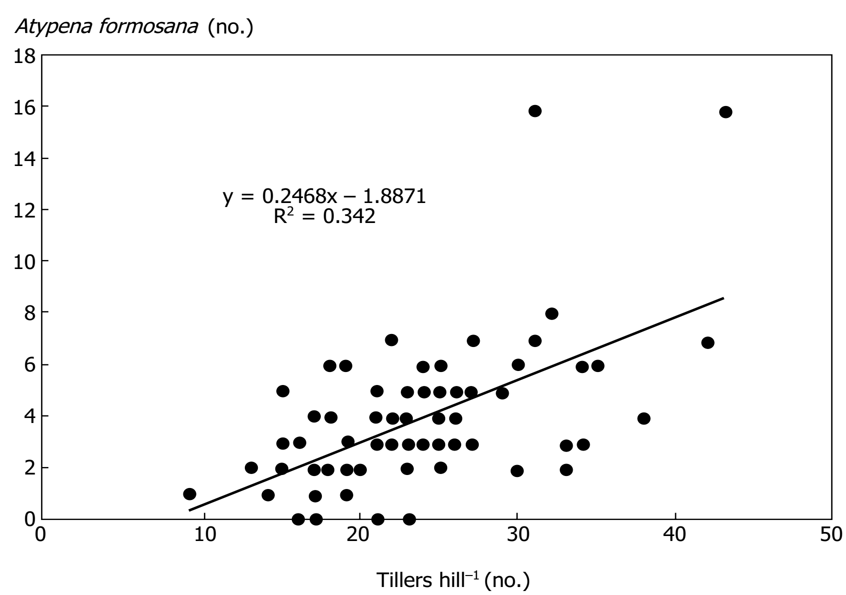

Fig. 2. Linear regression of the number of *A. formosana* over tiller number hill^{-1}.

ing green leafhopper (GLH) than was expected from daytime observations, confirming findings from sweep netting. At 30 DAT, the proportion of all instars in the middle and top parts of the canopy was highest at midnight. The movement up in the canopy at night was less distinct in older, 60-DAT rice, for which only a small proportion of spiders was observed in the middle and top portions of the canopy, > 20 cm above the ground. Both sweep-net sampling at 50 DAT and the counts for rice at 30 DAT found most adults in the upper portion of the rice canopy at midnight. Results for immatures using the two methods differed, with most immatures counted at midnight for 60 DAT and caught with a sweep net at 1800 h for 30 DAT. Differences in sampling method, crop age, or spider biology may account for this. Since the distribution of GLH follows the plant's growth upward, *A. formosana* will encounter fewer GLH in rice at 60 DAT than at 30 DAT. *A. formosana* has an increased probability of encountering BPH and GLH in larger rice hills.

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A randomization test and software to compare ecological communities

W.J. Zhang, Research Institute of Entomology and State Key Laboratory for Biological Control, Zhongshan University, Guangzhou 510275, People's Republic of China; K.G. Schoenly, Department of Biological Sciences, California State University, Stanislaus, CA 95382, USA E-mail: zhangwenjun@scientist.com

Some typical assumptions made in many statistical tests include (1) random sampling of individuals from the population of interest, (2) equal population standard deviations or means for two groups tested, and (3) normal distributions for index values within groups (Manly 1997). In community analyses, however, data usually have taxa as indices and samples or communities as groups to be tested, and complex relations exist among different taxa. These assumptions are generally not met. Randomization is an effective method for tests of a hypothesis with community data and has been used in rice community studies (Zhang and Schoenly 1999a).

Suppose that there are s taxa in both community i and community j. Let x_{ki} be the number of individuals from taxon k in community i, $k = 1, 2, \ldots, s$; $i = 1, 2, \ldots, n$. For communities i and j, $i = 1, 2, \ldots, n-1$; $j>i$, calculate the Euclidean distance (de_{ij}), Manhattan distance (dm_{ij}), and difference coefficient (dc_{ij}) as follows:

$$de_{ij} = \sqrt{(\Sigma(x_{ki} - x_{kj})^2/s)}$$
$$dm_{ij} = \Sigma \left| x_{ki} - x_{kj} \right| / s$$
$$dc_{ij} = 1\text{-}\Sigma\,(x_{ki} x_{kj}) / \sqrt{(\Sigma x_{ki}^2 \;\; \Sigma\, x_{kj}^2)}$$
$$i = 1, 2, \ldots, n-1;\; j>i$$

where summation is over the taxa, $k = 1, 2, \ldots, s$. The weighted standard Euclidean distance, weighted standard Manhattan distance, and weighted standard difference coefficient can be calculated as

$$dwe_{ij} = \sqrt{(\Sigma\, w_k\, (xx_{ki} - xx_{kj})^2/s)}$$
$$dwm_{ij} = \Sigma w_k \left| xx_{ki} - xx_{kj} \right| / s$$
$$dwc_{ij} = 1\text{-}\Sigma\,(w_k\, xx_{ki} xx_{kj}) \sqrt{(\Sigma w_k\, xx_{ki}^2 \;\; \Sigma w_k\, xx_{kj}^2)}$$
$$i = 1, 2, \ldots, n-1;\; j>i$$

where w_k is the weighting value for the kth taxon, $\Sigma w_k = 1$, and $xx_{ki} = (x_{ki} - \min x_{li})/(\max x_{li} - \min x_{li})$ $k = 1, 2, \ldots, s$ where $\min x_{1i} = \min(x_{1i}, x_{2i}, \ldots, x_{si})$ and $\max x_{1i} = \max(x_{1i}, x_{2i}, \ldots, x_{si})$.

The randomization test employed is based on the idea that, if no difference exists, then the distribution of individuals in communities i and j will be a result of allocating the mixed community values at random into two groups of a size equal to that of the original communities. The test involves comparing the observed difference between communities i and j with the distribution of differences found with random allocation (Manly 1997, Zhang and Schoenly 1999b). The threshold *P* value in the test can be defined as 0.01, etc. If the calculated *P* value is less than the threshold value, then communities i and j can be considered as being significantly different.

Of these distances, dc_{ij} and dwc_{ij} describe the dissimilarities of distribution of individuals with taxa between communities, while the other distances describe the overall difference for both taxa richness and abundance. If the functional importance for each taxon is considered to be different, a weighting value can be given to each taxon and the weighted distance should be chosen. The latter situation is recommended for use in analyzing functional diversity.

Two versions of the software were written for the algorithm. A Windows™-based version can be run on Windows 95 and MS-DOS platform or later with a desktop resolution of 800*600 pixels or finer. An Internet-based version can be run on the HotJava™ browser with an HTML file (105 b) as the introducing program. The data file required by each of the two versions, as described by Zhang and Schoenly (1999b), is a space-delimited .txt file in which the first row consists of a numerical label for each community and subsequent rows contain the taxon ID number (if the weighted distance was chosen, then they contain the weighting value for that taxon), followed by the sampled number of individuals for that taxon in each community.

These algorithm and software were tested against observed data for rice communities (L.P. Lan, pers. commun. 1997); they performed well.

Acknowledgment

This study was supported by the Foundation of Scientific Research for Personnel from Abroad (2000), Ministry of Education of China, and the "973" project (G2000046803) of China.

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Newspaper: a new attractant for golden apple snail management

R.C. Joshi and M.S. de la Cruz, Crop Protection Division, Department of Agriculture-Philippine Rice Research Institute (DA-PhilRice), Maligaya, Muñoz, Nueva Ecija 3119, Philippines E-mail: joshiravi@hotmail.com

Rice farmers in the Philippines widely use synthetic commercial molluscicides against golden apple snail (GAS) *Pomacea canaliculata*, with little, if any, consideration of hazards to nontarget organisms and the environment. Other management options are seldom employed on a community basis for various reasons. Farmers report that manual handpicking of GAS shells is backbreaking and herding of ducks after harvest and before planting produces an itch among farm workers. We studied several attractant materials, including newspaper, as potential tools to minimize human health hazards and inconvenience in managing GAS. Newspapers, not known to farmers as a GAS attractant, are easily biodegradable, readily available, and recyclable. In addition, they do not threaten plant biodiversity loss. We hope that this tool will further reduce the misuse of synthetic commercial molluscicides.

To determine the efficiency of materials that attract GAS, a series of tests was performed from September 2000 to February 2001.

Test 1. Leaves of three plant species familiar to lowland farmers [banana (*Musa* sp.), taro (*Colocasia esculenta*), and papaya (*Carica papaya*)] and newspapers were tested as GAS attractants. Each of the four materials was sized 6 cm^2 for uniform coverage of field water and soil surface. Each treatment was replicated seven times in a randomized complete block design. GAS were introduced at 0700 h in the screenhouse at a density of 10 m^{-2} microplot under no-choice conditions. The number of GAS attracted was recorded from 10 to 60 min, and finally at the end of 24 h.

Test 2. Materials for GAS attraction were the same as those used in trial 1, but were tested under free-choice conditions in a 2×5-m plot. Treatments were replicated four times and placed randomly in the middle of large plots. Ten GAS were released in each of the four corners of the plot. The test began at 0630 h. The number of GAS attached to the test material at 30 min, 5 h, 10 h, 24 h, and 32 h was recorded. At the end of 32 h, the percent surface area of material consumed was also recorded.

Test 3. The same attractants were again used for trial 3, but the only difference was that fields were treated with 40–40–40 kg NPK ha^{-1} before transplanting. The trial was replicated five times under free-choice conditions. Materials were placed at 1600 h and, at 0800 h the following morning, the number of GAS within a 1-m^2 circumference and those feeding on attractants was counted.

Test 4. The test was conducted at the Banaue rice terraces in Mountain Province, Philippines, where GAS is a new problem. Since papaya leaves are hard to find, trumpet flower leaves were used instead. Our past surveys indicated that the local people have been using trumpet flower leaves to attract GAS. Other attractants used were similar to those used in earlier trials. The attractants were placed at 0630 h in newly prepared fields.

Table 1. Number of GAS attracted over time to various materials in the same screenhouse under the free-choice test, DA-PhilRice, Nueva Ecija, September 2000.[a]

Attractant material	Minutes					Hours	
	10	20	30	40	50	1	24
Newspaper	0.0 c (0)	0.3 b (3)	1.9 b (19)	2.4 b (24)	2.3 b (23)	2.0 c (20)	2.3 c (23)
Banana	0.0 c (0)	0.6 b (6)	0.9 c (9)	1.0 c (10)	1.0 c (10)	0.2 d (2)	0.6 d (6)
Taro	3.0 a (30)	3.0 a (30)	3.1 a (31)	3.3 a (33)	4.4 a (44)	4.2 a (42)	4.1 a (41)
Papaya	2.1 b (21)	2.9 a (29)	3.1 a (31)	3.3 a (33)	4.1 a (41)	3.3 b (33)	3.0 b (30)

[a]Values in the same column followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test. Numbers in parentheses are % of GAS attracted.

Table 2. Number of GAS attracted and material consumed (%) in the free-choice test, screenhouse, DA-PhilRice, Nueva Ecija, November 2000.[a]

Attractant material	GAS feeding on attractant (no.)					Attractant consumed (% surface area)
	30 min	5 h	10 h	24 h	32 h	
Newspaper	1.7 a	1.2 ab	3.0 ab	2.7 b	2.0 b	25
Banana	0.7 a	0.0 b	1.0 c	1.0 c	0.0 c	50
Taro	2.0 a	1.2 ab	2.2 b	2.7 b	2.2 b	100
Papaya	2.2 a	1.5 a	3.7 a	4.0 a	3.0 a	100

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

Table 3. Number of GAS attracted to trumpet flower leaves compared with other materials under the free-choice test, Banaue rice terraces, February 2001.[a]

Attractant material	GAS attracted (no.)	
	8 h	24 h
Newspaper	3.2 b	9.1 ab
Banana	5.7 a	8.6 ab
Taro	4.8 ab	11.4 a
Trumpet flower	3.7 ab	5.6 b

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

Observations on number of GAS attached to various attractants were made 8 h and 24 h after the attractants were first placed.

In test 1, GAS was most attracted to leaves of taro, followed by papaya leaves 10 min after release (Table 1). It took a shorter time to attract GAS on taro and papaya leaves than with other test materials. After 1 h, taro leaves again had the highest GAS attraction (42%), followed by papaya leaves (33%), newspaper sheets (20%), and banana leaves (2%) (Table 1).

In the free-choice test (test 2), taro and papaya leaves attracted more GAS than banana and newspaper as shown by the number of GAS feeding on these materials at 32 h (Table 2). Taro and papaya leaves were completely consumed except for the midribs. Only 25% of the newspaper was consumed at the end of 32 h.

In test 3, GAS numbers did not differ among attractants, although the highest GAS numbers were found on papaya leaves as well as on a 1-m^2 circumference surrounding the attractant (data not shown).

In test 4, taro leaves had the highest number of GAS, while trumpet flower leaves had the lowest number—but statistically, this did not differ from banana leaves and newspaper. At the end of the second sampling (24 h), taro leaves were singled out as the most important indigenous material to attract GAS (Table 3).

All test materials attracted GAS but differed in the degree of attraction (Tables 1–3). We observed that no-choice conditions forced GAS to consume any test material, although they took longer to consume the less preferred attractants. In areas where leaves of attractants are scarce, newspaper can be used to attract GAS in rice fields prior to crop establishment (direct seeding/transplanting). However, in fields where rice crops have already been established, taro and papaya leaves are the best GAS attractants.

NOTE

The following table was left out in the June 2001 issue of IRRN 26(1):28–29. It is part of the note titled "Testing a yield loss simulation model for rice in Chinese rice-wheat system production environments" by D. Zhu, China National Rice Research Institute (CNRRI), Hangzhou 310006, Zhejiang, China; L. Willocquet, CBGP, Campus International de Baillarguet, CS 30 016, 34988 Montferrier/Lez cedex, France; Q. Tang, S. Huang, X. Lin, CNRRI; L. Fernandez, F.A. Elazegui, IRRI, Philippines; and S. Savary, CBGP.

Simulated and observed grain yield (g m^{-2}) in the experiment done at CNRRI in 1998.

Treatment[a]	PS2[b]		PS6[b]		PS7[b]	
	Observed	Simulated	Observed	Simulated	Observed	Simulated
CTRL	422	418	579	568	787	787
WH	420	408	-	-	-	-
SHB	393	402	519	517	689	711
WEED	319	331	523	550	669	686
COMBI	361	343	509	493	611	670

[a]CTRL = control, WH = white heads, SHB = sheath blight, WEED = weeds, COMBI = combination of the three injuries. [b]PS2 = reference production situation, PS6 and PS7 = production situations that prevail in Zhejiang Province.

Nutrient application reduces iron toxicity in lowland rice in West Africa

K.L. Sahrawat, S. Diatta, and B.N. Singh, West Africa Rice Development Association (WARDA), 01 BP 2551 Bouaké 01, Côte d'Ivoire E-mail: k.sahrawat@cgiar.org

Iron toxicity is a widespread nutrient disorder that affects rice growing in inland swamps and on irrigated lowland soils throughout the humid forest and savanna zones of West Africa. It has been reported to reduce lowland rice yields in West Africa by 12–100%, depending on the intensity of the toxicity and the tolerance of the rice cultivar (Sahrawat et al 1996).

The disorder occurs when large amounts of iron are mobilized *in situ* or when an inflow of iron occurs from adjacent upper slopes, especially in the inland valley systems of West and Central Africa. In mineral soils, the occurrence of iron toxicity is associated with a range of concentration of ferrous ions in the soil solution. Light-textured soils high in extractable acidity are especially prone to iron toxicity (Moormann and van Breemen 1978). It is also known that a high concentration of iron in solution decreases the absorption of other nutrients, especially phosphorus (P), potassium (K), and zinc (Zn) (Yoshida 1981).

To test the role of other nutrients in reducing iron toxicity, field experiments were conducted during the 1995-98 wet seasons (July to November) under irrigated conditions at an iron-toxic site at Korhogo, Côte d'Ivoire. The site is in the savanna zone and is at the bottom of a gently sloping toposequence. The soil is an Ultisol with pH in water, 5.7; pH in KCl, 4.0; organic C, 10.2 g kg^{-1}; Bray 1 extractable P, 7 mg kg^{-1}; exchangeable K, 65 mg kg^{-1}; exchangeable Ca, 320 mg kg^{-1}; exchangeable Mg, 75 mg kg^{-1}; DTPA-extractable Fe, 170 mg kg^{-1}; and DTPA-extractable Zn, 5 mg kg^{-1}. From 3 to 10 wk after flooding, the concentration of Fe^{2} in the soil solution is 50–150 mg L^{-1} (Narteh and Sahrawat 1999). This is much greater than in the groundwater along the toposequence, indicating that the Fe^{2} is formed *in situ* rather than brought in by interflow.

The effects of nine nutrient treatments (no fertilizer, N, N + P, N + K, N + Zn, N + P + Zn, N + K + Zn, N + P + K, and N + P + K +Zn) were tested in a randomized complete block design with four replications. The plot size was 24 m^2. Nitrogen was applied at 100 kg ha^{-1} as urea in three splits, P was applied at 50 kg ha^{-1} as triple superphosphate, K at 80 kg ha^{-1} as KCl, and Zn at 10 kg ha^{-1} as ZnO. All nutrients except N were applied basally. Rice seedlings (3–4 wk old) were transplanted using a spacing of 0.25 m × 0.25 m. Three lowland rice cultivars were tested: CK4, an iron-tolerant cultivar, and Bouake 189 and TOX3069-66-2-1-6, both iron-susceptible cultivars. Plants were visually scored for iron toxicity symptoms using a scale of 1–9 based on the IRRI *Standard evaluation system for rice*. A score of 1 indicates normal growth and 9 indicates that almost all plants are dead or dying. All data underwent analysis of variance and results presented are means of 4 years (1995-98).

Results showed that, without the application of nutrients, iron-tolerant CK4 outyielded susceptible cultivars Bouake 189 and TOX3069-66-2-1-6. With the application of N + P + K + Zn, yields of all three cultivars increased significantly, ranging from 4.7 to 5.7 t ha^{-1} (see table). The increase in yield of iron-susceptible Bouake 189 and TOX3069-66-2-1-6 was more than that of iron-tolerant CK4.

Iron toxicity scores based on normal symptoms were generally lower in treatments where plant nutrients were added than in treatments without fertilizer. Applying a combination of N + P + K + Zn resulted in the lowest iron toxicity score in all three cultivars, indicating that the application of other plant nutrients reduced iron toxicity and increased grain yields (see table). Results showed that grain yield on iron-toxic soils can be improved by applying nutrients.

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Effects of field application of nutrients on grain yield of iron-tolerant CK4 and susceptible Bouake 189 and TOX3069-66-2-1-6 lowland rice cultivars grown in an iron-toxic soil, Korhogo, Côte d'Ivoire.

Treatment	Grain yield (t ha^{-1})		
	CK4	Bouake 189	TOX3069-66-2-1-6
No fertilizer	4.3 (3)	3.4 (5)	2.9 (7)
N	4.4 (3)	4.1 (5)	3.3 (7)
N + P	5.3 (2)	4.3 (4)	4.2 (5)
N + K	4.8 (2)	4.4 (4)	3.8 (5)
N + Zn	4.8 (2)	4.6 (4)	4.6 (5)
N + P + Zn	5.0 (2)	4.4 (4)	4.2 (4)
N + K + Zn	5.2 (2)	4.6 (3)	4.6 (4)
N + P + K	5.4 (2)	4.5 (3)	4.5 (3)
N + P + K + ZN	5.7 (2)	4.7 (3)	4.7 (3)
LSD (0.05)	1.01	1.02	1.15

[a]Iron toxicity scores are given in parentheses. Results are av of 4 years (1995-98).

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Relationship between applied potassium and iron toxicity in rice

S.K. Sahu, Department of Soil Science and Agricultural Chemistry and B. Sandha, Department of Plant Breeding and Genetics, Orissa University of Agriculture and Technology (OUAT), Bhubaneswar 751003, Orissa; G. Dev, Potash and Phosphate Institute, Canada-India Programme, Gurgaon, Haryana, India

Highly weathered soils that are acidic, low in bases, deficient in P and K, and rich in sesquioxides occur on 11.7 million ha in India (Prasad and Biswas 2000) and 0.75 million ha in Orissa (Sahu 1993). Rice grown in low- to medium-elevation lands with this type of soil and adjacent to leached uplands often suffers from Fe toxicity associated with interflow of water from the uplands. The mechanism by which interflow exacerbates the toxicity is uncertain, but it appears to involve dilution of plant nutrients and upsetting of the plant's ability to exclude toxic Fe, rather than the inflow of large amounts of dissolved Fe (van Breemen and Moormann 1978). Related to this, the application of liberal doses of K has been found to reduce Fe toxicity in rice and increase yields.

To investigate the relationship between K application and Fe toxicity under these conditions and interactions with climate and genotypes, field experiments were conducted for three wet seasons (WS, 1991-93) and two dry seasons (DS, 1993-94) on an iron-toxic soil at the Central Research Station of OUAT in Bhubaneswar. The soil is an Aeric Haplaquept derived from highly weathered material, with pH 4.9, CEC 4.4 $cmol_c$ kg^{-1}, 0.36% organic C, 10 ppm Olsen's P, 51 ppm NH_4OAc K, and 398 ppm DTPA-extractable Fe. Treatments included five K levels (0, 33, 66, 99, and 132 kg K ha^{-1}) and four rice varieties—Mahsuri in the WS and Parijat in the DS (tolerant of Fe toxicity) and Jaya in the WS and Pathara in the DS (susceptible to Fe toxicity).

The experimental design was a split plot with rice varieties in the main plot and K levels in the subplots, replicated three times. All treatments received 80 kg N and 18 kg P ha^{-1} as urea and single superphosphate, respectively. Nitrogen was applied in three splits (25% at transplanting, 50% at mid-tillering, and 25% at panicle initiation). All the P and 50% of the K were applied at transplanting with the rest of the K at 25 d after transplanting (DAT). The K used was muriate of potash.

Symptoms of Fe toxicity appeared in the control and lowest K plots at 25 and 30 DAT in susceptible varieties in the WS and DS, respectively. Symptoms were reddish brown spots on the tips of lower leaves with bronzing, later spreading over the entire leaf. The intensity of bronzing decreased with K application. Bronzing symptoms were scored at 40 DAT according to the IRRI *Standard evaluation system for rice* (IRRI 1980). Data (Table 1) showed that, among the four rice varieties tested, Jaya and Pathara were more susceptible to Fe toxicity than Mahsuri and Parijat. Toxicity scores were higher during the WS than during the DS and in the year with higher rainfall and more rainy days. Presumably, this was due to the greater upwelling of water during the wetter season. The toxicity score decreased with K addition.

Grain and straw yields (Table 2) under different treatments varied in different years with differences in climate and intensity of Fe toxicity. Both grain and straw yields increased with the addition of K in all varieties. The effect of K on yield was greatest in the years that produced the greatest Fe toxicity. The application of 132 kg K ha^{-1} increased average grain yield by 136% in Jaya, 71% in Pathara, 59% in Mahsuri, and 42% in Parijat. The response to K application was greater in WS varieties than in DS varieties. The effect of K application on straw yields was similar to that on grain yields.

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Table 1. Effect of K application on Fe toxicity of susceptible and tolerant rice varieties during wet and dry seasons (1 = least severe, 9 = most severe).

K level (kg ha^{-1})	Wet season						Dry season			
	Jaya			Mahsuri			Pathara		Parijat	
	1991	1992	1993	1991	1992	1993	1992–93	1993–94	1992–93	1993–94
0	7	9	9	2	3	3	7	7	3	3
33	7	7	7	1	3	3	5	7	3	3
66	5	5	5	1	2	2	5	5	2	3
99	5	5	5	1	1	1	3	3	1	2
132	3	3	3	1	1	1	3	2	1	1

Table 2. Effect of K application on yield of susceptible and tolerant varieties grown in Fe-toxic lateritic soil, Orissa, India, 1991-93 wet seasons and 1993-94 dry seasons.

K level (kg ha^{-1})	Wet season								Dry season					
	Jaya				Mahsuri				Pathara			Parijat		
	1991	1992	1993	Mean	1991	1992	1993	Mean	1992-93	1993-94	Mean	1992-93	1993-94	Mean
Grain yield (t ha^{-1})														
0	1.3	1.1	0.7	1.3	2.1	1.8	1.6	1.8	2.1	1.7	1.9	2.7	2.4	2.4
33	1.5	1.2	1.3	1.4	2.6	2.1	1.8	2.2	2.3	2.1	2.2	3.1	2.9	3.0
66	2.1	1.7	2.1	1.9	2.2	2.2	2.4	2.3	3.0	2.5	2.7	3.2	3.2	3.2
99	2.2	2.0	2.4	2.2	2.8	2.4	2.7	2.6	3.0	2.9	3.0	3.4	3.3	3.4
132	2.6	2.2	2.5	2.4	3.2	2.6	2.8	2.9	3.2	3.3	3.2	3.7	3.6	3.6
Mean	1.9	1.6	1.8	–	2.6	2.2	2.3	–	2.7	2.5	–	3.2	3.1	–
CD (0.05)[a]														
K	0.38	0.13	0.25						0.30	0.18				
V	0.49	0.16	0.15						0.13	0.10				
K x V	ns	ns	0.15						ns	ns				
Straw yield (t ha^{-1})														
0	1.6	1.3	0.8	1.2	3.0	2.2	1.7	2.5	2.3	1.9	2.1	3.0	2.3	2.7
33	2.0	1.6	1.4	1.7	3.6	2.8	1.9	2.8	2.7	2.3	2.5	3.4	3.0	3.2
66	2.6	2.1	2.2	2.3	3.9	3.5	2.7	3.3	3.2	2.9	3.1	3.6	3.3	3.4
99	3.3	2.8	2.5	2.9	4.2	3.6	2.8	3.6	3.4	3.3	3.4	3.7	3.6	3.6
132	3.5	3.1	2.9	3.2	4.5	3.7	3.0	3.7	3.7	3.6	3.7	3.9	3.9	3.9
Mean	2.6	2.2	1.9		3.8	3.3	2.3		3.1	2.8		3.5	3.2	
CD (0.05)[a]														
K	0.52	0.33	0.30						0.24	0.26				
V	0.29	0.30	0.07						0.11	0.18				
K x V	0.29	ns	0.07						ns	ns				

[a]CD values refer to a season with two varieties, five treatments, and three replications in a split-plot design.

Blast incidence in relation to nitrogen management through the leaf color chart

Y.R. Hegde, V.V. Angadi, and Ganajaxi, Agricultural Research Station (ARS), Mugad, Dharwad 580007, Karnataka, India

Blast caused by *Magnaporthe grisea* (Hebert) Barr is an important disease in rice. Nitrogen plays a crucial role in the development of blast. Many experiments have shown that a high N supply induces heavy blast incidence, regardless of the phosphorus or potassium supply (Ou 1985). However, the severity of the disease varies with the method of N fertilizer application (Ou 1985). Hence, an experiment was conducted to evaluate the effect of N management through the leaf color chart (LCC) on blast incidence and rice productivity.

Field trials were conducted under rainfed conditions at ARS during the 1998 and 1999 wet seasons. Sowing was done on 10 June 1998 and harvest on 30 Oct 1998. P and K were applied at 22 and 41.5 kg ha^{-1} as single superphosphate and muriate of potash. An entire dose was applied during sowing. The experiment was laid out in a split-plot design with 12 treatments and 4 replications. The two varieties—Abhilash (moderately blast-resistant) and Intan (blast-susceptible)—were the main-plot treatments. Subplot treatments consisted of N management based on critical LCC readings of 2.0, 2.75, 3.5, 4.25, and 5.0 in addition to the recommended practice of applying N in three equal splits at 20 and 40 d after emergence (DAE) and just before panicle initiation. In treatments with N management based on the LCC, the quantity of N applied each time during early growth (21–28 DAE), rapid growth (35–49 DAE), and late growth (56 DAE to flowering) stages was 20, 30, and 20 kg ha^{-1}, respectively. Table 1 shows the total quantity of N applied in each treatment.

A 0–9 scale was used for scoring leaf blast, with a total of 15 leaves scored for each treatment from five plants. Percent disease index (PDI) was calculated using the following formula:

$$\text{PDI} = \frac{\text{Sum of individual ratings}}{\text{No. of leaves assessed} \times \text{maximum disease grade}} \times 100$$

Percent neck blast was calculated by counting the number of panicles with typical blast symptoms in one square area.

$$\text{Percent neck blast} = \frac{\text{No. of infected panicles}}{\text{Total panicles no.}} \times 100$$

Results indicated that leaf blast incidence was significantly higher in Intan than in Abhilash at all N levels. In moderately resistant Abhilash, leaf blast incidence with the recommended practice was on a par with a critical LCC value of 3.5 during 1998. During 1999, Abhilash was free from leaf blast incidence at all N levels. In susceptible Intan, leaf blast incidence at a critical LCC value of 3.5 (with 170 kg total N ha^{-1}) was significantly less than with the recommended practice (100 kg N ha^{-1}) in 1998 but statistically the same in 1999 (Table 2).

Neck blast incidence was also significantly more in Intan than in Abhilash. Different N application levels did not have any significant effect on neck blast incidence in Abhilash in 1999. In Intan, neck blast incidence under the recommended N practice was on a par with the critical LCC values of 3.5 and 4.25 (Table 2). In terms of grain yield, Abhilash responded to N management based on the LCC up to the critical value of 4.25. However, Intan responded only up to the critical value of 3.5, with a total N appli-

Table 1. Total quantity of N applied (kg ha^{-1}) in different treatments.

Variety	Leaf color chart value					Recommended practice
	2.0	2.75	3.5	4.25	5.0	
1998						
Abhilash	0	40	110	230	270	100
Intan	0	0	170	250	270	100
1999						
Abhilash	0	30	70	150	210	100
Intan	0	40	70	140	210	100

cation of 170 kg ha^{-1}. Grain yields in these treatments were significantly higher than those under recommended N management (Table 3).

Results indicated that N application based on an LCC value of 3.5 helped to manage blast more effectively in a susceptible variety (Intan) compared with the recommended practice of N application. Rice productivity can be increased by higher N application based on the LCC reading. The critical LCC value for N management varied between the two varieties.

Table 2. Percent blast disease index (PDI) and percent neck blast incidence (%).[a]

Variety	Leaf color chart value (%)[b]					Recommended practice	Mean
	2.0	2.75	3.5	4.25	5.0		
Leaf blast incidence							
1998							
Abhilash	12.7 b x	15.2 b wx	17.4 b w	21.4 b v	23.3 b v	17.1 b w	17.9 b
Intan	30.6 a w	31.9 a w	34.0 a w	39.7 a v	42.1 a v	39.3 a v	36.3 a
Mean	21.6 y	23.6 wx	25.7 x	30.5 v w	32.7 v	28.2 y	
1999							
Intan	17.5 y	20.8 xy	21.4 wx	24.4 w	30.1 v	23.3 wx	
Abhilash	0	0	0	0	0	0	0
Neck blast incidence							
1998							
Abhilash	16.1 b y	21.7 b x	27.4 b w	29.2 b w	34.8 b v	28.0 b w	26.2 b
Intan	22.5 a y	29.2 a x	34.0 a w	36.3 a w	40.7 a v	36.4 a w	32.2 a
Mean	19.3 y	25.5 x	30.8 w	32.8 w	37.7 v	32.2 w	
1999							
Abhilash	18.0 a v	20.5 a v	21.2 b v	21.4 b v	21.5 b v	20.6 b v	20.6 b
Intan	18.0 a z	21.6 a yz	25.0 a xy	32.2 a vw	37.0 a v	27.4 a xy	27.0 a
Mean	18.0 y	21.1 xy	23.2 x	26.8 vw	29.3 v	24.8 wx	

[a]Duncan's multiple range test (DMRT at 5%) was used to compare treatment means. [b]Rows/columns followed by the same letters do not differ significantly; comparison of means in a row is indicated by a to e and comparison of means in a column by v to z.

Table 3. Grain yield (t ha^{-1}), 1998.[a]

Variety	Leaf color chart treatment[b]					Recommended practice	Mean
	2.0	2.75	3.5	4.25	5.0		
	c	c	b	a	a	bc	
Abhilash	3.3 a x	3.1 a x	4.3 a w	5.2 a v	5.5 a v	4.0 a wx	4.2 a
	b	b	a	b	b	b	
Intan	2.9 a w	2.9 a w	4.4 a v	2.5 b w	2.2 b w	2.8 a w	3.0 a
	b	b	a	ab	ab	b	
Mean	3.1 w	3.0 w	4.4 v	3.9 vw	3.8 vw	3.4 w	

[a]Duncan's multiple range test (DMRT) at 5% was used to compare treatment means. [b]Rows/columns followed by the same letters do not differ significantly.

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Water and weed management studies in direct-seeded upland rice

K. Pathak, Krishi Vigyan Kendra, Assam Agricultural University (AAU), Arunachal 788025, Cachar; and A.K. Choudhury, Department of Agronomy, AAU, Jorhat, Assam, India

Direct-seeded upland rice is an important system of rice culture occupying almost 22% of the total rice area in India. In Assam, this crop is locally known as *ahu* rice (Mar/Apr–Jun/July). Assam farmers prefer this crop because this period is characterized by low rainfall, clear skies, and low frequency of floods. However, some constraints limit the widespread cultivation of ahu rice: uncertain rainfall; high evaporative demand, causing moisture stress; and weed infestation. Although the application of irrigation can solve the problem of moisture stress, scheduling of irrigation in upland situations where seed is sown in dry unpuddled soil is very difficult. Hence, upland rice should have drought tolerance to withstand possible moisture stress in between irrigation schedules. Seed hardening with potassium salt before sowing helps induce drought tolerance in crops (Chinoy et al 1970).

This study was carried out to assess the performance of upland rice under seed treatment and water and weed management practices. The experiment was conducted at AAU during the 1991 summer (Mar-Jul) in a randomized block design with three replications (net plot size, 4.5 × 3.0 m) using rice cv IR50, which is recommended for the ahu season. Three factors were studied: (1) seed treatment (normal practice: without seed soaking and application of recommended 16.6 kg K ha^{-1}; modified practice: seed soaking in 40% KCl solution, application of 49.8 kg K ha^{-1}; and 50 ppm paraquat spraying at tillering stage); (2) water management practices (rainfed, intermittent irrigation at 3 d and 6 d); and (3) weed control measures (weedy check and application of butachlor at 2 kg ai ha^{-1}): plots were surrounded by dikes and irrigation was applied by flash flooding the plots and bringing the soil water content to field capacity. The weedy check plot had no weed control, except for one manual weeding 15 d after sowing. The soil type was sandy loam with pH 4.29, 0.72% organic carbon, and 274 kg available N ha^{-1}, 3 kg P ha^{-1}, and 77 kg K ha^{-1}. Seeds were sown on 15 March and harvested on 15 July 1991. Before sowing, 10 t farmyard manure ha^{-1}, 40 kg N ha^{-1}, and 20 kg P ha^{-1} were uniformly applied. The differential levels of K were applied in two equal splits—at tillering and at panicle initiation. Seed soaking was combined with a higher K dose to induce drought tolerance where K could help a lot. The rainfall received during the crop growth period was 975 mm.

Water productivity was calculated as grain yield divided by consumptive use. Consumptive use was worked out based on moisture depletion from the root zone, rainfall received during crop growth, and irrigation water applied. Soil water content was measured by the volumetric method. Irrigation water was applied on a per-volume basis, providing a 5-cm depth each time. The required volume was divided by the discharge rate to find the time needed for irrigating the plot. Root volume per plant was measured by the volume displacement method (Mishra and Ahmed 1987). Weed dry matter was measured from a 0.5-m^2 sample area, with three samples per plot.

Results of the experiment showed that the modified seed treatment significantly increased the number of effective tillers and root volume compared with the normal practice, although there was no significant difference in yield (Table 1).

The 3-d intermittent irrigation resulted in a significant increase in root volume over the rainfed treatment. Water productivity was higher under the rainfed condition, followed by intermittent irrigation at 6 d. This may be due to the equal distribution of rainfall during the crop season.

In the weed control treatment, butachlor significantly increased the number of effective tillers, number of grain panicles, and grain yield over the weedy check (Table 1). Applying butachlor increased yield by 23% over the weedy check. Mishra et al (1988) and Singh and Bhattacharjee (1989) reported similar beneficial effects of butachlor in upland rice. Water productivity in the butachlor plots was greater than in the weedy check because of higher yield. The application of butachlor significantly reduced the dry matter weight of grassy weeds at all stages of observation (Table 2).

Presowing seed with 4% KCl combined with 49.8 kg K ha^{-1} and 50 ppm paraquat spray-

Table 1. Influence of seed treatment, water management, and weed control measures on yield components, grain yield, root volume, and water productivity of direct-seeded upland rice.

Treatment[a]	Effective tillers m^{-2} (no.)	Grains $panicle^{-1}$ (no.)	1,000-grain wt (g)	Yield (t ha^{-1})	Root volume (cm^3 $plant^{-1}$)	Consumptive water use (cm)	Water productivity (kg ha^{-1} cm^{-1})
Seed							
Normal	100	78	20.5	2.4	21.0	115	21
Modified	120	78	20.7	2.6	25.0	112	23
CD (0.05)	5	ns	ns	ns	3.4	–	–
Water management							
Rainfed	107	80	21.0	2.4	20.6	81	30
3 DII	113	77	20.6	2.6	26.5	139	18
6 DII	111	77	20.5	2.5	23.0	119	21
CD (0.05)	ns	ns	ns	ns	4.2	–	–
Weed control							
Weedy check	90	74	77.0	2.2	23.0	113	20
Butachlor at 2 kg ai ha^{-1}	130	82	78.0	2.8	23.5	114	24
CD (0.05)	5.5	3.7	ns	0.2	ns	–	–

[a]DII = days of intermittent irrigation; ns = not significant.

ing at tillering could give the crop protection against dought. Applying butachlor considerably reduced weed pressure.

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Table 2. Influence of seed treatment, water management, and weed control measures on weed dry matter (g m^{-2}).[a]

Treatment	30 DAS		60 DAS		Harvest	
	Grass	Nongrass	Grass	Nongrass	Grass	Nongrass
Seed						
Normal	53	5	54	21	99 (8)[b]	45 (6)
Modified	43	7	48	15	101 (9)	99 (6)
CD (0.05)	ns	ns	ns	5	ns	ns
Water management						
Rainfed	58	5	48	18	110 (9)	46 (5)
3 DII	44	5	53	20	99 (9)	57 (6)
6 DII	45	6	33	17	90 (8)	62 (6)
CD (0.05)	ns	ns	ns	ns	ns	ns
Weed control						
Weedy check	68	6	66	16	140 (11)	23 (5)
Butachlor at 2 kg ai ha^{-1})	30	5	39	20	59 (6)	60 (7)
CD (0.05)	14	ns	9	5	3	ns

[a]DAS = days after sowing, ns = not significant, DII = days of intermittent irrigation. [b]Numbers in parentheses are square-root-transformed values.

Effect of organic matter resources and inorganic fertilizers on yield and nutrient uptake in the rice-wheat cropping system

B. Singh, R.K. Niranjan, and R.K. Pathak, Department of Soil Science and Agricultural Chemistry, C.S. Azad University of Agriculture and Technology, Kanpur 208002, India

A field experiment was conducted at the Fertilizer Research Station, Pura, Kanpur (India), during 1997-98 and 1998-99 to study the influence of organic sources along with inorganic fertilizers on the rice-wheat cropping system. The soil had the following characteristics: sand 51.8%, silt 25.6%, clay 21.3%, pH 7.9, electrical conductivity (EC, dS m^{-1}) 0.39, organic carbon 4.3 g kg^{-1}, available N 163.2 kg ha^{-1}, 7.1 kg P ha^{-1}, and 103.8 kg K ha^{-1}. The experiment was laid out in a split-plot design consisting of five main-plot treatments: M_1—green manure (*Sesbania aculeata*), M_2—moong legume (*Phaseolus aureus*) straw (5 t ha^{-1}), M_3—farmyard manure (5 t ha^{-1}), M_4—rice straw (5 t ha^{-1}), and M_5—weedy fallow; and five subplot treatments: F_0—control, F_1—50% N, F_2—50% NP, F_3—50% NPK, and F_4—100% NPK of the recommended dose (120 kg N, 26.4 kg P, and 49.8 kg K).

Adding different sources of organic matter significantly increased rice yield over weedy fallow. Treatments also differed significantly from each other. Maximum grain yield (3.7 t ha^{-1}) during 1997 and 1998 was obtained by M_1, followed by M_3 (3.6 t ha^{-1}), M_2 (3.5 t ha^{-1}), and M_4 (3.4 t ha^{-1}). Minimum grain yield was obtained under the fallow treatment. Similarly, chemical fertilizers also significantly increased yield compared with the fertilizer control. A minimum yield of 2.0 t ha^{-1} in the control increased to 3.2 t ha^{-1} with F_1, to 3.6 t ha^{-1} in F_2, to 4.0 t ha^{-1} in F_3, and to 4.7 t ha^{-1} in F_4 during 1997. A similar trend was recorded in 1998 (Table 1).

Different organic matter sources exhibited significant residual responses on grain and straw yield of the wheat crop. Maximum yield in the wheat crop was noted in the treatment with green manure, followed by farmyard manure, moong straw, and rice straw (Table 2).

Table 1. Effect of organic matter sources and fertilizer levels on grain yield (t ha^{-1}) of rice.

Main treatment	1997 Fertilizer level					Mean	1998 Fertilizer level					Mean
	F_0	F_1	F_2	F_3	F_4		F_0	F_1	F_2	F_3	F_4	
M_1—Green manure (*Sesbania aculeata*)	2.2	3.4	3.8	4.2	5.0	3.7	2.3	3.4	3.8	4.2	5.0	3.7
M_2—Moong straw (*Phaseolus aureus*) (5 t ha^{-1})	2.0	3.2	3.5	4.0	4.7	3.5	2.0	3.2	3.6	4.0	4.8	3.5
M_3—Farmyard manure (5 t ha^{-1})	2.1	3.2	3.6	4.1	4.8	3.6	2.2	3.2	3.6	4.1	5.0	3.6
M_4—Rice straw (5 t ha^{-1})	1.9	3.1	3.5	3.9	4.7	3.4	2.0	3.1	3.5	4.0	4.7	3.4
M_5—Weedy fallow	1.8	2.9	3.4	3.8	4.5	3.3	1.8	3.0	3.5	3.8	4.6	3.3
Mean	2.0	3.2	3.6	4.0	4.7		2.1	3.2	3.6	4.0	4.8	
CD (0.05)	0.04 0.08											

Note: M compares M-means (averaged over F, subplot treatments) and F compares F-means (averaged over M, main-plot treatments).

Among organic matter sources, the total uptake of nutrient through the green manure treatment was maximum in relation to the total N, P, and K uptake. The contribution of the total uptake of N, P, and K was 17.4%, 14.9%, and 10.8% during 1997 and 17.4%, 14.8%, and 11.7% during 1998 (data for 1998 not shown) respectively, followed by the M_3 treatment during both years of the experiment (Table 3).

. . . .

Table 2. Residual effect of organic matter sources applied to rice on yield (t ha^{-1}) of the succeeding wheat crop.

Treatment	1997-98 Grain	1997-98 Straw	1998-99 Grain	1998-99 Straw
M_1	3.2	4.3	2.3	4.6
M_2	3.1	4.1	3.2	4.1
M_3	3.2	4.2	3.3	4.5
M_4	3.0	4.0	3.1	4.3
M_5	2.8	3.8	3.0	4.2
CD (0.05)	0.07	0.08	0.08	0.09

Table 3. Contribution of organic matter sources (%, in parentheses) to total uptake of nutrients in rice during 1996-97.

Treatment	Total N uptake[a] (kg ha^{-1})	Total P uptake[a] (kg ha^{-1})	Total K uptake[a] (kg ha^{-1})
M_1	76.39 (17.4)	13.42 (14.9)	88.89 (10.8)
M_2	70.12 (7.8)	12.44 (6.5)	84.98 (5.8)
M_3	73.19 (12.5)	12.92 (10.6)	87.02 (8.3)
M_4	67.56 (3.9)	12.03 (3.0)	85.52 (2.7)
M_5	65.05 (–)	11.68 (–)	80.32 (–)

[a]Grain + straw.

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Adapting a photoperiod-sensitive routine to the INTERCOM model for use in West Africa

F.J. Abamu, M.P. Jones, and M. Wopereis, West Africa Rice Development Association (WARDA), 01 BP 2551 Bouaké, Côte d'Ivoire E-mail: f.abamu@cgiar.org

In West Africa, weeds are the major constraint to rice production. Native African rice *Oryza glaberrima*, however, is very competitive against weeds and research is ongoing to introgress competitive traits of *O. glaberrima* into high-yielding *O. sativa* types (Jones et al 1997). To support this work, the crop-weed competition model INTERCOM (Kropff and van Laar 1993) is being adapted and parameterized to evaluate weed-competitive rice plant types in a prebreeding support project.

The accurate prediction of phenology is the first step in applying process-based mechanistic models as tools for rice research and decision support at the site or regional level. Phenology is important in situations in which weeds compete with rice because competitiveness is affected by the partitioning of dry matter to organs and partitioning is driven by phenology. Phenology in INTERCOM is calculated from a thermal time (°C day) approach that assumes a linear developmental rate from plant emergence to flowering and another from flowering to physiological maturity. Rice development to flowering, however, has been shown to respond to both temperature and photoperiod at specific stages. Thus, subphases—a basic vegetative phase (BVP), a photoperiod-sensitive phase (PSP), and a panicle formation phase (PFP)—have been identified (Vergara and Chang 1985). Varietal sensitivity to photoperiod modulates the duration of PSP, depending on the positive deviation of daylength from a critical daylength value. These were used to modify the phenology routine in INTERCOM in a way similar to that in ORYZA_1 but allowing for multispecies structure, which is characteristic of INTERCOM.

To quantify photoperiod sensitivity and parameterize the routine for 11 rice varieties (see table), data on sowing date, 50% flowering date, and physiological maturity were obtained from plantings done monthly from June to September 1998 at Mbe, Côte d'Ivoire. Data were transformed to Julian dates and inputted into the program DRATES in ORYZA_1 to obtain the duration of BVP, PSP, and PFP for each variety across planting time. In the results, PFP was constant across varieties and planting dates, but BVP and PSP varied considerably. Within a variety, the minimum BVP and PSP from the range were assumed as the value expected for that variety. Then, a photoperiod sensitivity index (PPSE) was derived from the b′-value of fitting a 2-parameter function [Y = a*EXP (b*X)] to the plot of duration to flowering (°C day) and photope-

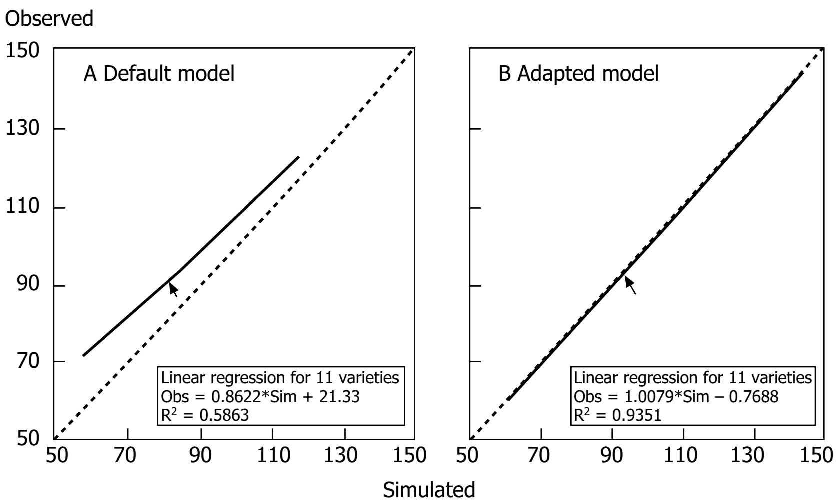
Duration (°C day, Tbase = 8 °C) to flowering, grain-filling phase, and photoperiod sensitivity of 11 rice varieties derived for the INTERCOM model from field trials at Mbe, Côte d'Ivoire.

Variety	Default[a]		Adapted[a]				Photoperiod regression statistics			
	E_F	CV%	BVP	PSP	PFP	GFP	R^2	Prob.	PPSE	SE
Bouaké 189	1,831	6	935	491	440	415	0.42	ns	0.135	0.090
CG14	1,417	10	538	309	440	392	0.79	0.05	0.344	0.104
CK4	1,730	3	903	365	440	457	0.64	ns	0.091	0.039
IG10	1,492	33	289	127	440	401	0.91	0.01	1.464	0.296
IR54	1,788	3	943	439	440	438	0.29	ns	0.052	0.047
LAC23	2,005	9	1,099	352	440	407	0.50	ns	0.245	0.138
Moroberekan	1,898	7	1,044	403	440	377	0.77	0.05	0.216	0.067
OS6	1,629	2	821	281	440	387	0.08	ns	0.014	0.028
WAB450-24-3-2-P18-HB	1,304	13	369	179	440	482	0.90	0.01	0.494	0.098
Suakoko 8	2,131	6	1,235	390	440	366	0.77	ns	0.184	0.058
WAB56-104	1,217	7	494	182	440	468	0.75	ns	0.228	0.077

[a]Default refers to the original INTERCOM model, while "Adapted" is INTERCOM with photoperiod sensitivity included. E_F = emergence to flowering (DVS 0.0–1.0), BVP = basic vegetative phase (DVS 0.0–0.4), PSP = photoperiod-sensitive phase (DVS 0.4–0.65), PFP = panicle formation phase (DVS 0.65–1.0), GFP = grain-filling phase (DVS 1.0–2.0), PPSE = photoperiod sensitivity index (°C day h^{-1}), SE = standard error, DVS = development stage of the crop.

riod at the start of PSP. A statistical analysis of this regression suggests that *O. glaberrima* IG10 had the strongest PPSE (PPSE = 1.46 °C day; $r^2 = 0.91^{**}$). Three other genotypes—CG14, Moroberekan, and WAB450-24-3-2-P18-HB (see table)—also showed significant responses ($P = 0.05$). The regression, however, was not significant in seven genotypes ($P = 0.05$), suggesting that duration to flowering of these varieties was not affected by the range of photoperiod experienced during the trials.

The parameters derived (see table) were inputted into the original (default) and the revised (adapted) INTERCOM crop model. A comparison (on a 1:1 basis) of simulated days to flowering with actual days to flowering is presented in the figure. Results show that days to flowering across genotypes was underestimated by as many as 21 d in the default procedure and by less than 1 d in the adapted procedure. R^2 for the comparison increased from 0.59 in the default model to 0.94 in the adapted model, which is an index for overall improvement in the prediction. Further evaluation, parameterization, and module development for phenology as affected by photoperiod are required in rice modeling work that involves the use of *O. glaberrima*. Parameterization and validation of the model for key West African rice weeds are also needed.



Comparisons between observed and simulated duration to flowering (days) of 11 rice varieties at Mbe, Côte d'Ivoire, using the model INTERCOM without (A, default model) and with (B, adapted model) photoperiod effects on duration to flowering.

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Acknowledgment

We thank the CGIAR-Canada Linkage Funds (CCLF) for the support given to Dr. Frank Abamu.

Virtual rice: simulating the development of plant architecture

T. Watanabe, Department of Information Science and Technology, National Agriculture Research Center, Tsukuba, Ibaraki 3058666, Japan; P.M. Room and J.S. Hanan, Center for Plant Architecture Informatics, Department of Mathematics, University of Queensland, Brisbane, Queensland 4072, Australia

Information on the architecture and morphogenesis of rice plants is important in a range of research fields, such as in the development of ideotypes and direct-seeding techniques and for understanding competition against weeds and compensation for pest damage. Although several simulation models for predicting rice yield exist, there is no detailed model for simulating rice morphogenesis and plant architecture. In this study, the three-dimensional (3D) structure of rice plants was measured and the results were used to construct a "virtual rice" model that simulates morphogenesis and the development of plant architecture.

The study involved three steps: (1) measurement of the 3D structure at intervals during growth, (2) construction of the virtual rice model by specifying rules of morphogenesis in the L-system formalism (Lindenmayer 1968), and (3) the use of specialized software that interprets L-system instructions to generate 3D simulations of plant development (Prusinkiewicz and Lindenmayer 1990). Plants of the japonica-type rice "Namaga" were grown in Brisbane, Australia, from September 1997 to February 1998. At the third-leaf stage, seedlings were transplanted singly into 17.5-cm-diam pots filled with loamy soil and fertilizer (10 g N, 11 g P, 8 g K m^{-2}). Urea was applied twice during growth: 5 g N m^{-2} before panicle initiation and 10 g N m^{-2} after panicle initiation. The geometry of the plants was measured using a 3D sonic digitizer interfaced to a special software called FLORADIG© (Hanan and Room 2000) that recorded 3D coordinates (x, y, z) labeled according to the types and topological positions of the plant parts. The data were imported into a database and standard query procedures were used to select subsets of data for analysis. The structural development of plant architecture was expressed as mathematical functions and an L-system model was created and tested (Prusinkiewicz and Linden-mayer 1990). The model was interpreted by the Plant and Fractal Generator tool (Mech 1998).

During vegetative development in rice, each apical meristem (A) produces a module that consists of a series of metameters (line 1 in Fig. 1). Each metameter comprises an internode (I), an axillary meristem (B), and a leaf sheath (S) that is connected to a leaf blade (L). At the same time, as the leaf emerges at node n, an axillary bud produces the first leaf of a daughter tiller at node n-3 on the parent module (line 2 in Fig. 1). The onset of reproductive development occurs when the apical meristem transforms into the initial panicle (P) (line 3 in Fig. 1). Processes such as new meristem production, leaf expansion tillering, internode elongation, flowering, leaf senescence, and grain maturation were included in the model and related to the developmental index, DVI (Nakagawa and Horie 1995). The DVI varies continuously from 0 at emergence of the first leaf to 1.0 at the start of panicle initiation, 2.0 at heading, and 3.0 at maturity. As well as numerical output, the model generates realistic images, which can be rotated in 3D at will (Fig. 2).

The virtual rice model could be used to explore the efficiency of light interception of hypothetical plant architecture in the search for improved ideotypes. This

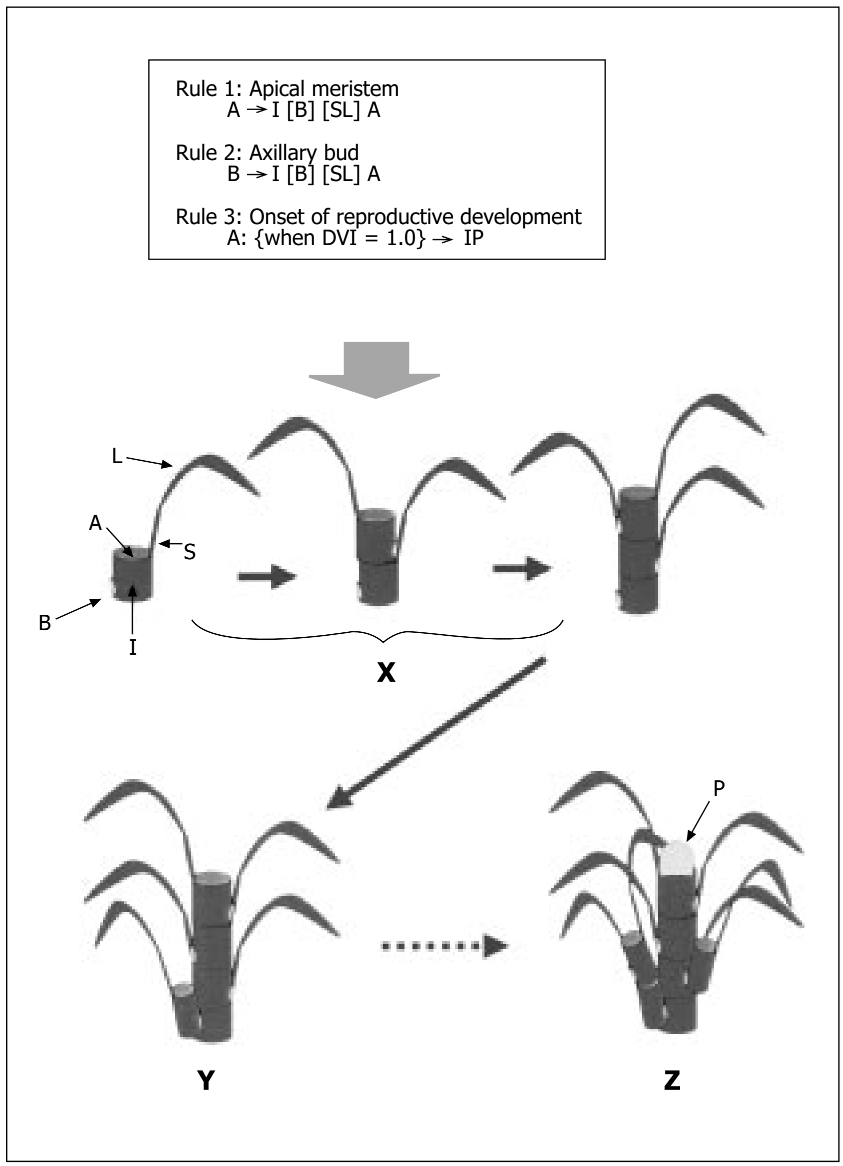

Fig. 1. L-system, production rules, and visualization of corresponding plant growth.
A = apical meristem, B = axillary bud, I = internode, S = leaf sheath, L = leaf blade, P = panicle, DVI = developmental index, x = growth of main stem, y = initiation of a tiller, z = panicle initiation.

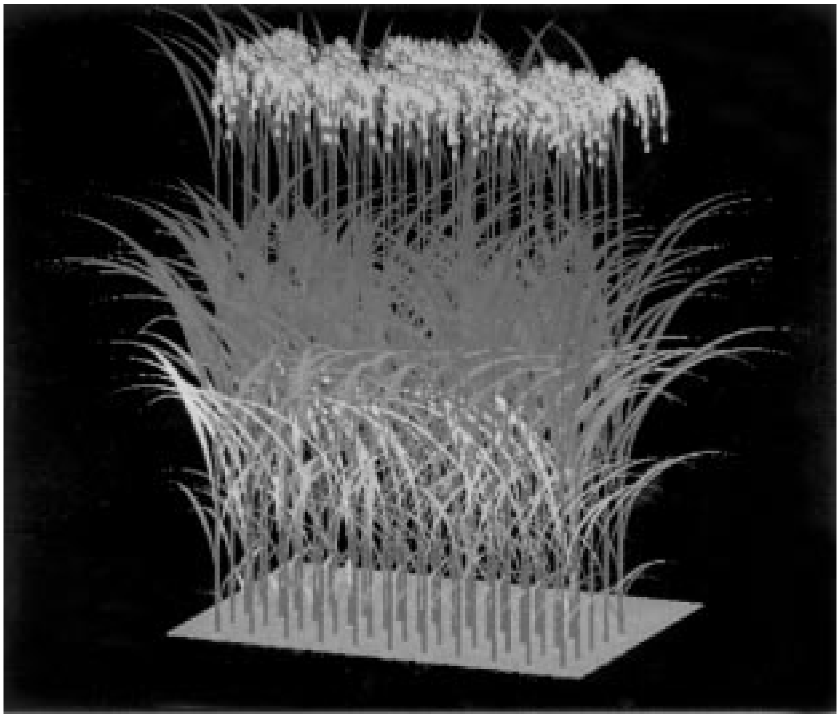

Fig. 2. Part of a "virtual rice field," an example of the simulation output.

could be done by changing the values of parameters controlling leaf shape and by using image-processing software to analyze the output. More extensive investigations of the interactions between morphogenesis and the environment, however, will require virtual rice to be interfaced with an ecophysiological model. This will enable expression of partitioning, calculated by the physiological model, in 3D structure. This is in preparation for analysis of effects on, for example, competition for resources and optimization of plant population density. Thus, virtual rice has the potential to become a valuable framework for integrating research results from different disciplines and for communicating research output to farmers and others in the form of scientific visualization.

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Source-sink characteristics of japonica/indica hybrid rice

J. Yang, Yangzhou University; S. Peng, IRRI; Z. Wang and Q. Zhu, Yangzhou University, Yangzhou, Jiangsu 225009, China
E-mail: s.peng@cgiar.org

Poor grain filling is the main barrier to using heterosis of japonica/indica hybrid rice (J/I-HR) (Wang et al 1991, Yuan 1990). This study aimed to explain the causes of poor grain filling by investigating the source-sink relations of 36 J/I-HR combinations. Six japonica lines with wide compatibility genes—PC 311, Lunhui 422, Jw-8, Ce-01, 02428, and Ce-03—were used as female parents and six typical indica lines—Milyang 23, 3037, Zaoxiandang-18, IR36, Minghui 63, and Yangdao 4—were used as male parents to make 36 first-generation J/I-HR combinations by the P × Q mode, that is, the females (P) were crossed to the males (Q). An indica hybrid rice combination, Shanyou 63, was used as a control. Seedlings were raised in a greenhouse and transplanted into the rice field on the Yangzhou University farm, Jiangsu Province, China (32°30'N, 119°25'E) during the 1997 rice-growing season (May-Oct). The experiment was repeated in 1998. Source-sink characteristics were determined by measuring sink size (defined as spikelet number m^{-2}), content of nonstructural carbohydrate (NSC) in culms and sheaths, and dry matter accumulation before and after heading. Flag leaves on the main stems were labeled with $^{14}CO_2$ at heading to examine ^{14}C-assimilate partitioning in the plants.

The average sink size of J/I-HR was large (55,000 spikelets m^{-2}), which was 30% and 21% larger than the average of the parents and of Shanyou 63, respectively (Table 1). J/I-HR combinations had obvious heterosis in dry matter production. Their average dry matter accumulation during the grain-filling period was 59% and 105% higher than the average of the parents and Shanyou 63, respectively, resulting in a high ratio of source to sink (dry weight/spikelet). The heterosis in dry matter production of J/I-HR was attributed to the large leaf area index at heading and high photosynthetic potential from heading to harvest (Table 1). The higher source-sink ratio indicated that poor grain filling of J/I-HR may not result from "large sink size without enough source" as reported before (Yuan 1997, Zhuang et al 1994).

However, J/I-HR poorly remobilized assimilates from vegetative tissues to grains. The transfer ratio of total NSC to grains, the apparent percentage of remobilized carbon reserves in the culm and sheath, and the harvest index of the J/I-HR combinations were much lower than those of their parents and Shanyou 63. At maturity, only 48% of the ^{14}C fed to flag leaves was partitioned into grains for J/I-HR, vs 82% for Shanyou 63 (Table 2). The poor remobilization of assimilates may be attributed to weak sink strength and delayed senescence (keeping "green" for too long at maturity) in J/I-HR (Wang et al 1998). Results suggest that poor transport of assimilates to grains accounted for the poor grain filling of J/I-HR. Grain filling could be improved by enhancing the translocation and remobilization of assimilates to the grain through breeding and crop management.

Table 1. Source-sink characteristics of japonica/indica hybrid rice (J/I-HR) combinations, their parents, and Shanyou 63.

Source-sink characteristic	Source		
	J/I-HR	Parents	Shanyou 63
Spikelets (no. × 10^6 ha^{-1})	534.0 ± 45[b]	411.0 ± 46	443.0
Leaf area index at heading	7.8 ± 0.5	6.0 ± 1.1	7.3
Photosynthetic potential (m^2 d^{-1} m^{-2})[a]	175.0 ± 13.0	142.0 ± 15.0	157.0
Dry matter weight (t ha^{-1})			
At heading	12.0 ± 1.4	8.9 ± 1.5	12.0
Heading to maturity	9.5 ± 0.9	6.0 ± 1.1	4.6
Dry weight spikelet^{-1} (mg)			
At heading	22.5 ± 2.3	21.8 ± 2.5	28.0
Heading to maturity	17.2 ± 1.2	14.5 ± 1.3	10.5

[a]Expressed as green leaf area d^{-1} m^{-2} from heading to maturity. [b]Data are expressed as means ± standard errors (SE). Samples (n) = 36 combinations for J/I-HR, 12 lines for the parents, and 1 combination for Shanyou 63. Each measurement is from 50 plants from each combination/line.

Table 2. Transport of assimilates of japonica/indica hybrid rice (J/I-HR) combinations, their parents, and Shanyou 63.

Transport of assimilates	Source		
	J/I-HR	Parents	Shanyou 63
Remobilized C reserves (%)[a]	7.5 ± 5.2[d]	43.7 ± 7.3	78.7
Transfer ratio of assimilates (%)[b]	62.4 ± 6.1	78.1 ± 7.3	93.3
Harvest index	0.4 ± 0.03	0.4 ± 0.06	0.5
NSC residue (mg g^{-1} DW)[c]	196.0 ± 11.0	172.0 ± 12.0	89.0
^{14}C partitioning (%)			
Panicle	48.3 ± 3.2	67.2 ± 4.9	81.6
Culm + sheath + leaf	51.7 ± 4.8	32.8 ± 5.1	18.4

[a][Nonstructural carbohydrate (NSC) in culms and sheaths at heading (a) – NSC in culms and sheaths at maturity]/a × 100. [b](Panicle weight at maturity – panicle weight at heading)/(NSC in culms and sheaths at heading + dry weight of plant at maturity – dry weight of plant at heading) × 100. [c]NSC remaining in culms and sheaths at maturity. [d]Data are expressed as means ± standard errors (SE). Samples (n) = 36 combinations for J/I-HR, 12 lines for the parents, and 1 combination for Shanyou 63. Each measurement is from 50 plants from each combination/line.

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Acknowledgments

This work was financed by the National Natural Science Foundation of China (Project No. 39970424) and the IRRI (Project No. IR1).

Response of irrigated rice to the application of poultry manure and inorganic fertilizers N, P, and K in Karnataka, India

A.S. Channabasavanna and D.P. Biradar, Agricultural Research Station (ARS), Siruguppa 583121, Karnataka, India

The integrated use of organic manures and inorganic fertilizers is important to sustain a higher level of soil fertility and productivity. Poultry manure is a rich source of nutrients and is available in abundant quantity near poultry farms. It has not been fully exploited as a source of organic manure. Hence, we studied the response of rice to poultry manure and NPK under irrigated conditions. The poultry manure used in this experiment contained 3.03% N, 2.6% P, and 1.4% K.

The field experiment was conducted during the 1998 and 1999 wet seasons (Aug-Dec). The soil has pH 8.2, 260 kg available N, 42 kg available P, and 650 kg available K ha^{-1}. The available N, P, and K were estimated by the Kjeldahl, Olsen's, and flame photometer method, respectively. The experiment was a split plot conducted at ARS with poultry manure in the main plot and NPK levels in the subplot, replicated thrice. The agronomic efficiency of N (AEN) was calculated by taking the ratio of rice yield to total N applied (Venugopalan and Prasad 1992).

Thirty-day-old seedlings of genotype SIRI-429 were transplanted during the first week of August in 16-m^2 plots with 20 × 10-cm spacing. A basal dose of 50% N and a full dose of P and K were applied at transplanting and the remaining 50% N was applied in two equal splits at 30-d intervals. The fertilizer dose was applied per treatment.

Grain yield increased with each increment of poultry manure application and was maximum at 3 t ha^{-1} of poultry manure during both years (see table). This was 26% and 19% higher than that of the control during 1998 and 1999, respectively. The significant increase was observed up to 2 t ha^{-1} of poultry manure. Data showed that 1 t ha^{-1} of poultry manure was on a par with 7 t ha^{-1} of farmyard manure. With the increasing application of poultry manure, AEN decreased. The highest AEN was observed when no organic manure was applied; the lowest was at 4 t ha^{-1} of poultry manure.

Increasing the fertilizer level from 75:35.5:37.5 to 150:75:75 kg NPK ha^{-1} increased grain yield significantly during both years (see table). The AEN was inversely related. AEN at 75% NPK (112.5:56.3:56.3 kg NPK ha^{-1}) was equivalent to 2 t ha^{-1} of poultry manure.

The interactive effect between poultry manure and inorganic fertilizer was not significant. However, data showed that an increase in poultry manure and fertilizer increased rice seed yield. This is true up to 3 t ha^{-1} of poultry manure. At 4 t ha^{-1} of poultry manure, a yield increase was noted only up to 75% NPK. Further increases in NPK did not improve yields. This clearly indicates that, at high poultry manure application rates, 75% NPK was optimum. The AEN decreased with an increased application of poultry manure and fertilizer. However, at 4 t ha^{-1} of poultry manure, agronomic efficiency did not vary with an increase in NPK. The AEN with farmyard manure (7 t ha^{-1}) was almost equivalent to poultry manure application at 1 t ha^{-1}.

Reference

Venugopalan MV, Prasad R. 1992. Relative efficiency of ammonium polyphosphate and conventional orthophosphate for wheat and wheat-fodder cowpea cropping sequence. Indian J. Agron. 37(2):226–230.

Effect of manure application and fertilizers N, P, and K application on grain yield and agronomic N efficiency.[a]

Application	Treatment						1998 WS		1999 WS	
	Manure			Inorganic			Grain yield (t ha^{-1})	AEN	Grain yield (t ha^{-1})	AEN
	N	P	K	N	P	K				
	(kg ha^{-1})			(kg ha^{-1})						
0 t M ha^{-1}	0	0	0	75.0	37.5	37.5	3.6± 0.5	48.1	3.6 ± 0.3	48.0
0 t M ha^{-1}	0	0	0	112.5	56.3	56.3	3.6± 0.1	31.8	4.0 ± 0.6	35.6
0 t M ha^{-1}	0	0	0	150.0	75.0	75.0	4.0± 0.4	26.9	5.3 ± 0.3	53.1
1 t PM ha^{-1}	30	26	14	75.0	37.5	37.5	3.5 ± 33.7	33.7	3.8 ± 0.2	36.0
1 t PM ha^{-1}	30	26	14	112.5	56.3	56.3	3.4 ± 0.1	23.6	4.7 ± 0.5	33.1
1 t PM ha^{-1}	30	26	14	150.0	75.0	75.0	4.6 ± 0.7	25.6	5.4 ± 0.6	30.2
2 t PM ha^{-1}	60	52	28	75.0	37.5	37.5	3.9 ± 0.3	28.7	4.6 ± 0.2	34.5
2 t PM ha^{-1}	60	52	28	112.5	56.3	56.3	4.4 ± 0.6	25.6	5.0 ± 0.1	28.7
2 t PM ha^{-1}	60	52	28	150.0	75.0	75.0	4.8 ± 0.2	23.1	5.4 ± 0.4	26.0
3 t PM ha^{-1}	90	78	42	75.0	37.5	37.5	4.2 ± 0.4	25.3	4.6 ± 0.1	27.7
3 t PM ha^{-1}	90	78	42	112.5	56.3	56.3	4.8 ± 0.1	23.9	4.9 ± 0.1	24.3
3 t PM ha^{-1}	90	78	42	150.0	75.0	75.0	5.1 ± 0.1	21.4	5.9 ± 0.0	24.4
4 t PM ha^{-1}	120	104	56	75.0	37.5	37.5	4.1 ± 0.2	21.2	4.3 ± 0.3	21.9
4 t PM ha^{-1}	120	104	56	112.5	56.3	56.3	4.8 ± 0.3	20.5	5.3 ± 0.4	22.7
4 t PM ha^{-1}	120	104	56	150.0	75.0	75.0	4.7 ± 0.7	17.3	5.8 ± 0.2	21.4
7 t FYM ha^{-1}	35	10.5	35	75.0	37.5	37.5	3.9 ± 0.1	35.5	4.1 ± 0.6	38.7
7 t FYM ha^{-1}	35	10.5	35	112.5	56.3	56.3	4.3 ± 0.3	29.1	5.1 ± 0.2	34.9
7 t FYM ha^{-1}	35	10.5	35	150.0	75.0	75.0	4.2 ± 0.6	22.7	5.3 ± 0.3	28.8
Treatment means										
0 t M ha^{-1}							3.7 ± 0.2 a*	35.6	4.3 ± 0.7 a*	39.6
1 t M ha^{-1}							3.8 ± 0.6 ab	27.6	4.6 ± 0.7 ab	33.1
2 t M ha^{-1}							4.4 ± 0.4 bcd	25.8	5.0 ± 0.3 bc	29.7
3 t M ha^{-1}							4.7 ± 0.4 d	23.5	5.1 ± 0.5 c	25.5
4 t M ha^{-1}							4.6 ± 0.3 cd	19.7	5.1 ± 0.6 c	22.0
7 t FYM ha^{-1}							4.1 ± 0.2 abc	29.1	4.8 ± 0.6 b	34.1
75.0	37.5	37.5	NPK				3.9 ± 0.2 a	32.1	4.2 ± 0.4 a	34.5
112.5	56.3	56.3	NPK				4.2 ± 0.6 b	25.7	4.8 ± 0.4 b	29.9
150.0	75.0	75.0	NPK				4.6 ± 0.2 c	22.8	5.5 ± 0.2 c	26.1
Interaction										
Manure × NPK							ns		ns	

[a]M = manure, WS = wet season, PM = poultry manure, FYM = farmyard manure, AEN = agronomic N efficiency.
* = significant at 0.05%, ns = not significant.

Adenine, adenosine monophosphate, and cytokinin: nutrients for rice seedling growth in the summer crop season

M.C. Hsieh and M.S. Tung, Department of Botany, National Chung-Hsing University, Taichung, Taiwan, Republic of China

Adenine, adenosine monophosphate (AMP), and cytokinin (isopentenyl adenine [IPA], trans-zeatin [t-Z], and dihydrozeatin [DHZ]) were tested to determine whether they could promote seedling growth of rice variety Tai-Keng 3 in Taiwan. Adenine and AMP are precursors of the biosynthesis of ATP, nucleic acids, coenzyme A, FAD NAD^+, and cytokinin. Cytokinin is an inducer of protein synthesis and cell division. Rice seeds were surface-sterilized with 10% NaOCl for 10 min, rinsed with distilled water a few times, and placed under white fluorescent lamps (20 µmol m^{-2} s^{-1}) for germination at 26 °C. Distilled water was replaced daily. Five-day-old germinating seeds were transferred to culture solutions, which included Hoagland solution [$Ca(NO_3)_2$, 5.0 $\times 10^{-3}$ mol L^{-1}; KNO_3, 5.0 $\times 10^{-3}$ mol L^{-1}; $MgSO_4$, 2.0 $\times 10^{-3}$ mol L^{-1}; KH_2PO_4 1.0 $\times 10^{-3}$ mol L^{-1}; Fe-

EDTA, 1.18×10^{-5} mol L^{-1}; and micronutrient solution consisting of H_3BO_3, 4.6×10^{-5} mol L^{-1}; $MnCl_2 \cdot 4H_2O$, 9.14×10^{-6} mol L^{-1}; $ZnSO_4 \cdot 4H_2O$, 7.65×10^{-7} mol L^{-1}; $CuSO_4$, 7.0×10^{-7} mol L^{-1}; and H_2MoO_4, 1.24×10^{-7} mol L^{-1}; pH 5.0; and in which adenine, AMP, IPA, t-Z, and DHZ were each added to make concentrations from 10^{-9} to 10^{-16} M]. A group of concentrations from each test chemical solution was tested each time and poured into plastic trays (11.5 cm diam, 3.5 cm depth) with two filter papers (Whatman no. 1, 9.0 cm diam) each. At least 15 germinating seeds in each tray were grown under white fluorescent lamps (20 µmol m^{-2} s^{-1}) for another 13 d at 26 °C. Each test concentration contained four replicates. The test solution in each tray was maintained at a sufficient level for seedlings to absorb enough nutrition during the experimental period. At harvest, seedlings from each cultured tray were washed with water (mainly for roots) and blotted with paper tissue. Seed was cut off from each seedling. The shoots were then separated from the roots and each portion was dried in an oven at 70 °C for 24 h. Dried shoots and roots for each cultured tray were weighed separately to provide a unit dry mass. Measured values from a group of concentrations of each test chemical solution were analyzed by Duncan's multiple range test at the 5% level.

Results (Table 1) showed that adenine at 10^{-9}–10^{-12} M, AMP at 10^{-12}–10^{-14} M, and DHZ at 10^{-9}–10^{-15} M were all effective in promoting shoot growth of this rice variety, whereas iPA and t-Z were ineffective and prohibitory, respectively. In root growth (Table 2), only adenine at 10^{-9}–10^{-11} M was effective; all the others were ineffective. Based on study results, it can be concluded that adenine, AMP, and DHZ mixed with Hoagland nutrient solution at low concentrations can effectively promote rice seedling growth. Among these three chemicals, DHZ is the most effective, but adenine and AMP are cheaper.

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Table 1. Effects of adenine, AMP, and cytokinin on shoot growth of rice seedlings and dry shoot weight (mg $plant^{-1}$).[a]

Nutrient	Concentration (M)								
	0	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}	10^{-14}	10^{-15}	10^{-16}
Ade	10.2 ± 0.2 b	10.9 ± 0.2 a	11.3 ± 0.2 a	11.2 ± 0.2 a	11.0 ± 0.2 a				
	10.5 ± 0.2 b					10.8 ± 0.2 b	10.9 ± 0.3 b	10.8 ± 0.2 b	10.6 ± 0.2 b
AMP	11.2 ± 0.1 b			10.8 ± 0.1 b	12.0 ± 0.1 a	12.0 ± 0.1 a	11.9 ± 0.1 b		
	10.3 ± 0.1 b							11.0 ± 0.4 b	10.6 ± 0.2 b
IPA	10.7 ± 0.2 a	10.9 ± 0.2 a	11.1 ± 0.2 a	11.3 ± 0.2 a	10.7 ± 0.2 a				
	10.3 ± 0.0 a					10.3 ± 0.0 a	10.7 ± 0.0 a	10.6 ± 0.1 a	10.6 ± 0.1 a
t-Z	11.2 ± 0.1 a	11.3 ± 0.0 a	10.8 ± 0.2 bcd	10.5 ± 0.1 d	10.6 ± 0.3 cd				
	10.6 ± 0.0 a					10.5 ± 0.0 a	10.4 ± 0.0 a	11.0 ± 0.1 a	11.0 ± 0.1 a
DHZ	10.7 ± 0.2 b	11.7 ± 0.1 a	12.0 ± 0.1 a	12.0 ± 0.1 a	11.7 ± 0.1 a				
	10.6 ± 0.2 b					11.5 ± 0.0 a	11.6 ± 0.3 a	11.4 ± 0.2 a	11.3 ± 0.3 b

[a]Ade = adenine, AMP = adenosine monophosphate, IPA = isopentenyl adenine, t-Z = trans-zeatin, DHZ = dihydrozeatin. Values followed by the same letter are not significantly different; growth period—May to August at 26 °C. In this table, each chemical treatment contained two separate experiments (the upper-row data were from one group of concentrations; the lower-row data were from the other group of concentrations).

Table 2. Effects of adenine, AMP, and cytokinin on root growth of rice seedlings and dry root weight (mg $plant^{-1}$).[a]

Nutrient	Concentration (M)								
	0	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}	10^{-14}	10^{-15}	10^{-16}
Ade	3.07 ± 0.0 b	3.34 ± 0.1 a	3.4 ± 0.0 a	3.57 ± 0.0 a	3.21 ± 0.1 a				
	3.65 ± 0.1a					3.62 ± 0.1 a	3.64 ± 0.0 a	3.60 ± 0.1 a	3.43 ± 0.1 a
AMP	3.44 ± 0.1 a			3.55 ± 0.2 a	3.67 ± 0.0 a	3.60 ± 0.3 a	3.42 ± 0.1 a		
	3.47 ± 0.1 a							3.57 ± 0.1 a	3.35 ± 0.1 a
IPA	3.55 ± 0.3 a	3.82 ± 0.2 a	3.79 ± 0.1 a	3.69 ± 0.0 a	3.36 ± 0.1 a				
	3.78 ± 0.0 a					3.62 ± 0.0 a	3.83 ± 0.0 a	3.76 ± 0.0 a	3.59 ± 0.1 a
t-Z	3.43 ± 0.1 a	3.56 ± 0.1 a	3.56 ± 0.1 a	3.24 ± 0.1 a	3.34 ± 0.1 a				
	3.80 ± 0.0 a					3.70 ± 0.0 a	3.80 ± 0.0 a	3.80 ± 0.0 a	4.00± 0.1 a
DHZ	3.26 ± 0.0 a	3.37 ± 0.0 a	3.28 ± 0.1 a	3.33 ± 0.0 a	3.31 ± 0.1 a				
	3.56 ± 0.0 a					3.53 ± 0.1 a	3.37 ± 0.0 a	3.43 ± 0.1 a	3.58 ± 0.1 a

[a]Values followed by the same letter are not significantly different. In this table, each chemical treatment contained two separate experiments (the upper-row data were from one group of concentrations; the lower-row data were from the other group of concentrations).

Stale seedbed—an alternate technology for preplanting to achieve total weed control in direct-seeded lowland rice

P.S. John and R. Mathew, Department of Agronomy, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur 680656, Kerala, India

Direct seeding of rice as a means of crop establishment is now recognized as a viable alternative to transplanting. It uses less labor and is less costly. However, it is constrained by heavy weed infestation, which reduces yield by 15–70%. The system, which now covers 12–14% of wetland rice tracts in Asia, can be sustained only if it is accompanied by an effective and low-cost weed control system that is free of phytotoxicity and pollution of the aquatic system.

The stale seedbed technology generally recommended for raising small grains under weed-free upland conditions can be used in direct-seeded lowland rice as a no-cost, ecofriendly, and energy-efficient weed control method. In this technique, field preparation to puddling and leveling is done as in normal rice culture. The field is then left as it is and is not allowed to dry completely. Weed seeds are allowed to germinate and water is let into the field after 7–10 d to a depth of 10–15 cm and retained for another 7–10 d. All the germinated weed seeds have decayed by this time and pregerminated rice is sown in water at 100 kg ha^{-1}. The field is drained after 12–24 h and rice seedlings come out in a weed-free environment.

A trial was conducted at the Rice Research Station, Moncompu, Kerala, India, and in farmers' fields in larger plots for 2 years during the main crop (*Puncha*) season (Oct-Feb). The rice tract was either rainfed or submerged lowland fields comprising 56,000 ha in the Kuttanad region, lying 0.5–1 m below mean sea level. This region is the rice bowl of the state. This area is representative of deltaic alluvium in river mouths in India and Asia. Land preparation and crop establishment are done after pumping out water from fields. A complete shift from transplanting to direct seeding has taken place in this tract because of labor scarcity and high cost. *Echinochloa stagnina*, *E. crus-galli*, and *Oryza rufipogon; Fimbristylis miliacea*, *Cyperus iria*, and *C. difformis;* and *Monochoria vaginalis* and *Sphenoclea zeylanica* are the native grasses, sedges, and broadleaf weeds, respectively, associated with rice cropping. Under uncontrolled conditions, yield can decline by 70%.

In the experiment, four treatments were tried in 20-m^2 plots and replicated thrice. Results pooled over 2 years (Table 1) showed that direct sowing under the stale seedbed system produced the highest yield, equivalent to that of an almost totally weed-free crop environment. Although statistically similar, both normal wetland sowing and transplanting resulted in lower yields possibly because of initial crop-weed competition. Transplanting in the stale seedbed resulted in a significantly higher weed population and lower yield.

The experiment in the farmers' fields consisted of four treatments, each in larger plots of 600 m^2 and replicated in three farmers' fields. Observations on weed parameters were collected from twelve 1-m^2 quadrats in opposite diagonals of each plot. Results (Table 2) showed the significant yield advantage of the stale seedbed system over hand weeding or chemical weed control, at no additional cost. Preemergence application of butachlor significantly damaged rice seedlings and reduced yield by 0.9 t ha^{-1}. The experiment in bigger plots proved

Table 1. Influence of planting system and method of weed control on weed population and rice yield.

Planting system and weed control method	Weed population at 20 DAS[a] (no. m^{-2})			Grain yield (t ha^{-1})
	Grass	Sedge	Broadleaf weeds	
Direct sowing in stale seedbed	3	4	6	4.6
Transplanting in stale seedbed	26	31	28	3.1
Normal direct sowing—weeded	60	49	41	2.6
Normal transplanting—unweeded	57	51	40	2.7
Normal direct sowing—hand-weeded at 23 DAS	64	48	37	4.3
Normal transplanting—hand-weeded at 23 DAS	58	51	35	4.4
CD (0.05)	8.3	5.3	6.7	0.4
CV	13.5	11.3	12.2	9.1

[a]DAS = days after sowing, CD = critical difference, CV = coefficient of variation.

Table 2. Comparison of stale seedbed and conventional methods in terms of crop establishment, weed population, and rice yield.

Weed method control	Crop plants (no. m^{-2} at 18 DAS)[a]	Weeds (no. m^{-2} at 70 DAS)				Grain yield (t ha^{-1})	Weed control cost ($ ha^{-1})
	Rice seedlings	Grass	Sedge	Broadleaf weeds	Wild rice		
Hand-weeded at 23 DAS	206	81	68	31	4	5.6	60.00
Unweeded	211	73	59	36	7	2.4	0
Preemergence application of butachlor at 0.8 kg ai ha^{-1} at 5 DAS	174	14	8	6	6	5.2	17.50
Stale seedbed	201	2	4	7	0	6.1	0
CD (0.05)	9.1	8.7	9.4	6.4	2.3	0.5	
CV	6.7	10.9	13.2	12.7	34.7	11.5	

[a]DAS = days after sowing, CD = critical difference, CV = coefficient of variation.

the adaptability of the stale seedbed system in farmers' fields. Results clearly showed that the stale seedbed is a no-cost, weed-control, productivity-facilitating system. Yield improvement over other systems is due to the direct effect of organic transformation of the soil environment and to efficient weed control. The stale seedbed system is also an effective tool to improve the quality of crop production in areas where wild rice is a problem.

The stale seedbed is not effective in a manually transplanted system, however, because of the emergence of secondary weed flushes as a result of soil disturbances. The minimal soil disturbance in using a mechanical transplanter is expected to make the stale bed system widely adaptable in countries such as Japan and Korea, where transplanting is mainly done using a transplanter.

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Influence of long-term crop management practices on grain yield and incidence of brown planthopper in rice

D.P. Biradar and M. Hegde, University of Agricultural Sciences, Dharwad, Agricultural Research Station (ARS), Siruguppa 583121, Karnataka, India

A correct ratio between organic and inorganic sources of nutrients is essential to ensure optimum yield in any crop, including rice. A long-term experiment to study the influence of organic and inorganic nutrient sources on rice yield started in the 1991 kharif season at ARS, Siruguppa, in the Tungabhadra project area of Karnataka, India. The experiment was laid out in a randomized block design with four replications at a fixed site. Different levels of inorganic fertilizers (NPK), organic sources (farmyard manure, *Gliricidia*, *Sesbania*), and plant population were included as treatments (see table). A common dose of zinc (at 20 kg ha^{-1}) in the form of zinc sulfate was applied to all treatments. Rice variety BPT-5204 was planted every kharif season at 20 × 10-cm spacing, except in treatments where 25% more seedlings were transplanted, which used a spacing of 15 × 10 cm. Brown planthopper (BPH) was recorded in the 1999 kharif season 90 d after transplanting (DAT) on 10 hills in each treatment and computed per hill. Both grain yield and BPH population data were subjected to statistical analysis.

The BPH population varied significantly among treatments even though lower pest incidence occurred during the 1999 kharif season (see table). The variation would have been more pronounced if the BPH population buildup had been high. The BPH population was significantly higher in treatments T9 and T10, which received more nutrients from both inorganic and organic sources. The higher amount of N applied in T9, coupled with more plant population (T10), resulted in a higher BPH population. Hence, caution must be exercised when giving advice on applying higher N doses. The highest grain yield during the 1999 kharif season was recorded in T10 (6.5 t ha^{-1}) and was on a par with T3 (6.2 t ha^{-1}), T4 (6.3 t ha^{-1}), T7 (6.0 t ha^{-1}), T8 (6.4 t ha^{-1}), and T9 (6.3 t ha^{-1}). Applying 100:50:50:20 kg NPKZn ha^{-1} as only inorganic fertilizer (T1) resulted in lower grain yield and BPH population

Influence of long-term crop management practices on grain yield and incidence of brown planthopper (BPH) in rice at Siruguppa, Karnataka, India.

Treatment no.	Treatment[a] N:P:K:Zn (kg ha^{-1})	BPH hill^{-1} (no.) (90 DAT)	Yield (t ha^{-1}) (1999 kharif)	Mean yield (t ha^{-1}) (1991-98 kharif)
T1	100:50:50:20	2.60 f	5.3 c	4.3
T2	150:75:75:20	3.57 ef	5.9 b	5.0
T3	200:100:100:20	6.93 c	6.2 ab	5.1
T4	T2 + FYM (5 t ha^{-1})	4.57 de	6.3 ab	5.1
T5	T2 + Gli. (3 t ha^{-1})	4.70 de	5.9 b	5.2
T6	T2 + Ses. (5 t ha^{-1})	4.83 de	5.9 b	5.1
T7	T2 + FYM (5 t ha^{-1}) + Gli. (3 t ha^{-1}) + Ses. (5 t ha^{-1})	5.57 cd	6.0 ab	5.2
T8	T2 + 25% more PP	4.63 de	6.4 ab	4.9
T9	T3 + FYM (5 t ha^{-1}) + Gli. (3 t ha^{-1}) + Ses. (5 t ha^{-1})	9.00 b	6.3 ab	5.3
T10	T9 + 25% more PP	11.27 a	6.5 a	5.2

[a]Numbers in a column followed by the same letter do not differ significantly at 5% by Duncan's multiple range test. Gli. = *Gliricidia*, Ses. = *Sesbania*, DAT = days after transplanting, PP = plant population.

during the 1999 kharif season. The mean yield over the 1991-98 kharif seasons also indicated a similar trend. Results suggest that applying medium fertilizer doses (150:75:75:20) with organic manures, combined with a normal plant population, gave better yields than using a higher dose of organic and inorganic nutrient sources coupled with a higher plant population, without encouraging BPH incidence.

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Effect of intercropping grain legume and green manure for multiple use on rice

R. Kalpana, S.P. Palaniappan, and S. Mythili, Department of Agronomy, Tamil Nadu Agricultural University (TNAU), Coimbatore, India

Multipurpose legumes can be grown in the summer, grain and haulms harvested (for fodder), and the ratooned regrowth used as green manure for the following rice crop. By adopting such a system, farmers get additional income from legume grains, fodder for animals, and green manure for rice. One such system involving red gram and green gram intercropped with two green manure crops was evaluated.

Field experiments were conducted at TNAU, Coimbatore, during the summer (Mar-Jun) and monsoon (Jul-Oct) seasons. The soil of the experimental field was black clay, classified taxonomically as Vertic Ustochreft, with low available N, medium available P, and high available K. Prerice crops included grain legumes, such as green gram (*Vigna radiata*) variety CO 45 and red gram (*Cajanus cajan*) variety ICPH 73, and green manure crops *Sesbania rostrata* and *S. aculeata*. In the intercropped stand, grain legumes and green manure crops were raised in a 3:1 proportion. The grain legume and green manure treatments were laid out in a randomized block design and replicated thrice.

The green manure crops were cut 45 d after sowing at a height of 30 cm from the ground using sickles. Immediately after cutting, plants were irrigated and allowed to regenerate. Green gram was harvested and the haulms were removed for fodder. Red gram was harvested by picking the pods; the remaining red gram stalks and green manure biomass were cut and incorporated *in situ*. These were allowed to decompose for 10 d and then the succeeding rice crop was transplanted. Variety CO 45 was raised in a split-plot design and replicated thrice with eight treatment combinations of grain legumes and green manure crops in the main plots and three levels of N (0, 50, and 100 kg ha^{-1}) in the subplots. Biometric observations and yield were recorded at different stages of crop growth for prerice crops and rice.

Results indicated that *S. rostrata* yielded significantly higher biomass than *S. aculeata* and hence contributed significantly more to rice. The intercrop treatments resulted in significantly higher biomass and N accumulation over the sole grain treatments. Grain legumes yielded 0.3–0.4 t ha^{-1} when intercropped with green manure crops. The green manure crops gave 10.3–13.4 t of fodder ha^{-1} and their ratoon regrowth contributed 4.7–7.5 t of green manure biomass ha^{-1}. Incorporation of red gram stalks and ratooned green manure biomass contributed 16–55 kg N ha^{-1} (Table 1).

Rice yield, obtained by incorporating sole *S. rostrata*/*S. aculeata* along with the application of 50 kg N ha^{-1}, was on a par with yield from the treatment with 100 kg N ha^{-1}, resulting in a savings of 50 kg N ha^{-1}. It was also found that after applying sole *Sesbania* spp. without fertilizer N, rice yields (3.6 t ha^{-1}) were on a par with yields obtained with 50 kg N ha^{-1} alone (3.8 t ha^{-1}). These results show the possibility of saving 50 kg N ha^{-1} by incorporating green manure (Table 2).

Table 1. Biomass production and yield of grain legumes and green manure crops.

Treatment[a]	Grain yield (t ha^{-1})	Biomass removed for fodder (t ha^{-1})	Biomass incorporated (t ha^{-1})	N contribution (kg ha^{-1})
Sole GG	0.4	7.4	–	–
Sole RG	0.7	6.8	3.1	16.7
Sole SA	–	22.7	12.0	73.5
Sole SR	–	24.9	15.6	82.2
GG + SA	0.3	12.2	4.8	33.5
GG + SR	0.3	13.4	5.5	42.5
RG + SA	0.4	10.3	70.4	50.9
RG + SR	0.3	11.2	7.5	55.8
CD (P = 0.05)	–	1.32	0.11	0.70

[a]GG = green gram, RG = red gram, SA = *Sesbania aculeata*, SR = *S. rostrata*.

Table 2. Grain yield of rice (t ha^{-1}).

Treatment[a]	N_0	N_{50}	N_{100}	Mean
Sole GG	2.7	3.8	4.6	3.7
Sole RG	3.0	4.3	5.0	4.1
Sole SA	3.6	5.6	6.0	5.0
Sole SR	3.6	5.6	6.1	5.1
GG + SA	3.2	4.8	5.2	4.4
GG + SR	3.3	4.8	5.3	4.5
RG + SA	3.4	5.0	5.4	4.6
RG + SR	3.5	5.1	5.7	4.8
Mean	3.3	4.9	5.4	
		SEd	CD (P = 0.05)	
	T	0.17	0.36	
	N	0.10	0.21	
	T at N	0.29	0.61	
	N at T	0.30	0.61	

[a]GG = green gram, RG = red gram, SA = *Sesbania aculeata*, SR = *S. rostrata*, SEd = Standard error of the difference.

Comparative growth performance of rice and the weed *Echinochloa oryzicola* in lowland and upland conditions

N. Trillana, IRRI; R. Chaudhary, Participatory Rural Development Foundation, India; T. Inamura and T. Horie, Faculty of Agriculture, Kyoto University, Japan E-mail: n.trillana@cgiar.org

Most upland rice cultivars grow successfully in flooded conditions, whereas most lowland rice cultivars can survive in well-watered aerobic soils. It is known that rice has C_3 photosynthesis, whereas the weed *Echinochloa oryzicola* possesses a C_4 photosynthetic pathway. It was hypothesized that plant species with a C_4 photosynthetic pathway had a greater growth rate than C_3 plants (Black 1971). Scientists such as Baskin and Baskin (1978) reviewed several studies and obtained results that generally disagreed with the hypothesis. They suggested that many factors other than the C_4 pathway are more important in determining plant growth rate. Little is known about the comparative growth performance of rice in upland and lowland field conditions with *E. oryzicola* as a "vegetative mimic" of rice. This study compared the growth performance of rice and *E. oryzicola* under upland and lowland conditions and determined related photosynthetic traits such as stomatal conductance and net photosynthetic rate.

A field experiment was conducted at the Kyoto University crop science experimental site. Two rice cultivars of different ecotypes—IET1444, an indica upland rice that originated from India, and Nipponbare, a lowland japonica from Japan—and the weed *E. oryzicola* were used in this study. Upland and lowland fields were prepared and laid out in a randomized complete block design with three replications. Fourteen-day-old seedlings were transplanted in the field. In the upland field, watering was done three times a week; in the lowland field, continuous irrigation was employed by maintaining a 2–3-

cm water depth. Five plants from each replication were sampled at 15 and 30 d after transplanting (DAT) for growth analysis. Plant height was measured as length from the soil surface to the longest leaf tip. Leaf area measurements were made with a leaf area meter. Plant parts were categorized into leaf, stem, and root; oven-dried at 65 °C for 96 h; and then weighed.

Calculations of relative growth rate (RGR), leaf area ratio (LAR, ratio of leaf area to total plant weight), and unit leaf rate [ULR (E) = dW/dT × 1/LA, where W = total dry weight, T = time, LA = leaf area, and dW/dT is the value at a time when LA is known] were made using standard equations described by Evans (1972) and Nobel (1983). Photosynthetic responses such as stomatal conductance (g_s) and net photosynthesis (Pn) were also measured using the leaf chamber analysis (LCA-3) machine at 15 and 30 DAT. Student's t tests were used to determine significant differences in growth and photosynthetic responses.

Results showed that *E. oryzicola* had a significantly higher RGR than rice cultivars IET1444 and Nipponbare under both upland and lowland conditions (Table 1). IET1444 had a significantly higher RGR than Nipponbare in the upland, but they had a similar RGR in the lowland (Table 1). The RGR of all test materials declined during the course of the experiment. This was attributed to the decline in ULR because of self-shading (Table 1). There were no consistent differences in ULR between the weed and the two rice cultivars in either upland or lowland conditions (Table 1). The LAR of *E. oryzicola* in both lowland and upland conditions was considerably higher than that of the two rice cultivars; IET1444 had a significantly higher LAR than Nipponbare during the 30-d growing period. The increase in LAR in all three test materials was observed under lowland conditions from 15 to 30 DAT. In contrast, LAR decreased in the upland field (Table 1). *E. oryzicola* also had a higher photosynthetic rate than the two rice cultivars (Table 2).

Results show that the weed *E. oryzicola* had a higher and faster growth rate than rice under both upland and lowland conditions; greater differences were observed in the lowland. The overall higher growth performance of *E. oryzicola* was associated with its

Table 1. Relative growth rate (RGR, wk^{-1}), unit leaf rate (ULR, g m^{-2} wk^{-1}), and leaf area ratio (LAR, cm^2 g^{-1}) of two rice cultivars and the weed *E. oryzicola* at 15 and 30 DAT grown under upland and lowland field conditions. (Mean total dry weights per plant are computed based on a log_{10} scale.)

Growth trait	Sampling date	Weed *E. oryzicola*[a]	Rice cultivar	
			IET1444	Nipponbare
Lowland field				
RGR	15	0.397 ± 0.0016 a	0.358 ± 0.013 b	0.347 ± 0.007 b
	30	0.320 ± 0.033 a	0.235 ± 0.024 b	0.180 ± 0.021 b
ULR	15	4.393 ± 0.106 a	3.846 ± 0.235 b	1.588 ± 0.621 a
	30	3.813 ± 0.178 ab	3.314 ± 0.358 b	3.848 ± 0.208 b
LAR	15	80.16 ± 1.83 a	78.70 ± 1.99 a	57.70 ± 0.36 b
	30	93.62 ± 2.17 a	73.19 ± 1.79 b	64.35 ± 3.97 c
Upland field				
RGR	15	0.328 ± 0.019 a	0.292 ± 0.022 b	0.180 ± 0.005 c
	30	0.286 ± 0.014 a	0.237 ± 0.025 b	0.119 ± 0.043 c
ULR	15	4.453 ± 0.279 a	4.425 ± 0.274 a	4.387 ± 0.265 a
	30	2.953 ± 0.203 c	3.962 ± 0.291 b	2.727 ± 0.151 c
LAR	15	83.13 ± 4.48 a	74.44 ± 1.44 b	60.23 ± 0.83 c
	30	77.44 ± 1.50 a	67.90 ± 2.93 b	59.89 ± 0.58 c

[a]Values for the same entry in a row in the two growing conditions (upland and lowland) followed by the same letter are not significantly different. Shown ± SD.

Table 2. Stomatal conductance (g_s, cm s^{-1}) and net photosynthesis (Pn, µmol CO_2 m^{-2} s^{-1}) of two rice cultivars and the weed *E. oryzicola* at 15 and 30 DAT under upland and lowland field conditions.

Physiological trait	Sampling date	Weed *E. oryzicola*	Rice cultivar	
			IET1444	Nipponbare
Lowland field				
g_s	15	0.38 b	0.96 a	0.99 a
	30	0.39 c	0.55 b	0.86 a
Pn	15	19.47 a	15.83 b	14.90 b
	30	20.03 a	8.47 c	13.17 b
Upland field				
g_s[a]	15	0.37 c	0.81 a	0.75 b
	30	0.22 c	0.33 b	0.72 a
Pn[a]	15	13.10 a	12.93 b	13.90 a
	30	14.53 a	9.07 b	5.97 c

[a]Values in a row followed by the same letter are not significantly different at $P<0.05$.

higher photosynthetic rate. Between the two rice cultivars, IET1444 had better growth in the upland than Nipponbare; however, it was not associated with photosynthetic response.

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Evaluation of stand establishment techniques in lowland irrigated rice

M.N. Budhar and N. Tamilselvan, Regional Research Station, Tamil Nadu Agricultural University (TNAU), Paiyur 635112, South India

Transplanting of rice seedlings is an age-old practice. In recent years, the migration of labor to the industrial sector, especially in India, has led to the nonavailability of labor for transplanting at the appropriate time, resulting in a yield reduction. This method of stand establishment is also laborious and time-consuming and results in drudgery among women workers. Cultivation practices, such as nursery preparation and management, fertilizer and pesticide application and irrigation to the nursery, pulling out seedlings, and transplanting in the main field, account for the major share of cultivation costs. Hence, an alternative method had to be found to overcome problems encountered in using the transplanting technique.

Direct seeding and throwing of seedlings under puddled conditions are viable alternatives to transplanting. Matsushima (1980) cited the advantages of throwing seedlings over a puddled field instead of transplanting. Hence, a study was conducted to evaluate the feasibility of different stand establishment techniques in lowland irrigated rice during the 1999 wet season (Aug-Dec) and 2000 dry season (Feb-May).

Four stand establishment techniques—transplanting (T_1), seedling throwing (T_2), direct seeding by manual broadcasting (T_3), and wet seeding by a drum seeder (T_4)—were tested in a randomized block design with five replications. The test variety was ADT43 (110 d) and the recommended dose of NPK (125:50:50 kg ha^{-1}) was applied. In transplanting, the recommended 15 × 10-cm spacing was adopted. Seedling throwing consisted of separating two or three seedlings, as is done during normal transplanting, and randomly throwing them in a standing position on a puddled and leveled field to maintain the same plant density per unit area. Twenty-day-old seedlings were used for transplanting and seedling throwing. Seeding rates of 80 and 100 kg ha^{-1} were used for drum seeding and manual broadcasting, respectively. Sprouted seeds were used for direct seeding. The eight-row drum seeder used in this trial was developed by TNAU's Department of Agricultural Engineering.

The various stand establishment techniques—direct (wet) seeding by manual broadcasting or a drum seeder or transplanting—showed no significant difference in grain yield in both seasons (see table). In a pooled analysis of two seasons, grain yield was highest in wet seeding by manual broadcasting, closely followed by direct seeding using a drum seeder and traditional transplanting. A similar trend was observed in straw yield. Although wet seeding by manual broadcasting and drum seeding had no significant difference in grain yield, intercultural operations, such as weeding and spraying, could be easily adopted in wet seeding by a drum seeder since there is a definite row arrangement. In both wet-seeding practices and seedling throwing, the cultivation cost was less than with transplanting; less labor cost translated into an increase in income. In both seasons, the net income and benefit-cost ratio were highest in wet seeding by manual broadcasting, closely followed by wet seeding by a drum seeder. Using wet seeding by manual broadcasting and a drum seeder could result in a higher net income and benefit-cost ratio than traditional transplanting. Both direct-seeding

Effect of stand establishment techniques on yield and economics of lowland irrigated rice.

Treatment	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})			Days to 50% flowering		Net income (Rs ha^{-1})[a]			Benefit-cost ratio		
	Wet	Dry	Mean	Wet	Dry	Mean	Wet	Dry	Wet	Dry	Mean	Wet	Dry	Mean
T_1 Transplanting	6.0	5.2	5.6	9.6	7.5	8.6	85.6	78.6	18,666	12,984	15,825	2.10	1.76	1.93
T_2 Seedling throwing	4.9	4.7	4.8	8.1	6.9	7.5	85.2	79.0	14,853	12,605	13,732	2.01	1.86	1.93
T_3 Wet seeding: broadcasting manually	6.1	5.3	5.7	9.3	7.6	8.4	76.8	73.0	21,551	16,529	19,039	2.51	2.16	2.33[b]
T_4 Wet seeding: drum seeder	6.1	5.3	5.6	9.1	7.5	8.3	76.8	72.8	21,214	15,959	18,587	2.48	2.11	2.29[b]
CD at 5%	0.13	0.13	0.11	0.53	0.55	0.11	2.0	1.7	na	na	na	na	na	na

[a]US$1 = Rs 46. [b]Additional seed cost also included. na = not applicable.

practices reduced the time to 50% flowering by 6 and 9 d in the wet and dry seasons, respectively, since the seedlings did not suffer from transplanting shock as in transplanting and seedling throwing. Santhi et al (1998) reported similar benefits of direct seeding over transplanting.

Thus, direct (wet) seeding, preferably through the drum seeder, could be recommended wherever labor is scarce and costly. In this way, farmers could obtain higher net incomes besides shortening the field-use duration in lowland irrigated rice.

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Influence of seedling age and number of seedlings on yield attributes and yield of hybrid rice in the wet season

M.A.H. Molla, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Department of Agronomy, Mohanpur 741252, West Bengal, India E-mail: drzaman@cal3.vsnl.net.in

In the irrigated rice ecosystem that uses high-yielding varieties (HYVs), yields have already started plateauing. In India, where it is not possible to put more area into rice cultivation, adopting hybrids with suitable management practices would certainly be an alternative for increasing rice productivity. A study conducted at the C Block Seed Farm of BCKV during the 1998 and 1999 wet seasons examined the performance of hybrids as well as HYVs with different seedling ages and seedling number hill^{-1}.

The field was sandy loam to clay loam with a neutral soil reaction. Seeds were collected from the Rice Research Station in Chinsurah. Treatments consisted of two hybrid rice cultivars (Pro-Agro 6201 and CNRH 3) and one HYV (IET4786), two seedling ages (21 and 28 d), and two levels of seedling number hill^{-1} (1 and 2 seedlings hill^{-1} for hybrid rice and 3 and 6 seedlings hill^{-1} for the HYV). The crop was transplanted in the last week of July for both seasons using the rectangular planting method. The spacing was 20 cm × 10 cm. A dose of 80 kg N, 17.6 kg P, and 33.2 kg K ha^{-1} was applied under recommended practices of split doses of N and K. The experiment was laid out in a factorial randomized block design with three replications. Results revealed that Pro-Agro 6201 gave a significantly higher yield than IET4786, not only because of more mature panicles m^{-2} but also because of a higher number of filled grains panicle^{-1} and greater seed weight. Pro-Agro 6201 showed a more profuse tillering habit at an early stage than the HYV, which could be due to hybrid vigor (heterosis). Twenty-eight-day-old seedlings produced more tillers, panicles m^{-2}, and grain yield than did 21-d-old seedlings, which performed poorly because of insufficient growth at earlier stages. Seedlings hill^{-1} significantly influenced number of tillers and mature panicles m^{-2} and, consequently, rice yield. Two seedlings hill^{-1} gave a significantly higher yield than one seedling, along with

Effect of seedling age and seedling number hill^{-1} on yield and yield attributes of hybrid rice.

Treatment	Tillers m^{-2} (no.)		Mature panicles m^{-2} (no.)		Filled grains panicle^{-1} (no.)		1,000-grain weight (g)		Grain yield (t ha^{-1})	
	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
Cultivar										
Pro-Agro 6201	422	419	332	335	83.2	86.0	21.74	21.64	5.6	5.5
CNRH 3	410	409	319	317	80.0	81.0	21.38	21.41	5.3	5.3
IET4786	345	349	266	268	75.4	76.7	21.16	21.33	4.2	4.1
CD[a] (5%)	9.6	8.7	7.0	6.3	2.38	2.30	0.124	0.112	0.178	0.172
Age of seedling										
21 d old	388	385	300	301	78.8	80.6	21.42	21.40	4.8	4.8
28 d old	402	400	311	312	80.2	82.1	21.44	21.42	5.3	5.1
CD (5%)	7.9	7.1	5.7	5.1	ns	ns	ns	ns	0.145	0.139
Seedling number hill^{-1}										
Hybrid										
1	406	408	318	320	83.3	84.0	21.60	21.50	5.3	5.3
2	424	422	333	332	79.9	83.4	21.52	21.55	5.6	5.5
HYV										
3	345	342	261	265	77.0	75.9	21.02	21.35	4.1	4.1
6	363	356	270	272	73.8	77.5	21.30	21.31	4.4	4.1
CD (5%)	18.5	12.3	10.0	8.9	ns	ns	ns	ns	0.251	0.221

[a]CD = coefficient of determination.

other parameters in hybrid cultivars. For the HYV, no significant response was obtained by increasing the number of seedlings from three to six (see table). Thus, it was concluded that hybrid Pro-Agro 6201 could be grown profitably, replacing IET4786 (HYV) using 28-d-old seedlings transplanted at two seedlings hill^{-1}. Three seedlings hill^{-1} were sufficient for growing IET4786.

Effect of cooking on aleurone in the caryopsis of indica rice

A.B. Nadaf and S. Krishnan, Department of Botany, Goa University, Goa 403206, India

Aleurone, the principal nourishing layer in the rice grain, consists of one to several layers of uniform, highly differentiated cells (Beteke et al 1997). In cooking, the starchy components in the caryopsis expand both laterally and vertically. This study was undertaken to determine the effect of cooking on aleurone in the rice caryopsis. Local varieties used in this study were long-, medium-, and short-grain types. Rice grains were dehusked manually and cooked in a domestic cooker with excess water, with and without aleurone. To attain a caryopsis without aleurone, the aleurone layer was manually removed. For the measurement, an average of 100 grains was used.

The caryopsis cooked with aleurone showed three specific patterns of aleurone breakage—breakage at one end, breakage at both ends, and longitudinal breakage. Longitudinal breakage was maximum in all varieties, except Ambemohar. Varieties Ghansal and Kothmirsal were followed by IET lines, Pusa Basmati, Kernal Local, Jaya, and Jyoti with one-end breakage. IET15392 and IET13549 recorded 100% longitudinal breakage of aleurone. Local short-grain varieties such as Ambemohar, Ghansal, and Kothmirsal showed maximum breakage at one end. The caryopsis cooked without aleurone showed maximum elongation in all varieties studied (see figure). The caryopsis cooked with aleurone acted as a limiting factor to the expansion. However, the pressure exerted by the components made the aleurone layer break (see figure).

The table shows that the caryopsis cooked with aleurone, which broke at both ends, had the maximum length, whereas the grain with longitudinal breakage had maximum breadth. Among the varieties studied, IET15396 had the maximum length (2–13 cm), with breakage at two ends; maximum breadth was recorded in Jyoti (0.54 cm), with longitudinal breakage. Data show that longitudinal breakage is directly proportional to grain length.

Different varieties of rice with and without palea and lemma (upper two rows). Rice caryopsis with aleurone (A) and without aleurone (B) after cooking. Note the maximum elongation in the caryopsis cooked without aleurone (B). The aleurone layer acts as a limiting factor that minimizes elongation (A).

Dimensions of cooked grains with and without the aleurone layer in some rice varieties.[a]

Variety	Before cooking		Grains with aleurone with breakage at						Grains without aleurone	
			One end		Two ends		Along the furrow			
	Length (cm)	Breadth (cm)	Length (cm)	Breadth (cm)	Length (cm)	Breadth (cm)	Length (cm)	Breadth (cm)	Length (cm)	Breadth (cm)
IET12875	0.74	0.25	1.78	0.42	1.72	0.42	1.04	0.52	1.42	0.53
IET13548	0.70	0.24	1.30	0.40	1.34	0.41	1.01	0.52	1.38	0.51
IET13549	0.72	0.25	–	–	–	–	1.09	0.52	1.26	0.51
IET14131	0.71	0.20	1.30	0.50	1.50	0.40	0.97	0.50	1.33	0.50
IET15390	0.84	0.20	1.40	0.30	1.94	0.39	1.12	0.43	1.92	0.43
IET15391	0.85	0.20	–	–	1.07	0.40	1.12	0.54	1.74	0.42
IET15392	0.92	0.20	–	–	–	–	1.10	0.50	1.71	0.42
IET15396	0.83	0.20	1.82	0.30	2.13	0.30	1.15	0.45	2.37	0.35
Pusa Basmati	0.84	0.20	1.40	0.30	1.66	0.31	1.19	0.38	1.91	0.42
Kernal Local	0.85	0.20	1.40	0.50	1.60	0.35	1.11	0.44	1.55	0.45
Ambemohar	0.48	0.25	1.18	0.37	–	–	0.72	0.52	1.12	0.41
Ghansal	0.49	0.25	0.90	0.41	–	–	0.64	0.48	0.92	0.50
Kothmirsal	0.46	0.25	1.01	0.36	–	–	0.74	0.50	0.82	0.49
Girga	0.45	0.24	0.88	0.32	–	–	0.68	0.47	0.80	0.46
Jaya	0.62	0.25	1.32	0.58	1.43	0.46	1.03	0.52	1.49	0.47
Jyoti	0.67	0.25	1.05	0.40	1.23	0.42	1.01	0.54	1.43	0.45

[a]– = not recorded.

Little and Dawson (1960) recorded breakage of the aleurone layer in the ventral side, along the longitudinal fissure. They also found that splitting of bran occurs at irregular points around the surface with no fixed pattern. The study, however, clearly revealed three specific patterns of breakage of aleurone. When longitudinal breakage occurs, it takes place on one lateral side of the caryopsis, where the aleurone is thin and where the lemma and palea join, and not on the ventral side as shown by Little and Dawson (1960). This study also clearly revealed that the caryopsis cooked without aleurone showed maximum elongation compared with that cooked with aleurone. Thus, the aleurone layer limits both vertical and lateral expansion.

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Acknowledgment

The authors thank the Council for Scientific and Industrial Research (CSIR) (no. 38(0989)/ /EMR-II), New Delhi, India, for assistance.

Response of rice genotypes to dissolved oxygen during seedling establishment under lowland conditions

J.K. Biswas, H. Ando, and K.I. Kakuda, Faculty of Agriculture, Yamagata University, 997-8555, Tsuruoka, Japan
E-mail: biswasjiban@hotmail.com

Despite its high oxidation potential, calper coating cannot ensure stable seedling establishment under direct-seeded lowland culture (Hagiwara and Imura 1995). Varying responses of calper to soils in accumulating dissolved oxygen (DO) and to genotype may affect seedling establishment in the lowland environment. A study was conducted using two soils: soil (Inceptisols, pH 4.8) collected from an upland and calcareous soil (Entisols, pH 6.8) collected from Akita Prefecture, Japan. The organic C content of both soils was 4%. To manipulate DO, one or five coated or noncoated seeds of Haenuki or Sasanishiki (rice genotype) were sown in test tubes containing 5 g of soil flooded by 10 mL of water and allowed to grow for 7 d at 30 °C in the dark.

Irrespective of calper coating, Akita soil accumulated only a trace amount of DO. Accumulated DO in upland soil for one and five coated seeds was 10.6 and 20.0 mg L^{-1}, respectively, measured using the hand-held DO temperature system (YSI model 55). Seedling establishment was excellent for Haenuki in both Akita and upland soils (Fig. 1). Compared with Haenuki, seedling establishment in Sasanishiki was poorer in Akita soil. The upland soil showed a fair amount (4.3–4.4 mg L^{-1}) of accumulated DO in noncoated seeds. Under this condition, the establishment of Sasanishiki was excellent. With an increase in accumulated DO, the establishment and subsequent growth of this genotype decreased exponentially (Figs. 1 and 2). Seedling establishment and first-leaf growth of Haenuki were not affected by DO accumulation. However, its subsequent growth followed a polynomial pattern (Fig. 2) as shown by plant height and root elongation.

Results suggest that Sasanishiki did not tolerate either anoxia (0–0.12 mg L^{-1} of DO) or accumulated DO equivalent to or more than the aerobic level under flooded conditions. Aerobic conditions can enhance oxygen uptake seven times faster than can anaerobic conditions (Biswas 1994). Therefore, under saturated levels, accumulated DO was supposed to be consumed as soon as possible. Hence, germinating seeds were forced to encounter anaerobic stress. Since the oxidizing effect of calper is short-lived (Hagiwara and Imura 1995),

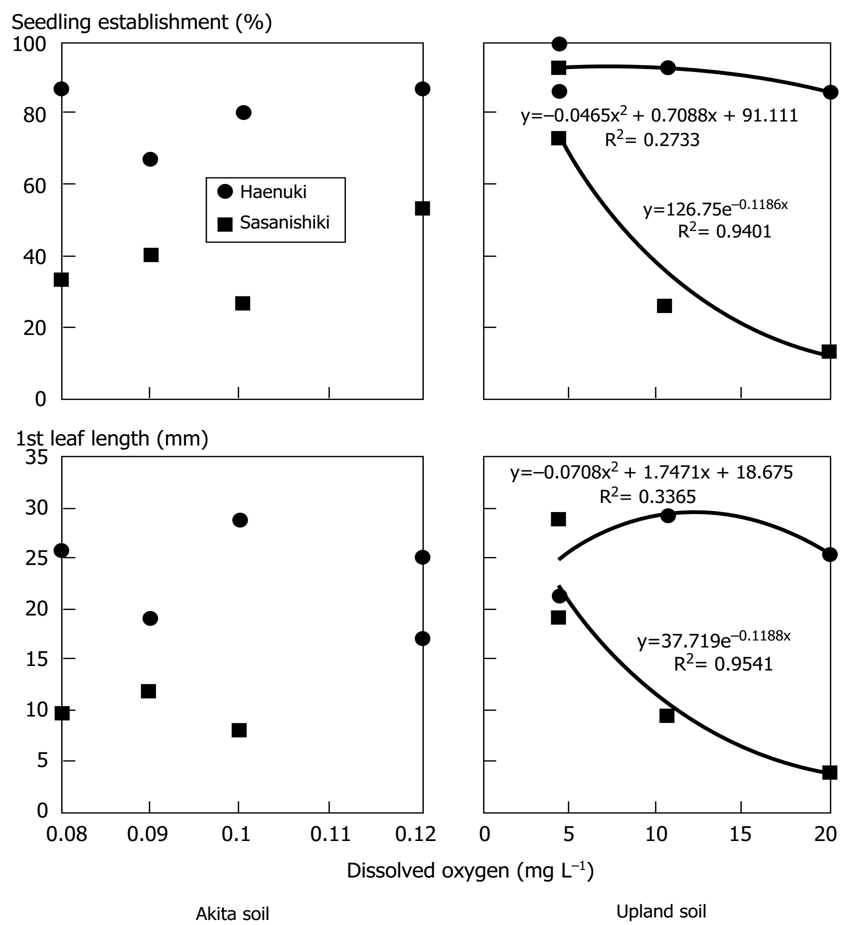

Fig. 1. Effect of dissolved oxygen (DO), soil, and genotype on seedling establishment and 1st leaf length.

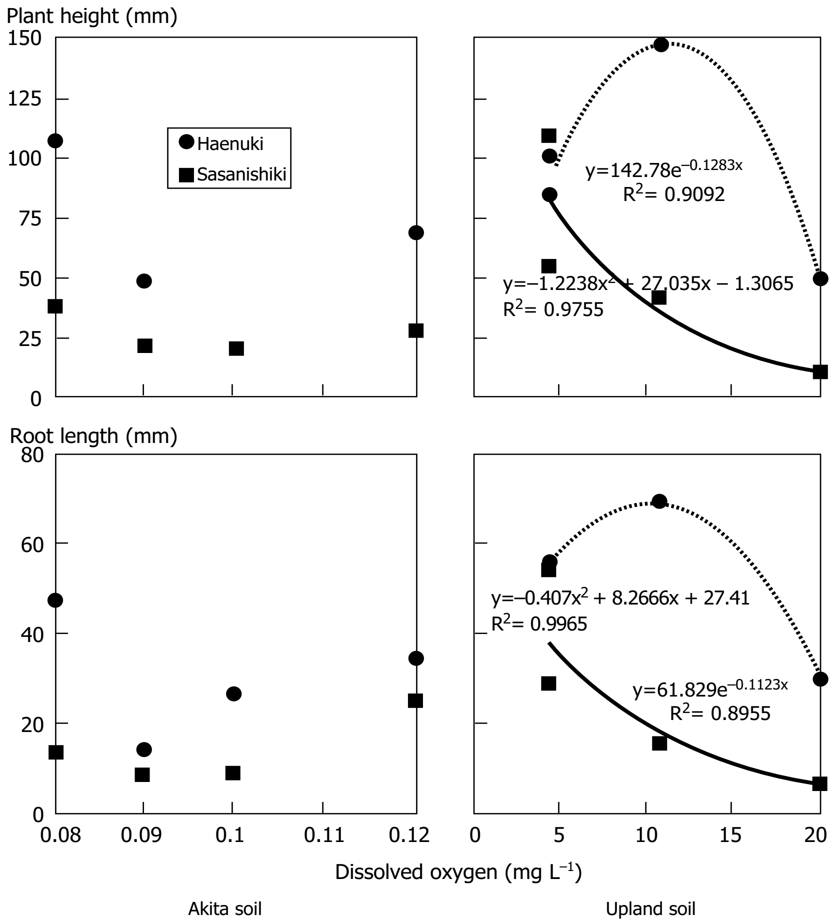

Fig. 2. Effect of dissolved oxygen (DO), soil, and genotype on plant height and root length.

anaerobic stress on the seed has an irreparable effect. Haenuki may have tolerance for anoxia to sustain the stress. In contrast, Sasanishiki could not overcome the stress most probably because of its inability to withstand anoxia. Thus, the efficiency of calper coating seems to depend on both soil and genotype.

Acknowledgment

The senior author is indebted to the Japanese Society for the Promotion of Science (JSPS) for providing the postdoctoral fellowship to perform this work.

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The International Rice Functional Genomics Working Group

To facilitate collaboration and transfer of new findings from genomic research to applications, IRRI organized the International Rice Functional Genomics Working Group. The Working Group has the following objectives:

- Build a research community with a shared vision on rice functional genomics
- Create a common resource platform to broaden access to new knowledge and tools in functional genomics
- Accelerate application of functional genomics to rice improvement

The Working Group is intended to be broad-based collaborative network that will benefit participants by pooling expertise and resources. To date, several institutions have expressed interest to participate in this working group.

Through a series of meetings and consultations, three activities that are considered high priority by the rice research community were identified:

1. Create an information node to communicate information related to functional genomics
2. Promote the sharing of genetic stocks
3. Facilitate sharing of resources for microarray analysis

A Web-based information node was established as an entry point for finding and sharing information and providing links to individual laboratories or organizations with interest in rice functional genomics. For more information about the site and the Working Group, go to: http://www.cgiar.org/irri

To send comments, inputs, and suggestions, write or e-mail: genomics@irri.exch.cgiar.org

Water fees for irrigated rice in Asia

M.S. Valencia, D. Dawe, P. Moya, and D. Pabale, IRRI E-mail: d.dawe@cgiar.org

Because of increasing demand for domestic and industrial uses, water will be in short supply for agriculture, and it will be important to allocate and use water efficiently. Yet, because agricultural water prices are often low, farmers have little incentive to apply water efficiently to a given crop or to choose crops that economize on water use. The purpose of this paper is to document the level of water fees from various surface-water irrigation systems in different countries in Asia and to compare these fees to the costs of other important inputs used in production. Water fees (prices) are defined here as any financial charges levied by the government that allow farmers to divert water from irrigation canals constructed with government funds.

This paper uses data collected from six sites of the joint IRRI-national agricultural research systems project "Reversing Trends of Declining Productivity" (RTDP) located in India, Vietnam, China, the Philippines, Thailand, and Indonesia (Moya et al 2002). Irrigation at all of these sites is primarily from surface water and requires little or no government or communal pumping to reach farmers. All sites grow at least two rice crops per year and are located in the traditional "rice bowls" of Asia, where water is often plentiful (at least in the wet season) and, historically, little water is used by households and industry.

Surface-water fees are by far highest at sites in China and the Philippines (see table). Within China, agricultural surface-water fees vary substantially across regions, depending on the relative degree of water scarcity. The data reported here come from Zhejiang Province, south of the Yangtze River, where water is much more plentiful than in the Yellow River Basin. Thus, although these water fees are the highest among the six sites, they are substantially lower than those on the north China plain. They are also lower than water fees reported by Moya et al (2001), which averaged US$35 ha^{-1} for two villages in the Zanghe Irrigation System in Hubei Province (located in the Yangtze River Basin). This varied within the system because fees depend on the quantity of water diverted by the farmers' irrigation group.

Throughout the Philippines, water fees are assessed in terms of a fixed quantity of rice (per hectare) valued at the government support price. This quantity is higher in the dry season than in the wet season. Because rice prices are much higher in the Philippines than in neighboring countries, this partially explains the high absolute level of water fees. However, even as a share of gross revenue, water fees in the Philippines are still higher than in neighboring countries (with the exception of China). In the mid-1990s, water fees were about double current levels. However, the previous administration decided to lower fees in an effort to win the support of farmers.

While the level of water fees appears to be generally higher in China and the Philippines than at other sites in the survey, water fees are still substantially less of a burden for farmers than fertilizer costs. At these two sites, the share of water fees in gross revenue is closer to that of pesticides (see table).

Irrigation fees for farmers at RTDP sites in the other four countries were substantially lower than those in China and the Philippines. Farmers in Thailand and

Irrigation fees and fertilizer costs at six RTDP project sites, 1999.[a]

Site	Irrigation cost ($ ha^{-1} crop^{-1})	Fertilizer cost as share of gross revenues (%)	Irrigation cost as share of gross revenues (%)	Pesticide cost as share of gross revenues (%)
Aduthurai, Grand Anicut Dam, Cauvery Delta, Tamil Nadu, India	0	7	0.0	0.0
Cuu Long, Cantho, Mekong Delta, Vietnam	6	13	1.0	4.1
Jinhua, Zhejiang, China[b]	25	12	2.5	3.0
Nueva Ecija, Upper Pampanga River Irrigation System, Central Luzon, Philippines	13	7	1.5	2.2
Suphan Buri, Pho Phaya Irrigation System, Central Plain, Thailand	0	10	0.0	6.9
Sukamandi, Jatiluhur Irrigation System, West Java, Indonesia	4	5	0.5	4.3

[a]Data are averages of two crops. [b]Data for China pertain to 1998.

India paid no water fees at all. While these areas may have a plentiful supply of water (at least in the wet season), the opportunity cost of using this water for other purposes will rise as economic development proceeds, and it will become increasingly important to allocate water more efficiently. The current system of low prices at these sites appears to hinder such efficient allocation.

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Farmers' participatory identification of gall midge (*Orseolia oryzae* Wood-Mason)-resistant rice varieties for desired characters

H.S. Singh, Central Horticultural Experiment Station, Indian Council for Agricultural Research (ICAR), Plandu, PO-Rajaulatu, Tata Road, Ranchi, Jharkhand; H.K. Awasti, and S.M. Kumar, Indira Gandhi Agricultural University (IGAU), Krishi Vigyan Kendra, PO-Pala, Balaghat, Madhya Pradesh, India

Rice is cultivated on 24,000 ha, mostly under rainfed conditions, with an average production of approximately 1.1 t ha^{-1} in Balaghat District of Madhya Pradesh, India. The average annual rainfall in the district is 1,600 mm, with 70% occurring from mid-June to late September. Consequently, nearly 70% of the rice area under medium and low-lying conditions is transplanted. Being located near gall midge (*Orseolia oryzae* Wood-Mason)-prone areas such as Raipur and Sakoli, the rice crop in the district suffers almost every year from attacks from this pest. The state government of Madhya Pradesh had introduced gall midge-resistant varieties such as Asha, Surekha, and IR36. However, farmers stopped growing resistant varieties, except for IR36, after one or two cropping seasons because they did not meet their requirements. Consequently, susceptible varieties (e.g., Kranti, Kalture, MW10) possessing characteristics desired by farmers were adopted. In recent years, heavy gall midge attacks in the district compelled farmers to look for resistant varieties with the desired characteristics.

To reduce losses caused by the pest, factors that contributed to gall midge incidence were pinpointed for appropriate intervention and resistant rice varieties with the desired characters were identified through a three-phase farmers' participatory program in the district by IGAU from 1994 to 1997.

Through brainstorming sessions, interactive group discussions, and matrix ranking with 123 farmers from 36 villages and 21 rural agricultural extension officers, the factors contributing to gall midge incidence were identified in the first phase of the program (Table 1). In the second phase, 11 rice varieties (resistant as well as local susceptible varieties as checks) were collected from IGAU and local farmers. These were grown and evaluated by 125 farmers at four growth

Table 1. Factors that farmers think contributed to gall midge incidence in rice.

	Factors (in order of priority)
1	Lack of resistant varieties with desired characters and use of susceptible varieties
2	Unbalanced use of fertilizers—i.e., high N, less P, and little or no K
3	Continuous rain from July to September, resulting in waterlogging and making insecticides ineffective
4	No direct seeding and late transplanting because of dependence on rain
5	Summer rice cultivation and late harvesting just before the onset of the next cropping season, leading to pest multiplication
6	Late and suboptimal dose of insecticides
7	No preventive control measures and lack of alternative control measures
8	Poor technical know-how and poor economic conditions to combat pest attack
9	Dependence on unskilled laborers

stages—tillering, panicle formation, milking, and maturity—and at postharvest for desired characters (Table 2). Farmers used evaluation sheets to rate the varieties. Scores for each variety at every evaluation stage were averaged. Based on these averages, six varieties—Mahamaya, Baibhav, Kalture, R296-260, Abhaya, and Purnima—were selected by farmers (Table 3). Kalture was already being used by farmers, so the other five varieties were evaluated in farmers' fields in 10 villages in the third phase of the program. These varieties were again evaluated for gall midge incidence, blast attack, grain filling, and yield. Despite its good yield potential, Abhaya was rejected in farmers' fields because of heavy blast incidence (40.2%); R296-260 was likewise rejected because of its high amount of chaffy grains (Table 3). On the basis of better performance, farmers selected and adopted varieties Mahamaya, Baibhav, and Purnima. Farmers multiplied seeds and distributed them through a farmer-to-farmer seed exchange program. Within two cropping seasons, farmers produced gall midge-resistant varieties.

Table 2. Farmers' preferred characters in a rice variety.

Characters
Gall midge-resistant
Duration is suitable for specific land types and water availability in the field
Can be sustained and yields better under water stress and biotic pressure
Tall enough to produce sufficient biomass for year-round cattle feeding, bundle making, transportation, and indoor storage
Stable yield—i.e., equal to or greater than that of existing varieties
Good market value—i.e., fit for flaked rice or parboiling
Easy threshing quality

Table 3. Performance of rice varieties evaluated by farmers.

Variety	Average score[b]	Gall midge incidence (% tillers infested)		Blast infection (% tillers infected)		Grain filling (%)		Yield (t ha^{-1})	
		IGAU farm	Farmers' field	IGAU farm	Farmers' field	IGAU farm	Farmers' field	IGAU farm	Farmers' field
Mahamaya	4.07	0.5	0.4	5.5	10.2	86.0	87.5	4.2	4.1
Abhaya	3.94	0.8	0.8	12.5	40.2	80.2	80.6	3.6	3.5
Purnima	3.88	1.1	0.0	11.6	16.6	88.9	89.6	3.2	2.9
R321-49	3.72	6.5	–	6.5	–	73.6	–	3.2	–
R37-1	3.17	45.5	–	8.5	–	88.2	–	1.8	–
R-296-260	4.18	1.2	0.7	3.1	13.5	78.6	76.5	3.8	3.8
Kalture[a]	3.95	24.6	–	8.2	–	84.3	–	3.2	–
Kranti[a]	3.19	65.6	–	16.6	–	83.0	–	1.0	–
Ananda[a]	3.14	76.7	–	16.6	–	93.6	–	0.9	–
Baibhav	4.05	2.2	0.0	3.2	14.6	80.9	82.6	3.6	3.9
IR36[a]	3.73	25.6	–	8.2	–	87.8	–	3.3	–

[a]Locally available rice varieties. [b]Av score for desired characters. Scale used: 1–5, where 1 = low and 5 = high.

Farmers' participatory evaluation of rice production technologies in Bay Islands

S.C. Pramanik, R.L. Sagar, B. Singh, and Z. Ahmed, Central Agricultural Research Institute, Port Blair 744101, Andaman, India E-mail: drpramanik@rediffmail.com

This study was conducted among farmers in the South Andaman islands through the participatory rural appraisal technique for agroecosystem analysis (Conway 1985) to evaluate the comparative performance of four different high-yielding varieties (HYVs) (Jaya, Bhavani, Mansarovar, and IR18351) with local variety C14-8 from the farmers' perspective. It also investigated the level of awareness and adoption of rice-based technologies among farmers in these islands. A sample of 150 farmers was selected randomly from five villages (i.e., 30 from each) in South Andaman District. Farmers were mostly small and marginal landholders (with a landholding of 0.1–2.0 ha) living in clusters. A group of 30 farmers in each village was asked to rank the different rice varieties prevalent in their locality based on different characteristics. Actual rice production data were collected from farmers' fields from 1995 to 2000 and adjusted to give a per hectare yield. Also, through a semistructured interview schedule, data on knowledge and adoption about the recommended package of practices in rice in these islands were collected from 150 farmers. Knowledge index (KI) and adoption index (AI) were calculated.

The ranking of rice varieties prevalent in the area showed that the majority of farmers preferred cultivating C14-8 over medium and short-duration HYVs (Table 1). Although the yield and profitability of HYVs were significantly higher, indigenous variety C14-8 had greater yield stability and less production risk than the other HYVs. The humid tropical climate, with its uncertain monsoon rainfall, favors biotic (insect pests, diseases, and weeds) and abiotic (water stress, waterlogging) stresses in rice cultivation in these islands. Moreover, because of the islands' remoteness, plant protection chemicals, farm machinery, and other infrastructure are not always available. Also, there is no government procurement system for rice. Rice cultivation among small and medium farmers is mainly subsistence in nature. Farmers observed the incompatibility of HYVs such as Mansarovar, IR18351, and Bhavani, despite their higher potential, under biotic and abiotic stress conditions in the field. HYVs are mostly cultivated in a small area (0.1 ha) because of more risks involved. HYVs are susceptible to most insect pests and diseases; hence, the risk of crop failure was high. Incessant rainfall for 8 mo (May-December), coupled with the unavailability of a covered threshing floor, threshing machine, and sunny days, made the farmers prefer long-duration photoperiod-sensitive varieties despite their low yield. These could be harvested, threshed, and stored easily during the rain-free period in December-January. Production of straw for cattle fodder was also considered an important criterion among poor, small, and marginal farmers.

Farmers' knowledge and adoption of HYVs and local varieties and key recommended packages of practices in rice were also assessed during the survey (Table 2). Only 14% of the farmers adopted HYVs. Typically,

Table 1. Farmers' ranking[a] of characteristics of several rice varieties.

Characteristic	Jaya	Bhavani	Mansarovar	IR18351	C14-8
Yield	4 (3.6)	3 (3.3)	4 (4.2)	5 (4.5)	2 (2.5)
Yield stability	3	2	2	3	5
Risk involved in cultivation	3	4	4	3	1
Profitability	4	4	4	5	2
Seed availability	3	3	2	2	5
Insect pest and disease incidence	3	4	4	3	2
Tolerance for weed infestation	2	1	1	2	5
Tolerance for water stress	1	1	1	1	3
Labor use	4	4	4	4	2
Compatibility with weather	2	2	2	3	5
Taste	2	2	2	3	5
Digestibility	2	3	3	3	5
Grain size	Medium	Medium	Medium	Medium	Coarse
Straw yield	3	3	3	3	5
Parched rice making quality[b]	2	1	1	1	5
Food security	3	2	3	3	5

[a]Scale 1–5, 1 = least/minimum, 5 = maximum/high/more/best. Yield scores were based on visual assessment by farmers. Numbers in parentheses are yields (t ha^{-1}). [b]Rice that is partially cooked, flattened, and dried.

Table 2. Knowledge and adoption of recommended technologies for rice (HYV and local) production among farmers in South Andaman villages.

Technology component	Knowledge index (KI)	Adoption index (AI)
Recommended HYV	35	14
Summer plowing	41	9
Use of certified seeds	39	13
Optimum seeding rate	46	27
Seed treatment	19	0
Nursery management	65	36
Row-to-row spacing	53	22
Plant-to-plant spacing	47	29
Weed control	47	18
Use of balanced fertilizers	26	11
Plant protection measures	49	36
Optimum time of harvesting	71	53
Postharvest technology	52	44
Av	45.4	24.0

farmers who adopted them had more land (1–2 ha), were moderately literate, had better access to infrastructure, and had fields located above low-lying valleys. Farmers had a relatively high awareness (KI = 71) of optimal harvesting time; 53% of the farmers adopted a variety that could be harvested comfortably under good weather during the dry period (AI = 53). More than half of the farmers were aware of proper nursery management and adoption of this technology was moderate (AI = 36). Because of poor knowledge of seed treatment (KI = 19), farmers did not adopt this technology (AI = 0) at all. On the whole, although many farmers (KI = 45.4), were aware of the various technologies, natural (biotic and abiotic stress) and cultural (farm labor, fertilizer, plant protection chemicals, infrastructure, and marketing facilities) constraints hindered the adoption (AI = 24) of many of these practices in rice cultivation in the South Andaman Islands.

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Apple snails
http://www.applesnail.net/

Bibliography on the golden apple snail (*Pomacea* spp.)
http://www.applesnail.net/content/contributions/biblio_joshi/bibliography.htm

The Apple Snails Web site is a well-illustrated compendium on the biology, ecology, and taxonomy of "the biggest living freshwater snails on earth. A large amount of material is devoted to the maintenance of apple snails as aquarium pets. Information on the management of apple snails as agricultural pests is limited. However, linked to the Apple Snails Web site is the Bibliography of the Golden Apple Snail, which provides full citations for papers on this pest published since 1994. (Two earlier print bibliographies, cited on the Web site, catalog the golden apple snail literature published prior to 1994.) The bibliography is maintained by scientists from the Philippine Rice Research Institute and Central Luzon State University, Philippines.

Agricultural Science and Technology Indicators
http://www.asti.cgiar.org

The Agricultural Science and Technology Indicators (ASTI) initiative compiles, processes, and makes available internationally comparable data on institutional developments and investments in agricultural research and development (R&D) worldwide, and analyzes and reports on these trends in the form of occasional policy digests for research policy formulation and priority-setting purposes. It is a joint project of the International Food Policy Research Institute (IFPRI) and the International Service for National Agricultural Research (ISNAR) in collaboration with many other organizations worldwide. This Web site contains a recent global overview report on agricultural research titled "Slow magic: agricultural R&D a century after Mendel," as well as other interesting reports and graphs on agricultural research around the world. The site also contains large time-series databases on the number of researchers and public expenditures in agricultural research for a large number of countries. Data on the site are freely available to all. One section contains links to Web sites of numerous agricultural research institutions around the world.

Mohanty BB. 1999. **Agricultural modernization and social inequality: case study of Satara District**. Econ. Polit. Wkly. 34(26):A50–A61.

Agriculture is the mainstay of the rural Indian economy. Studies on the effects of agricultural modernization in India vary in style and temper. Studies generally pose three effects of agricultural modernization on equality in India: it increases equality, decreases it, or has a mixed effect. This paper explores the nature and extent of agricultural modernization and its impact on various categories of the rural population in a historical perspective and attempts to understand the pattern and trend of social inequality.

Satara District witnessed profound changes during the British period because of the introduction of new forms of land tenure, the commercialization of agriculture, and the growth of Bombay as a center of capitalist development. Changes in agriculture had a polarizing effect on the rural population of the district since they were based on exploitative land, labor, and credit relations guided by colonial interests. This process served to impoverish many and enrich only a few. Large landholders and moneylenders, with better (irrigated) land and cheap labor, prospered, whereas the poorer farmers and landless laborers did not. Over time, this exacerbated existing social inequality. The situation was aggravated during the post-independence period (after 1947), as agricultural modernization was pursued more systematically and elaborately and without an equally systematic view toward erasing historical patterns of inequality. However, it is also true that new measures have brought prosperity to farmers from all social classes, although the level of prosperity is very much related to the degree of resource ownership.

Because of this, large farmers dominated the economic and sociopolitical sphere, while landless or small farmers remained disadvantaged. Ultimately, the author surmised that inequality will continue to breed inequality, unless specific measures are taken to check it at the initial stage of development. Even though agricultural modernization is desirable, it often is not appropriate for removing social inequalities.

Van den Berg H, Soehardi. 2000. **The influence of the rice bug *Leptocorisa oratorius* on rice yield.** J. Appl. Ecol. 37:959–970.

This is an important addition to the literature on yield losses caused by rice bugs, a topic that has received little detailed study. The authors monitored rice bug densities and several other crop-related variables in 94 farmers' fields during the 1997-98 wet season in east Java, Indonesia. They observed an average rice bug density of 3.5 adults m^{-2}. A statistical model incorporating rice bug density and other variables found that rice bug density had no measurable effect on yield. In field cage experiments, the authors found that rice bug feeding caused more yield loss during peak flowering than during the dough stage. Feeding at the flowering stage and milky stage resulted in unfilled grains but, contrary to general beliefs, it did not result in partially filled grains. The rice bug is a large and mobile insect that is easily observed by farmers and thus is often a target of insecticide application. The results of this paper suggest that much of the insecticide use directed against rice bugs is unnecessary.

Peng S, Laza RC, Visperas RM, Sanico AL, Cassman KG, Khush GS. 2000. **Grain yield of rice cultivars and lines developed in the Philippines since 1966.** Crop Sci. 40:307–314.

Genetic improvement of grain yield has been intensively studied in wheat, barley, oat, maize, and soybean. Most of these studies reported a positive historical cultivar trend in grain yield. Such information on rice is limited. This study determined the trend in yield of rice cultivars/lines developed by IRRI for the irrigated lowland ecosystem since 1966. Twelve cultivars/lines were grown at the IRRI farm and the Philippine Rice Research Institute farm during the 1996 dry season. Seven cultivars/lines were grown at the IRRI farm in the 1998 dry season. Growth analyses were performed at key growth stages and yield and yield components were determined at physiological maturity.

Regression analysis of yield versus year of release indicated an annual gain in rice yield of 75–81 kg ha^{-1}, equivalent to 1% $year^{-1}$. The increasing trend in yield of cultivars released before 1980 was mainly due to improvement in harvest index (HI), whereas an increase in total biomass was associated with yield trends in cultivars/lines developed after 1980. Results suggest that further increases in rice yield potential will likely occur through an increase in biomass production rather than an increase in HI. The highest yields obtained with the most recently released cultivars were 9–10 t ha^{-1}, which is equivalent to reported yields of IR8 and other early IRRI cultivars obtained in the late 1960s and early 1970s at these same sites. Therefore, the 1% annual increase in yield may not represent genetic gain in yield potential. The authors could not exclude the possibility that there have been new biotic and/or abiotic constraints in the intensive irrigated lowland rice ecosystems, and that the more recent cultivars are better adapted to these changes. They suggest that studies be conducted to determine the causes of poor grain filling and low crop growth rate during the grain-filling period in IR8 and other older cultivars under the present environment.

Cabunagan RC, Castilla N, Coloquio EL, Tiongco ER, Truong XH, Fernandez J, Du MJ, Zaragosa B, Hozak RR, Savary S, Azzam O. 2001. **Synchrony of planting and proportions of susceptible varieties affect rice tungro disease epidemics in the Philippines.** Crop Prot. 20:499–510.

This paper adds substantial new support to the view that synchronous planting and resistant varieties can help to reduce the incidence of rice tungro disease. The authors used various statistical methods to analyze categorical data gathered from six provinces in the Philippines. Asynchronous planting and planting of susceptible varieties were significantly associated with higher tungro incidence as measured by visual inspection. The interaction between the varieties planted and synchrony of planting is critical for the occurrence of tungro. The planting of susceptible varieties in areas where synchronous planting is widely practiced is more likely to lead to high tungro incidence than in areas planted asynchronously. Tungro incidence was not significantly associated with agroecosystem (irrigated vs rainfed) or location within the Philippines. In addition, serological detection of rice tungro spherical virus (RTSV) and rice tungro bacilliform virus (RTSV) showed that asynchronous planting and planting of susceptible varieties favored double infection with RTSV and RTBV. The study confirmed the results of earlier studies that RTSV infection alone can play a more important role in tungro epidemics than RTBV infection alone. RTBV infection was independent of the varieties planted and synchrony of planting, whereas RTSV infection alone was associated with both factors. Moreover, tungro incidence based on visual inspection was associated with not only double RTBV and RTSV infections but also single RTSV infection.

Digital Literacy for Rice Scientists

To help rice scientists take advantage of new information and communication technologies, the IRRI Training Center has developed the *Digital Literacy Course for Rice Scientists*. The course aims to provide scientists with information about what resources are available on the Internet and how they can go about accessing these resources.

The course is unique in that it focuses on the needs of rice scientists, it provides a forum for rice scientists to share their experiences and Internet resources with other rice scientists online, and it establishes a learner-centered knowledge network in the form of an online community centered on rice research.

The topics covered by the course include

- What is the Internet
- What is the World Wide Web and what makes it work
- Key Internet terminology
- How to use the Internet for communication with other scientists
- How to use Web browsers
- How to search for information efficiently andeffectively
- What are some of the good sources of information for rice scientists available on the Internet
- How to cite Internet documents
- What training opportunities are available online

Connection to the Internet offers national scientists a low-cost communication medium with other scientists linked to the Internet, gives them access to the ever-growing body of information available on and through interlinked computers throughout the world, and provides access to formal and informal training offered online from virtually anywhere.

http://www.cgiar.org/irri

IRRN welcomes three types of submitted manuscripts: research notes, mini reviews, and "notes from the field." All manuscripts must have international or pan-national relevance to rice science or production, be written in English, and be an original work of the author(s), and must not have been previously published elsewhere.

Research notes

Research notes submitted to IRRN should

- report on work conducted during the immediate past 3 yr or work in progress
- advance rice knowledge
- use appropriate research design and data collection methodology
- report pertinent, adequate data
- apply appropriate statistical analysis, and
- reach supportable conclusions.

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

Preliminary research findings. To reach well-supported conclusions, field trials should be repeated across more than one season, in multiple seasons, or in more than one location as appropriate. Preliminary research findings from a single season or location may be accepted for publication in IRRN if the findings are of exceptional interest.

Preliminary data published in IRRN may later be published as part of a more extensive study in another peer-reviewed publication, if the original IRRN article is cited. However, a note submitted to IRRN should not consist solely of data that have been extracted from a larger publication that has already been or will soon be published elsewhere.

Multiple submissions. Normally, only one report for a single experiment will be accepted. Two or more items about the same work submitted at the same time will be returned for merging. Submitting at different times multiple notes from the same experiment is highly inappropriate. Detection will result in the rejection of all submissions on that research.

Manuscript preparation. Arrange the note as a brief statement of research objectives, a short description of project design, and a succinct discussion of results. Relate results to the objectives. Do not include abstracts. Up to five references may be cited. Restrain acknowledgments. Limit each note to no more than two pages of double-spaced typewritten text (approximately 500 words).

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

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

Methodology

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

Terminology

- If local terms for seasons are used, define them by characteristic weather (dry season, wet season, monsoon) and by months.
- Use standard, internationally recognized terms to describe rice plant parts, growth stages, and management practices. Do not use local names.
- Provide scientific names for diseases, insects, weeds, and crop plants. Do not use local names alone.
- Do not use local monetary units. Express all economic data in terms of the US$, and include the exchange rate used.
- Use generic names, not trade names, for all chemicals.
- Use the International System of Units for all measurements. For example, express yield data in metric tons per hectare (t ha^{-1}) for field studies. Do not use local units of measure.
- When using acronyms or abbreviations, write the name in full on first mention, followed by the acronym or abbreviation in parentheses. Use the abbreviation thereafter.
- Define any nonstandard abbreviation or symbol used in tables or figures in a footnote, caption, or legend.

Mini reviews

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

Notes from the field

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

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Developed jointly by the International Rice Research Institute (IRRI) and the Centre for Pest Information Technology & Transfer (CPITT) at the University of Queensland, *RiceIPM* is an interactive training and resource package for researchers, advisers, and students. Focusing on tropical rice, this CD provides a comprehensive source of information and training material for improving the management of rice pests, including insect pests, diseases, and weeds.

A major feature of this knowledge management tool is that users can navigate through the content in any way they want to meet their own, specific information and learning needs. The combination of videos, images, hypertext links, and interactive keys provides a unique way of accessing the wealth of material contained on the CD. For instance:

- A diagnostics key assists users to shortlist the likely causes of observed rice disorders.
- A series of interactive, multimedia Lucid keys provide help to users in identifying insects found in rice.
- A customized search engine provides a rapid means of directing the user to specific topics to be found on the CD.
- The CD provides links to web sites that provide further information on specific topics.

The content of the CD—structured according to the competency standards required for proficient integrated pest management—has been researched and developed by an international team of IPM specialists from various countries in Southeast Asia and IRRI based in the Philippines.

RiceIPM contains sections on pest ecology; crop checking; fact sheets on major insect pests, rats, diseases, weeds, nutrient deficiency and toxicity; crop growth and pest damage; pest management options and decision-making and economics. A separate section of the CD provides material for researchers and advisers on various aspects of implementing IPM, including farmer field schools, multimedia campaigns, and stakeholder workshops. Other components include frequently asked questions, a multiple-choice quiz, a "slide-tape" tutorial on biological control, and an information sources section, including references, rice statistics, and glossary.

For ordering instructions go to www.irri.org/pubcat2000/newtitles.htm#IPMCD

IRRI
International Rice Research Institute
DAPO Box 7777, Metro Manila, Philippines

ISSN 0117-4185
9 770117 418005

Printed Matter